Fishery Technology 57 (2020) : 234 - 242

# Life Cycle Assessment based identification of Environmental Hotspots in Commercial Trawl Fisheries of Kerala and Mitigation Strategies

**Renju Ravi*, P. H. Dhiju Das and Leela Edwin**
*Central Institute of Fisheries Technology, P. O. Matsyapuri, Cochin - 682 029, India*

## Abstract

Life Cycle Assessment (LCA) is used to identify environmentally preferred products or processes and can be used as a support tool for decision-making and policy development. In India, LCA of trawl fishing, wherein impact categories such as Global warming potential (GWP), Abiotic depletion potential (fossil) (ADP), Acidification potential (AP), Eutrophication potential (EP), Marine aquatic ecotoxicity potential (MAETP), Ozone layer depletion potential (ODP) and Photochemical ozone creation potential (POCP), are not studied. In this study, LCA and carbon footprint of fish production by trawlers operating in Kerala fisheries sector has been carried out. Direct energy input for fishing operations due to consumption of fuel account for 75 to 90% of the total energy inputs when compared with energy inputs associated with vessel construction and maintenance, fishing gear and others. The study showed that, the impact categories such as GWP, ADP, AP, EP and POCP are predominantly related to the consumption of diesel for vessel operation and hence identified as the main hotspot with respect to environmental burdens which need focussed action in mitigation approaches. The results of this study delineates approaches for reducing carbon footprint of the trawl caught resources in Kerala.

**Keywords:** LCA, global warming potential, trawling, Kerala fisheries, fuel conservation, climate change

Received 26 August 2019; Revised 14 February 2020; Accepted 02 November 2020

**Present Address: National Institute of Fisheries Post Harvest Technology and Training, Cochin - 682 016, India*

**E-mail: renjuraviif@yahoo.com*

## Introduction

Combustion of fossil fuels and the release of greenhouse gases to the atmosphere has environmental impacts and contributes to climate change and ocean acidification. Mechanised fishing operations are dependent on fossil fuels, the burning of which releases high levels of carbon dioxide to the atmosphere contributing to greenhouse effect. Climate change threatens the sustainability of fisheries and is likely to affect biological processes and biodiversity.

Intensification of fishing effort, extension of fishing grounds, increase in overall length and fish hold capacity and fishing effort in terms of enhanced fishing hours and multi-day fishing in the mechanised sector is recorded in the trawling sector of the country in general and Kerala in particular. Trawling is the most energy intensive fishing which consumes 1.8 to 11 times more fuel when compared to gillnetting, trapping, longlining, ring seining and purse seining for every kilogram of fish produced (Gulbrandsen, 1986; Edwin & Hridayanathan, 1997; Boopendranath, 2000, 2008, 2012; Thrane, 2004; Winther et al., 2009; Vivekanandan et al., 2013). Direct fuel energy for fishing operations typically account for 75 to 90% of the total energy inputs and the remaining 10 to 25% is comprised of direct and indirect energy inputs associated with vessel construction and maintenance, fishing gear and others (Tyedmers, 2000). Life Cycle Assessment (LCA) and Carbon Footprint (CF) studies will be useful for selecting energy efficient fishing systems and for delineating approaches for fuel conservation in fishing operations.

Information on LCA, wherein impact categories like Global warming potential (GWP), Abiotic depletion potential-fossil (ADP fossil), Acidification potential (AP), Eutrophication potential (EP), Marine aquatic eco-toxicity potential (MAETP), Ozone depletion potential (ODP) and Photochemical ozone creation potential (POCP) are assessed, are lacking in respect of Indian trawl fisheries. In this communication hotspots causing maximum environmental impacts pertaining to trawl fisheries of Kerala have been identified using LCA and approaches to reduce the Global Warming Potential (GWP) and related impact parameters have been delineated to facilitate sustainable and energy efficient fisheries.

## Materials and Methods

LCA is a useful decision making tool for evaluating inputs and their relative contribution to impact categories causing environmental burdens in fish production systems and to identify hotspots and mitigation measures (Pelletier et al., 2007; Vázquez-Rowe et al., 2010a; Avadi & Freon, 2013; Ravi, 2015). It is extensively used to analyse the environmental burdens along the life cycle of products and processes (ISO 14040, 2006a, 2006b). Environmental hotspots of products or processes can be related using LCA and this information can be used to improve the environmental performance at every stage of a product life cycle.

GaBi-6 software (PE International, Leinfelden-Echterdingen) was used for Life Cycle Assessment (LCA) and Carbon Footprint analysis. The CML 2001 - Apr. 2013 method developed by the Centre of Environment Science of Leiden University, Netherlands was used in order to perform the Life cycle impact assessment (LCIA) in GaBi-6 software. The seven impact categories included in this study were; Global warming potential (GWP), Abiotic depletion potential (fossil) (ADP- fossil), Acidification potential (AP), Eutrophication potential (EP), Ozone layer depletion potential (ODP steady state), Photochemical ozone creation potential (POCP)and Marine aquatic ecotoxicity potential (MAETP).

For the analysis of LCA of mechanised trawl fishing operations, the entire process was separated into three subsystems *viz*., Fishing Sub-system I (fishing vessel construction and maintenance); Fishing Sub-system II (trawl net construction and maintenance); and Fishing Sub-system III (fishing operation) (Fig. 1).

In this study, cradle to gate approach has been followed and mass allocation was considered. For each subsystem, the quantity of material used in one year was obtained and corresponding amount of impact was determined using GaBi 6 database. The capital items such as fishing vessel, machinery and equipment; and fishing gear were amortised over their anticipated useful lifetimes. Representative samples from each category of vessel and gear were examined, to collect design and operational details. Material input details of 65 trawlers (belonging to 15 types) were collected for LCA analysis. The types were 10.66 m small wooden single day trawler, 13.71 m medium wooden multiday trawler, 15.3 m medium wooden multiday trawler, 18.9 m large wooden multiday trawler, 19.81 m large wooden multiday trawler, 21.33 m large wooden multiday trawler, 13.71 m medium steel multiday trawler, 15.3 m medium steel multiday trawler, 18.9 m large steel multiday trawler, 19.81 m large steel multiday trawler, 21.33 m large steel multiday trawler, 22.86 m large steel multiday trawler, 24.38 m very large steel multiday trawler, 25.9 m very large steel multiday trawler and 27.43 m very large steel multiday trawler. Detailed material input and design details of 15 different types (total 137 Nos.) of trawl nets were collected for LCA of trawl nets. For operational analysis, a total of 1074 fishing trips of trip duration ranging from one day to 12 days were collected using structured questionnaires, during June 2012 - May 2013.

Fishing harbours and mechanised fish landing centres of Kerala, were visited during the study and details on design and construction of fishing vessels, gear, operation, engine and other relevant information were collected from boatyard operators, net makers, fishermen and other stakeholders using structured questionnaires. Data regarding fishing

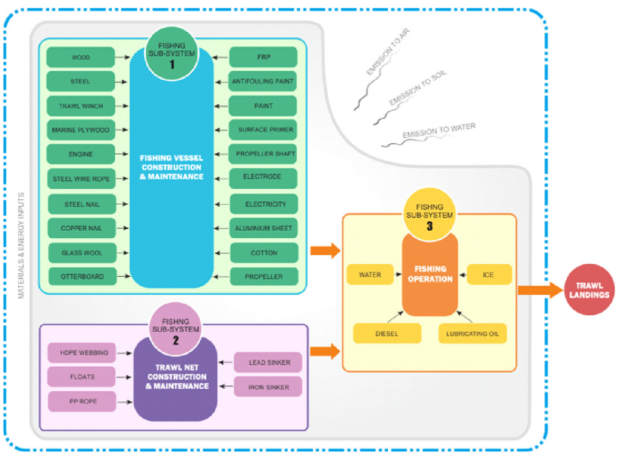


Fig. 1. System boundaries for life cycle assessment of mechanised trawl fishing operations

vessels were also collected from Fishing Vessel Registration Database of the Marine Products Export Development Authority (MPEDA) and data on fish landings were sourced from Fishery Resources Assessment Division of ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI). Major fishing centres visited were Cochin fisheries harbour, Munambam fisheries harbour, Munambam mini fisheries harbour, Kalamukku and Murikumpadam landing centres in Ernakulam district; Sakthikulangara and Neendakara in Kollam district and; Cheruvathur and Thaikadappuram in Kasaragod district (Fig. 2.). About 58% of the trawlers operating from the state are from these areas (CMFRI, 2012).


Fig. 2. Landing areas selected for the study

## Results and Discussion

Commercial trawlers in Kerala are mostly in the size range of 10.66 to 24 m $L_{OA}$ but recently trawlers up to 28 m $L_{OA}$ have also been introduced. Trawlers are classified into four categories, *viz.*, small trawlers, medium trawlers, large trawlers and very large trawlers based on the $L_{OA}$ using general classification and regression tree model analysis (Edwin et al., 2014) (Table 1). The values estimated for the different impact categories namely GWP, ADP-fossil, AP, EP, MAETP, ODP and POCP for different categories of wooden and steel trawlers are presented in Table 2.

Table 1. Classification of trawlers based on $L_{OA}$

| Type of trawlers | $L_{OA}$ (m) |
|---|---|
| Small trawlers | < 12 |
| Medium trawlers | 12 - 16 |
| Large trawlers | 16 - 24 |
| Very large trawlers | > 24 |

Trawl nets operated along the coast of Kerala are mostly two-seam designs. Based on the target groups for which the nets are used, trawl nets can be classified into three, viz., fish trawls; shrimp trawls and cephalopod trawls (Table 3). The values estimated for the different impact categories namely GWP, ADP-fossil, AP, EP, MAETP, ODP and POCP for different categories of trawl nets are presented in Table 4.

Estimates of impact category values per tonne of marine fish landed during single-day and multi-day trawling operations are given in Table 5.

Most of the environmental concerns with respect to commercial fishing focus on direct impacts to targeted species, bycatch and discards, alterations to benthic communities, and modifications to trophic dynamics (Pauly et al., 2002). These concerns do not cover all aspects related to the environmental impacts of fishing activities. As material and energy inputs to vessel construction and maintenance have previously been found to make relatively small contributions to the environmental impacts of seafood products (Hayman et al., 2000), most of the studies have not taken into account information on these aspects (Hospido and Tyedmers, 2005). Literature pertaining to environmental burdens related to gear production and their use in fisheries are scarce (Ramos et al., 2011; Vázquez-Rowe et al., 2011). Ghosh et al. (2014) had studied the carbon footprint of marine fisheries from Visakhapatnam. The hotspots identified in trawler construction and maintenance, trawl net construction and maintenance and trawling operations; fuel consumption in mechanised trawling operations and approaches to reduce environmental impacts of the trawl fisheries are discussed below.

In the case of wooden trawlers, higher Global warming potential (GWP) is for aluminium, followed by steel. In the case of steel trawlers, higher GWP is for steel especially hull, followed by welding electrodes. Steel as a construction material

Table 2. Comparison of LCA impact categories from different trawlers

| Impact Categories | Type of vessel | | | | | |
|---|---|---|---|---|---|---|
| | Wooden Trawlers | | | Steel Trawlers | | |
| | Small wooden single-day trawlers (<12m $L_{OA}$) | Medium wooden multi-day trawlers (12-16m $L_{OA}$) | Large wooden multi-day trawlers (16-24m $L_{OA}$) | Medium steel multi-day trawlers (12-16m $L_{OA}$) | Large steel multi-day trawlers (16-24m $L_{OA}$) | Very large steel multi-day trawlers (>24m $L_{OA}$) |
| GWP, kg $CO_2$ Equiv. | -2165 | -2953 – -3297 | -3781 – -4328 | 2824 - 3245 | 4206 - 4956 | 5202 - 6648 |
| ADP-fossil, MJ | 1.42E+04 | 1.72E+04 - 2.05E+04 | 2.59E+04 - 3.09E+04 | 4.54E+04 - 5.34E+04 | 6.75E+04 - 7.68E+04 | 8.02E+04 - 9.91E+04 |
| AP, kg $SO_2$ Equiv. | 5.62 | 6.87 - 8.26 | 10.64 - 12.89 | 19.89 - 23.19 | 29.17 - 33.27 | 34.81 - 43.13 |
| EP, kg Phosphate Equiv. | 0.43 | 0.56 - 0.68 | 0.89 - 1.19 | 1.21 - 1.42 | 1.79 - 2.05 | 2.14 - 2.66 |
| MAETP, kg DCB Equiv. | 6.51E+05 | 8.28E+05 - 1.05E+06 | 1.35E+06 - 1.79E+06 | 1.52E+06 - 1.76E+06 | 2.22E+06 - 2.52E+06 | 2.63E+06 - 3.26E+06 |
| ODP, kg R11 Equiv. | 2.17E-07 | 4.72E-07 - 6.99E-07 | 1.13E-06 - 1.77E-06 | 4.22E-08 - 5.26E-08 | 6.69E-08 - 7.64E-08 | 8.07E-08 - 1.02E-07 |
| POCP, kg Ethene Equiv. | 1.00 | 1.25 - 1.45 | 1.78 - 2.09 | 2.06 - 2.43 | 3.07 - 3.46 | 3.60 - 4.41 |

has higher global warming potential than wood. However, scarcity of wood appropriate for vessel construction is a limiting factor. Upgrading of wooden boat building materials sourced from high yielding short life span wood species after preservative treatment, can be considered for construction, wherever appropriate, particularly for coastal operations.

In the case of trawl nets, higher GWP is for HDPE webbing, followed by iron sinkers, HDPE floats, PP ropes and lead sinkers. As GWP value is higher for HDPE webbing, approaches to reduce its usage in trawl construction such as trawl design improvement, use of large meshes, knotless webbing and substitution with thinner and stronger materials with low drag have to be reviewed.

There is considerably higher environmental impacts for multi-day trawl landings mainly due to the high energy consumption. The fuel consumption (diesel production and use) is the major factor contributing to GWP in both single day and multiday trawler operations and hence offers maximum scope for impact reduction, through operational fuel savings. This observation is in agreement with earlier studies by Boopendranath (2000, 2008, 2012); Thrane (2004); Hospido and Tyedmers (2005); Tyedmers et al. (2005); Schau et al. (2009); Vázquez-Rowe et al. (2010b, 2011); Iribarren et al. (2011) and Vivekanandan et al. (2013). The GWP was incrementally higher for multi-day trawler operations corresponding to increase in size of trawlers, due to the inorganic emissions to air especially $CO_2$ emissions. The ADP-fossil was incrementally higher for single-day trawler operation and multi-day trawler operation corresponding to increase in size of trawlers, due to consumption of diesel. The AP for single-day trawler operation and multi-day trawler operation also showed increase corresponding to increase in size of trawlers, due to the inorganic emissions to air especially Sulphur dioxide and Nitrogen oxides mostly derived from diesel. Similarly, the EP also showed incrementally higher values for single-day trawler operation and multi-day trawler operation corresponding to increase in size of trawlers, due to the inorganic emissions to air especially Nitrogen oxides mostly derived from diesel. The MAETP

Table 3. Size ranges of trawl nets based on target groups

| Type of trawls | Head rope length (m) |
|---|---|
| Fish trawl | 39.6 - 85.6 |
| Cephalopod trawl | 33.4 - 57.6 |
| Shrimp trawl | 34.2 - 58.0 |

Table 4. Comparison of LCA impact values from different trawl nets

| Impact Categories | Type of trawls | | |
|---|---|---|---|
| | Fish trawls | Cephalopod trawls | Shrimp trawls |
| GWP, kg $CO_2$ Equiv. | 214 - 1357 | 282 - 608 | 214 – 522 |
| ADP-fossil, MJ | 3.15E+03 - 2.90E+04 | 6.45E+03 - 1.20E+04 | 3.15E+03 - 9.73E+03 |
| AP, kg $SO_2$ Equiv. | 1.61 - 9.34 | 2.38 - 4.34 | 1.61 - 3.78 |
| EP, kg Phosphate Equiv. | 0.088 - 0.553 | 0.112 - 0.248 | 0.088 - 0.213 |
| MAETP, kg DCB Equiv. | 2.08E+05 - 1.26E+06 | 2.38E+05 - 5.73E+05 | 2.08E+05 - 4.90E+05 |
| ODP, kg R11 Equiv. | 6.57E-09 - 6.90E-08 | 1.65E-08 - 3.05E-08 | 6.57E-09 - 2.23E-08 |
| POCP, kg Ethene Equiv. | 0.112 - 0.725 | 0.191 - 0.329 | 0.112 - 0.280 |

Table 5. Estimates of impact category values per tonne of marine fish landed during trawling operations in Kerala

| Impact categories | Single-day trawl sector | Multi-day trawl sector | Both single-day and multi-day trawl sectors |
|---|---|---|---|
| GWP, kg $CO_2$ Equiv. | 985 | 1764 | 1674 |
| ADP-fossil, MJ | 1.26E+04 | 2.18E+04 | 2.07E+04 |
| AP, kg $SO_2$ Equiv. | 3.16E+00 | 5.47E+00 | 5.21E+00 |
| EP, kg Phosphate Equiv. | 1.53E-01 | 2.67E-01 | 2.54E-01 |
| MAETP, kg DCB Equiv. | 5.22E+04 | 1.01E+05 | 9.52E+04 |
| ODP, kg R11 Equiv. | 5.60E-09 | 6.52E-09 | 6.42E-09 |
| POCP, kg Ethene Equiv. | 0.23 | 0.39 | 0.37 |

values increased for single-day trawler operation and multi-day trawler operation corresponding to increase in size of trawlers, due to the inorganic emissions to air especially Hydrogen fluoride mostly derived from HDPE webbing and use of iron sinkers in trawl nets; diesel; and steel and electricity for vessel construction and maintenance. Vázquez-Rowe et al. (2012) studied that ODP in fishing vessels was mainly associated with the leakage of refrigerants such as R22 from the storage freezers onboard. In Kerala, ODP related with trawl fishing was low, as there are no storage freezers onboard mechanised commercial trawlers. However, ODP was incrementally higher for single-day and multi-day trawler operations corresponding to increase in size of the trawlers, due to the halogenated organic emissions into the air especially R114 (dichlorotetrafluoroethane) and R11 (trichlorofluoromethane) emissions mostly derived from copper nails and aluminium sheets used for wooden vessel construction. POCP values for single-day and multi-day trawler operations increased in accordance with increase in size of the trawlers, due to the inorganic emissions to air especially Sulphur dioxide, Nitrogen oxides and organic emissions especially the group NMVOC to air mostly derived from diesel.

All mechanised trawlers use diesel for propulsion, gear handling and operations. It was estimated from the present study that, single-day trawling operations from Kerala consumes 7.6 million litres of fuel and the multi-day trawling operations from Kerala consumes 98.7 million litres of fuel annually. The total quantity of diesel burned by the mechanised trawl sector in Kerala fisheries accounted for 106.3 million litres of fuel during the period June 2012 to May 2013. The quantity of fuel consumed per kg of marine fish landed works out to be 0.25 kg for single-day trawlers, 0.43 kg for multi-day trawlers and 0.41 kg for both the sectors together. Studies by Boopendranath (2000, 2008, 2012) in India showed a fuel consumption rate of 0.41, 0.38 and 0.33 kg fuel kg $fish^{-1}$ from motorised mini-trawling, small-scale mechanised bottom trawling and large-scale mechanised aimed midwater trawling, respectively. Studies by Tyedmers (2001) in North Atlantic showed a fuel consumption rate of 0.44, 0.76 and 0.85 kg fuel kg fish$^{-1}$ for groundfish trawling, shrimp trawling and Norwegian lobster trawling, respectively. Tyedmers (2001); Eyjólfsdóttir et al. (2003); Ziegler et al. (2003); Thrane (2004); Ellingsen & Aanondsen (2006) and Guttormsdóttir (2009) reported 0.67 kg fuel kg fish$^{-1}$ for cod harvested by trawling. Studies by Thrane (2004) showed a fuel consumption rate of 0.4 and 0.84 kg fuel kg fish$^{-1}$ respectively, for cod and flatfish harvested by bottom trawling in Denmark. Studies by Ziegler & Hansson (2003) in Iceland and Schau et al. (2009) in Norway reported a fuel consumption rate of 0.65 and 0.28 kg fuel kg fish$^{-1}$ respectively for groundfish trawling. Thrane (2004); Iribarren et al. (2010) and Vázquez-Rowe et al. (2010b) reported a fuel consumption rate of 0.30 kg fuel kg fish$^{-1}$ for mackerel caught by trawling. Studies by Emanuelsson et al. (2008) showed a fuel consumption rate of 0.52 kg fuel kg fish$^{-1}$ for artisanal trawling of shrimps and prawns, in Senegal. Parker & Tyedmers (2015) have studied the current understanding and knowledge gaps in fuel consumption of global fishing fleets and reported that the median fuel use intensity of global fisheries since 1990, as 639 litres per tonne and that fuel inputs to fisheries vary by several orders of magnitude, in different categories of fishing.

In the Indian context, annual fuel consumption by the mechanised and motorised fishing fleet has been reported to be 1220 million litres which formed about 1% of the total fossil fuel consumption in 2000 (Boopendranath, 2000). These release an estimated 3.17 million tonnes of $CO_2$ into the atmosphere at an average rate of 1.13 tonnes of $CO_2$ per tonne of marine fish landed. Vivekanandan et al. (2013) had estimated the fuel used by the mechanised and motorised fishing vessels in India as 1378.8 million litres in 2010. These release about 3.13 million tonnes of $CO_2$ into the atmosphere at an average rate of 1.02 tonnes of $CO_2$ per tonne of live-weight of marine fish landed. The current LCA studies indicate that about 0.362 million tonnes of $CO_2$ Equiv. was released into the atmosphere from sources such as construction and maintenance of trawlers and trawl fishing gears and trawling operations, in Kerala, at an average rate of 1.674 tonnes of $CO_2$ per tonne of marine fish landed by trawling.

The LCA performed on mechanised trawl fishing operations in Kerala covering impact categories such as GWP, ADP-fossil, AP, EP, MAETP, ODP and POCP has highlighted several hotspots where attention is required to minimise the environmental impacts. The GWP, ADP-fossil, AP, EP, MAETP, and POCP was consistently higher in steel trawlers, and their values increased with increase in size of the trawlers and consumption of steel in construction. Hence there is scope for optimisation in hull design and material substitution wherever appropriate, aiming at reduction in steel consumption, in the construction of steel trawlers. It will also be advisable to optimise vessel size for coastal and distant water trawling operations. Though GWP values were consistently negative for wooden vessels and decreased with increase in vessel size, wood appropriate for vessel construction is becoming scarce and expensive. ODP, though low in value, was higher in wooden trawlers compared to steel hulled trawlers, due to the use of copper nails and aluminium sheathing in their construction, it will be appropriate to identify substitutes for copper and aluminium in the construction of wooden trawlers. The values for GWP, ADP-fossil, AP, EP, MAETP, POCP and ODP for trawl construction mostly depended on the consumption of HDPE webbing, followed by use of iron sinkers and floats. As pointed out, approaches to reduce the consumption and use of HDPE webbing, iron sinkers and HDPE floats through design optimisation and material substitution, wherever appropriate, seem to be necessary. Among the LCA impact categories, GWP, ADP, AP, EP and POCP are predominantly related to the consumption of diesel. Hence, diesel used for trawling operations can be highlighted as the main hotspot, in respect of environmental burdens and, therefore, focussed action is required for minimizing fuel consumption, particularly in fishing operations. Approaches for fuel conservation from fishing operations have been reviewed by Gulbrandsen (1986); Boopendranath (1996, 2009); Rihan et al. (2010); Walsh (2010) and Boopendranath and Hameed (2013). Studies suggest that fish stocks that are managed in a sustainable way are capable of maintaining their GHG emissions at lower levels (Hornborg et al., 2012). The introduction of new vessels into the fisheries with improved hull shapes can provide energy efficiency improvements up to 20% (Schau et al., 2009) and need to be considered as a long term strategy. As trawlers use high powered engines, skippers tend to move at high speed for going to and from fishing grounds which consumes more fuel. Gulbrandsen (2012) estimated that a reduction of 10-20% engine rpm will save 20-40% fuel. Economic vessel speed is a well-known practical measure among the fuel saving practices. Appropriately smaller engines have multiple benefits of lower investment cost, lesser maintenance and huge reduction in the fuel consumption. Preventive maintenance including regular cleaning or replacement of the required parts of engine are very important practical steps in conserving fuel and controlling pollution.

Selection and deployment of energy efficient mix of harvesting technologies appropriate for target resources is one of the main options suggested for fuel conservation. Adoption of energy and material conservation and optimisation technologies and practices in vessel and gear construction and trawling operations will pave way for reduction of environmental impacts from trawl sector. As the information derived from LCA studies enables the consumers and seafood processing industries to opt for fishes harvested by methods causing less environmental burdens, such studies need to be widely adopted to facilitate production of eco-friendly seafood and for market driven conservation of resources through eco-labelling.

## Acknowledgements

The study was carried out under the project "Green Fishing Systems for Tropical Seas" funded by ICAR under National Agricultural Science Fund (NASF) and operated at ICAR-CIFT, Cochin. The authors are thankful to the Director, CIFT and Director, NIFPHATT for granting permission to publish this paper; to Director, CMFRI, Chairman, MPEDA and stakeholders in fisheries sector of Kerala, for their support, cooperation and assistance during the course of this study.

## References

Avadi, A. and Freon, P. (2013) Life cycle assessment of ûsheries: A review for fisheries scientists and managers. Fish. Res. 143: 21-38

Boopendranath M. R. and Hameed, M. S. (2013) Gross Energy Requirement in Fishing Operations. Fish.Technol. 50: 27-35

Boopendranath, M. R. (1996) Approaches to energy conservation in fishing. In: Study Report, Regional Training Course in Commercial Fishing Technology 1996. TD/RP/39. pp. 23-31. Training Department, Southeast Asian Fisheries Development Centre, Thailand

Boopendranath, M. R. (2000) Studies on Energy Requirement and Conservation of Selected Fish Harvesting Systems. Ph.D. Thesis. 273 p. Cochin University of Science and Technology, Kochi, India

Boopendranath, M. R. (2008) Climate change impacts and fishing practices, Paper presented in Workshop on Impact of Climate Change in Fisheries, ICAR, New Delhi, 15 December 2008

Boopendranath, M. R. (2009) Responsible fishing operations. In: Handbook of Fishing Technology (Meenakumari, B., Boopendranath, M.R., Pravin, P., Thomas, S.N. and Edwin, L., Eds.), pp. 259-295. Central Institute of Fisheries Technology, Kochi

Boopendranath, M. R. (2012) Waste Minimisation in Fishing Operations. Fish.Technol. 49: 109-119

CMFRI (2012) Marine Fisheries Census 2010 Part I India, 98 p, Department of Animal Husbandry, Dairying & Fisheries and Central Marine Fisheries Research Institute, Kochi

Edwin, L. and Hridayanathan, C. (1997) Energy efficiency in the ring seine fishery of south Kerala coast. Indian J. Fish. 44(4): 387-392

Edwin, L., Thomas, S. N., Pravin, P., Remesan, M. P., Madhu, V. R., Baiju, M. V., Sreejith, P.T., Ravi, R. and Das, D. P. H. (2014) CIFT Fishing System Catalouge 1- Mechanised Marine Fishing Systems: Kerala, 113 p, Central Institute of Fisheries Technology, Kochi

Ellingsen, H. and Aanondsen, S. (2006) Environmental impacts of wild caught cod and farmed salmon - a comparison with chicken. Int. J. Life Cycle Assess. 11(1): 60-65

Emanuelsson, A., Flysjö, A., Thrane, M., Ndiaye, V., Eichelsheim, J. L. and Ziegler, F. (2008) Life Cycle Assessment of southern pink shrimp products from Senegal. In: 6th International Conference on Life Cycle Assessment in the Agri-Food Sector, pp 1-9. Zurich

Eyjólfsdóttir, H., Yngvadóttir, E., Jónsdóttir, H. and Skúladóttir, B. (2003) Environmental effects of fish on the consumers dish – life cycle assessment of Icelandic frozen cod products. IFL Report 06-03, 40 p, Technological Institute of Iceland and Icelandic Fisheries Laboratories, Reykjavik, Iceland

Ghosh, S., Rao, H. M. V., Kumar, S. M., Mahesh, U. V., Muktha, M. and Zacharia, P. U. (2014). Carbon footprint of marine fisheries: life cycle analysis from Visakhapatnam. Curr. Sci. 107(3): 515-521

Gulbrandsen, O. (1986) Reducing Fuel Cost of Small Fishing Boats, BOBP/WP/27, 15 p, Bay of Bengal Programme, Madras

Gulbrandsen, O. (2012) Fuel savings for small fishing vessels – A manual, 57 p, FAO, Rome

Guttormsdóttir, A. B. (2009) Life Cycle Assessment on Icelandic cod product based on two different fishing methods: Environmental impacts from fisheries. Master's thesis, 105 p, University of Iceland, Reykjavik, Iceland

Harikumar, G. and Rajendran, G. (2007) An overview of Kerala fisheries - with particular emphasis on Aquaculture, IFP Souvenir 2007. Pp 1-19

Hayman, B., Dogliani, M., Kvale, I. and Fet, A. M. (2000) Technologies for reduced environmental impact from ships - Ship building, maintenance and dismantling aspects. ENSUS-2000, Newcastle upon Tyne, UK

Hornborg, S., Nilsson, P., Valentinsson, D. and Ziegler, F. (2012) Integrated environmental assessment of fisheries management: Swedish Nephrops trawl fisheries evaluated using a life cycle approach. Mar. Policy 36: 1193-1201

Hospido, A. and Tyedmers, P. (2005) Life cycle environmental impacts of Spanish tuna fisheries. Fish. Res. 76: 174-186

Iribarren, D., Vázquez-Rowe, I., Hospido, A., Moreira, M. T. and Feijoo, G. (2010) Estimation of the carbon footprint of the Galician fishing activity (NW Spain). Sci. Total Environ. 408(22): 5284-5294

Iribarren, D., Vázquez-Rowe, I., Moreira, M. T. and Feijoo, G. (2011) Updating the carbon footprint of the Galician fishing activity (NW Spain). Sci. Total Environ. 409: 1609-1611

ISO (2006a) ISO 14040:2006, Environmental management-Life Cycle Assessment-Principles and framework. International Organization for Standardization

ISO (2006b) ISO 14044:2006, Environmental management-Life Cycle Assessment-Requirements and guidelines. International Organization for Standardization

Parker, R. W. R. and Tyedmers, P. (2015) Fuel consumption of global fishing fleets: Current understanding and knowledge gaps. Fish Fish. 16(4): 684-696

Pauly, D., Christensen, V., Guenette, S., Pitcher, T. J., Sumaila, R. U., Walters, C. J., Watson, R. and Zeller, D. (2002) Towards sustainability in world fisheries. Nature. 418: 689-695

Pelletier, N.L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A., Robillard, G., Ziegler, F., Scholz, A. J. and Sonesson, U. (2007) Impact categories for Life Cycle Assessment research of seafood production systems: Review and prospectus. Int. J. Life Cycle Assess. 12(6): 414-421

Ramos, S., Vázquez-Rowe, I., Artetxe, I, Moreira, M. T., Feijoo, G. and Zufía, J. (2011) Environmental assessment of the Atlantic mackerel (*Scomber scombrus*) season in the Basque Country. Increasing the timeline delimitation in fishery LCA studies. Int. J. Life Cycle Assess. 16(7): 599-610

Ravi, R., Vipin, P. M., Boopendranath, M. R., Joshy, C. G. and Edwin, L. (2014) Structural changes in the mechanised fishing fleet of Kerala, South India. Indian J. Fish. 61(2): 1-6

Ravi, R. (2015) Studies on Structural Changes and Life Cycle Assessment in Mechanised Trawl Fishing Operations of Kerala. Ph.D. Thesis. 314 p, Cochin University of Science and Technology, Kochi, India.

Rihan, D., O'Regan, N. and Deakin, B. (2010) The Development of a "Green Trawler", First International Symposium on Fishing Vessel Energy Efficiency E-Fishing, Vigo, Spain, May 2010.

Schau, E. M., Ellingsen, H., Endal, A. and Aanondsen, S. A. (2009) Energy consumption in the Norwegian fisheries. J. Clean. Prod. 17(3): 325-334

Thrane, M. (2004) Energy consumption in the Danish fishery. identification of key factors. J. Ind. Ecol. 8: 223-239

Tyedmers, P. (2000) Salmon and Sustainability: The Biophysical Cost of Producing Salmon Through the Commercial Salmon Fishery and the Intensive Salmon Culture Industry. PhD Thesis, 272 p, University of British Columbia, Vancouver, Canada

Tyedmers, P. (2001) Energy consumed by North Atlantic fisheries. In: Fisheries' Impacts on North Atlantic Ecosystems: Catch, Effort and National/Regional Datasets. (Zeller, D., Watson, R. and Pauly, D., Eds.), pp. 12–34, Fisheries Centre, University of British Columbia, Vancouver

Tyedmers, P. H., Watson, R. and Pauly, D. (2005) Fueling Global Fishing Fleets. Ambio. 34 (8): 635-638

Vázquez-Rowe, I., Iribarren, D., Hospido, A., Moreira, M. T. and Feijoo, G. (2010a) Linking fuel consumption and eco-efficiency in fishing vessels, A brief case study on selected Galician fisheries, First International Symposium on Fishing Vessel Energy Efficiency E-Fishing, Vigo, Spain, May 2010.

Vázquez-Rowe, I., Moreira, M. T. and Feijoo, G. (2010b) Life cycle assessment of horse mackerel ûsheries in Galicia (NW Spain). Comparative analysis of two major ûshing methods. Fish. Res. 106(3): 517-527

Vázquez-Rowe, I., Moreira, M. T. and Feijoo, G. (2011) Life cycle assessment of fresh hake fillets captured by the Galician fleet in the northern stock. Fish. Res. 110: 128-135

Vázquez-Rowe, I., Moreira, M. T. and Feijoo, G. (2012) Environmental assessment of frozen common octopus (*Octopus vulgaris*) captured by Spanish fishing vessels in the Mauritanian EEZ. Mar. Policy 36(1): 180-188

Vivekanandan, E., Singh, V. V. and Kizhakudan, J. K. (2013) Carbon footprint by marine fishing boats of India. Curr. Sci. 105(3): 361-366

Walsh, S. J. (2010) Emission Profile of a Keystone Fishery and Recommendations for Fuel Management - A Case Study on the Isle of Man Scallop Fishery, Non-Technical Summary, Report to DEFA, School of Environmental Sciences, University of East Anglia, University Plain, Norwich, NR4 7TJ.

Winther, U., Ziegler, F., Skontorp Hognes, E., Emanuelsson, A., Sund, V. and Ellingsen, H. (2009) Carbon footprint and energy use of Norwegian seafood products. SINTEF Report Nr. SHF80 A096068. 91 p, Trondheim, Norway

Ziegler, F. and Hansson, P. A. (2003) Emissions from fuel combustion in Swedish cod fishery. J. Clean. Prod. 11: 303-314

Ziegler, F., Nilsson, P., Mattsson, B. and Walther, Y. (2003) Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts. Int. J. Life Cycle Assess. 8(1): 39-47