Fishery Technology 53 (2016) : 273 - 283

Comparative Environmental Life Cycle Assessment of Indian Oil sardine Fishery of Kerala, India

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

Abstract

The pelagic fishery resources play a significant role of fish production in India. Small pelagics such as the Indian oil sardine and Indian mackerel together contribute 21% of the marine landings. Ring seining is one of the most efficient fishing methods used for small pelagic fishery in India and the state of Kerala in the south west coast is the major contributor. Ring seines contribute 51% of the marine fish landings and 98.8% of sardine landings of Kerala. Kerala is said to be the birthplace of ring seine and at the time of introduction, ring seine were operated from small canoes with very low power engines. Presently ring seines are operated with large number of high power motorised and mechanised vessels. In this study, an Life Cycle Assessment (LCA) methodology is used to analyze the environmental burdens associated with the Indian oil sardine exploited by mechanised, motorised and traditional ring seine fishing systems. The analysis encompassed operational inputs to fishing activities, inputs to fishing craft and gear construction, maintenance and service life of fishing system. This is done using material wise analysis for ring seine fishing systems in detail and is the first of its kind in Indian fisheries. Results show that in oil sardine landings, fuel used for fishing contributed more than half of the total impacts in eight of the ten impact categories analysed. Motorized ring seine fleet is having higher impact when compared to mechanized ring seine fleet except for ADP element and ODP, due to the high use of lead weight and polyamide webbing in mechanized fleets. Impact of motorised fleet ADP fossil, AP, EP, GWP, HTP and POCP showed more than 20% impact than mechanized fleet with a higher value of 24% in GWP. Through this study some important interventions are proposed for the improved efficiency of this fishery.

Keywords: Ring seines, Indian oil sardine fishery, life cycle assessment, webbing, *Sardinella longiceps*

Introduction

Small pelagics such as the Indian oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) together contribute 21% of the total catch in India. In Kerala, two species (sardine and mackerel) together contribute 67% of the total landings with artisanal ring seine fishery contributing 98.8% of sardine and 56% of mackerel landings. Ring seines contribute 55.7% of the total state production (CMFRI, 2013).

Ring seines can be classified based on the mode of propulsion and the two types of ring seine fishing crafts operating along the Kerala coast are mechanized craft using an inboard motor and motorized craft using outboard motor, henceforth referred to as mechanized ring seine and motorized ring seine respectively. According to State of Environment Report (SER) Kerala (2005), a total of 2800 units of ring seines are operating in Kerala with 2100 motorised units and 700 mechanised units. 12-24 m wooden/ steel/ FRP (Fiberglass Reinforced Plastic) vessels with 120-440 hp engines are used for mechanized ring seine operation and 7- 16 m L_{OA} FRP or wooden vessels with one or two 9.9/ 25 and/ or 40 hp engines are used for motorized ring seine operation. The ring seine use skiff for assistance in fishing operation and transfer of catch to the landing centre.

Received 28 October 2016; Revised 25 November 2016; Accepted 05 December 2016

* *E-mail: leelaedwin@gmail.com*

Mechanized and motorized fishing operations are dependent on fossil fuels which are non-renewable and releases high levels of carbon dioxide to the atmosphere contributing to green house effect. In this scenario, energy analysis are relevant in relation to fisheries LCA due to the accepted importance of fuel consumption for feet operations (Tyedmers, 2001) and associated environmental impacts (Thrane, 2004; Schau et al., 2009; Driscoll & Tyedmers, 2010). Very few studies have been reported energy analysis of non-motorized, motorised and mechanized fish harvesting systems operating in Indian waters (Edwin & Hridayanathan, 1997; Boopendranath, 2000; Boopendranath & Hameed, 2009; 2010; Vivekanandan, 2013). Capture fisheries in India annually consumes 1378.8 million litres of fuel and releases 3.13 million tonnes of CO_2 into the atmosphere which is equivalent to 1.02 tonnes of CO_2 per tonne of live fish weight (Vivekanandan, 2013).

In this context, some innovative fishermen of Kerala have come up with a cost effective motorized ring seine unit and within a short time it got wide acceptance. This recently introduced ring seine is also included in the present study as motorized traditional ring seine (TrRS). In this study, an attempt is made to conduct a LCA analysis on oil sardine fishery of Kerala including craft, gear and operations. Moreover, a comparison has been attempted among three different types of ring seine fishery *viz.,* (i) mechanized (MeRS), (ii) motorized (MoRS) and (iii) motorized traditional ring seine (TrRS)) operated in the same geographical space and time, to determine their environmental burdens.

Material and Methods

Kalamukku, (9°58′55.48"N ; 76°14′34.27"E) an important landing center of MeRS and MoRS vessels was selected as the study area (Fig. 1). Motorized traditional ring seines (TrRS) are usually landed in beaches. Data on TrRS landings were collected from *Chellanam* beach landing center, Cochin.

Fishing operation of ring seines are restricted to single day, the operation starting early in the morning and ending late at night. The operations are similar to purse seine and pursing is done by means of both mechanized and manual mode and net hauling is done manually by fishermen. One or two numbers of skiff vessels are commonly attached to a ring seine unit.

The daily fish production data for 30 ring seiners (15 mechanized, 10 motorized and 5 traditional) were collected. These vessels represent the different categories of ring seine fishing fleet of the state. This study was conducted during January 2013- January 14. The three types of fishing systems were designated as MoRS, MeRS and TrRS. This classification is based on an all India study conducted by the Central Institute of Fisheries Technology (Edwin et al., 2014a).

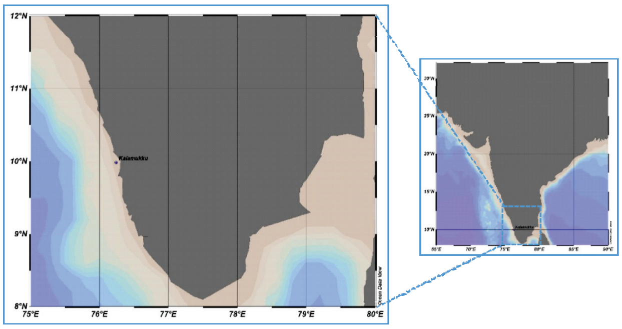

Fig. 1. Study area, *Kalamukku* landing center, Kerala, India

LCA is generally organized into a four step process *viz.,* goal and scope definition, inventory analysis, impact assessment and interpretation of results. The functional unit taken for the study is one tonne of oil sardine (*S. longiceps*) landing. The functional unit (FU) is a quantified definition of the function of a studied system and it provides a reference to which the inputs and outputs can be related (ISO:14040, 2006). The major operational inputs and outputs associated with fishing activity of MoRS, MeRS and TrRS fishing in the south east Arabian sea was collected and analyzed. Under MoRS, MeRS and TrRS six categories of fishing systems were identified based on the material of construction (Table 1). Ring seine gear were classified into three types based on the size of the gear and mesh size (Table 2).

The following types of fishing systems (FS) were identified based on the craft-gear combinations

Category 1. Mechanised fishing system

FS-1 Steel vessel MeRS with skiff-1 operating RS-1

FS-2 FRP vessel MeRS with skiff-1 operating RS-1

FS-3 Wooden vessel MeRS with skiff-1 operating RS-1

Category 2. Motorised fishing system

FS-4 FRP vessel MoRS with skiff-2 operating RS-2

FS-5 Wooden vessel MoRS with skiff(s)-2 operating RS-2

Category 3. Traditional fishing system

FS-6 FRP vessel MoRS operating RS-3

LCA analysis were conducted on each of the systems separately. The analysis also included all activities pertaining to vessel construction onboard equipment like purse winch, purse line reel, fishing gear construction, fuel production and consumption and all activities related to the manufacture of fishing accessories.

All major actives associated with the inputs for assessment of LCA are depicted in the system boundary chart comprising of three sub systems is given in Fig. 2. The system boundary defines which processes will be included in, or excluded from, the system and describes the processes and their relationships. In this study LCA analysis for individual fishing unit (vessel and gear) and its operation was conducted using a *cradle to gate* approach and system boundary has been limited to the point at which the catch reach the harbor (Fig. 2).

Gabi 6 LCA software was used for analysis of the data. As per the requirements of this software the data for each unit process can be classified as energy inputs, raw material inputs, ancillary inputs, other physical inputs, products, co-products and wastes.

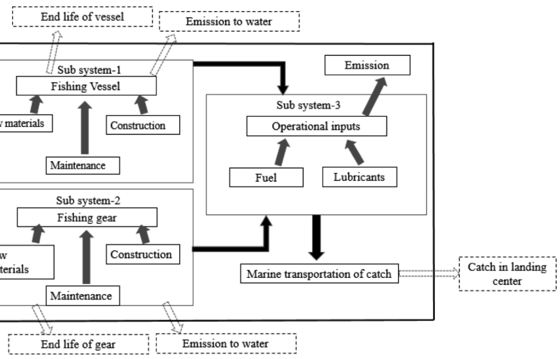

Fig. 2. Block diagram of the studied system. Dotted line represent the system boundary

CML 2001 methodology which includes classification, characterization and normalization of the environmental impacts resource inputs and emissions is adopted by Gabi 6. As per the recommendations of Guinee et al. (2001), ten environmental impact categories, namely abiotic depletion potential elements (ADP elements, Sb equivalents [kg]), abiotic depletion potential fossil (ADP fossil, Sb equivalents [kg]/ MJ) acidification potential (AP, SO_2 equivalents [kg]), eutrophication potential (EP, PO_4 equivalents [kg]), global warming potential (GWP, CO_2-equivalents [kg]), human toxicity potentials (HTP, 1, 4 DCB equivalents [kg]), marine aquatic eco-toxicity potentials (MAETP, 1, 4 DCB equivalents [kg]), stratospheric ozone depletion potential (ODP, R11 equivalents [kg]) and finally photochemical ozone creation potential and terrestrial eco toxicity potential (POCP, C_2H_4 equivalents [kg] and

Table 1. Fishing vessel characteristics

	Vessel 1	Vessel 2	Vessel 3	Vessel 4	Vessel 5	Vessel 6	Skiff-1	Skiff-2
Number of vessels sampled (No.)	8	7	5	5	5	6	10	10
Average length (m)	18-22	18-21	16-18	14-16	12-14	7-9	16-18	14-16
Average Main engine power (hp)	250-350	180-250	120-200	25 and/ or 40	25 and/or 40	9.9	2x25	2x25
Avg. Number of crew	50	50	50	30	30	10		
Mode of pursing the gear	Mechanized	Mechanized	Mechanized	Mechanized/ manual	Mechanized / manual	Manual		
Mode of hauling	Manual	Manual	Manual	Manual	Manual	Manual		
Estimated life (year)	15	10	10	8	8	6	8	8

Table 2. Fishing gear characteristics

	RS-1	RS-2	RS-3
Number of gear sampled	15	10	5
Mesh size (mm)	18-22	10-14	8-12
Length (m)	800-1000	500-799	200
Estimated life (year)	1	1	1

TETP, 1, 4 DCB equivalents [kg]) were chosen to quantify the environmental impacts associated with the activities.

The three categories of vessels differ mainly with respect to the type of engine, fuel used, material used for construction and size of fishing craft and gear. Details of materials used for construction of fishing vessel were collected from local boat building yards by interviews with boat builders, skippers and log books maintained at boat yards and vessels. Quantity wise data on materials like steel (for hull, engine, propeller shaft etc.) welding rod, electricity for welding, grinding, light (unit kwh) plywood for deck, wooden material, alloy for propeller, fiber glass mat, resin, other ingredients (accelerator, catalyst, etc.) material, details of primer, paint, antifouling paint, transportation etc. were collected. Collected quantitative vessel characteristics were amortized with the life span of the fishing vessel and calculated for one tonne landings. Inventory data for subsystem-1 fishing vessel is given in Table 3.

Quantity of polyamide multifilament webbing, high density polyethylene webbing, polypropylene rope, plastic floats, lead sinkers, brass rings were collected from net fabrication sites and net making factory. Maintenance of the fishing vessel and gear also come under the purview of the data collected. In fishing gear webbing life span is considered as one year and the quantitative inputs were expressed in teams of per tonne sardine landings. Inventory data for subsystem-2 fishing gear is given in Table 4.

Details of engine and its horsepower, number, types and size of fishing gear, details of fishing operations including the number of fishing days in an year, time of shooting the net, time of hauling, number of hauls, fuel used (diesel, petrol, kerosene and lubrication oil) were collected from skippers and fishing vessel owners and species wise catch details were collected from fishermen cooperative societies which maintained the daily landing log books (Table 5).

Table 3. Inventory for fishing sub system-I (data for one tonne of landed Indian oil sardine)

Particulars	FS-1 Steel	FS-2 FRP	FS-3 Wood	FS-4 FRP	FS-5 Wood	FS-6 FRP	Skiff-1 FRP	Skiff-2 Wood
Paints (surface primer, paint, antifouling paint, etc.)	1.79E-01	3.32E-01	2.69E-01	1.31E-01	1.73E-01	2.87E-02	1.44E-01	1.20E-01
Copper	-	-	1.02E-01	-	3.09E-02	-	-	2.14E-02
Cotton fibers packed	-	-	7.68E-02	-	1.03E-01	-	-	7.13E-02
Electricity	1.43E-01	8.69E-02	1.13E-01	1.92E-02	2.97E-02	9.38E-02	2.11E-02	2.06E-02
Welding Electrodes	8.82E-02	5.21E-03	4.23E-03	6.42E-04	5.66E-04	2.35E-03	7.02E-04	3.92E-04
Fiber reinforced plastic material (Resin, gel and glass mat)	4.48E-02	2.93E+00	1.44E-01	8.03E-01	1.00E-01	3.76E+00	8.79E-01	6.94E-02
Gunmetal	2.56E-02	5.05E-02	4.10E-02	-	-	-	-	-
Hard wood log mix	8.82E-02	5.21E-02	2.68E+00	4.81E-01	1.41E+00	7.51E-01	3.51E-01	8.82E-01
Limestone	1.92E-02	7.58E-02	-	1.05E-02	-	3.84E-02	1.15E-02	-
Plywood board	9.62E-03	1.90E-02	1.54E-02	1.40E-01	-	5.12E-01	1.53E-01	-
Steel	2.03E+00	5.21E-01	3.80E-01	2.57E-01	2.26E-01	9.38E-02	3.51E-02	2.94E-02

Table 4. Inventory for fishing sub systems-II (data for one tonne of landed Indian oil sardine)

	FS-1	FS-2	FS-3	FS-4	FS-5	FS-6
Polyamide Webbing Material	1.42E+00	1.53E+00	1.59E+00	9.16E-01	1.08E+00	9.40E-01
HDPE Webbing Material	3.16E-01	3.40E-01	3.54E-01	2.62E-01	3.09E-01	2.35E-01
Polypropylene Rope	4.34E-01	4.68E-01	4.87E-01	3.40E-01	4.02E-01	3.29E-01
Lead Sinker	9.87E-01	1.06E+00	1.11E+00	5.24E-01	6.19E-01	4.70E-01
Brass	1.03E-01	1.11E-01	1.15E-01	1.05E-01	1.24E-01	1.41E-01
Plastic float	3.16E-01	3.40E-01	3.54E-01	2.88E-01	3.40E-01	1.88E-01

Table 5. Details of average species wise landing days per year

Species	FS-1 Steel	FS-2 FRP	FS-3 Wood	FS-4 Wood	FS-5 FRP	FS-6 FRP
Sardine	139.7	137.5	143.0	156.2	159.5	57.2
Mackerel	43.9	39.3	40.9	10.9	11.0	3.4
Anchovy	9.558	8.25	3.02	33.26	20.25	42.3
Others	19.558	19.25	20.02	14.42	19.75	52.87
Total	212.7	204.3	206.9	214.7	210.5	155.8

Compared to any other fishing systems ring seine have more number of days without catch because of non-availability of shoals/ unsuitable condition for shooting the net like rough sea condition, distracted shoals, fast moving shoal, small shoals etc. This study has taken into consideration such days also. The data were validated with secondary data obtained from Central Marine Fisheries Research Institute (CMFRI), Cochin. Inventory data for Indian oil sardine harvesting sub systems is per tonne of oil sardine landed. Inventory data for subsystem-3 fishing operation is given in Table 6.

Harvest loses during transfer of catch at the landing center, solid and liquid waste generated in the fishing vessel, discharges of such matter into the sea were not taken into account for the study due to difficulty in collection of data. Quantitative data on electric wiring circuits, navigational equipment also did not come under the purview of this study.

Life cycle assessment has been used previously for small pelagic fishes captured in different fishing methods and has used as management tool for fishery performance evaluation. Other than the previous studies, LCA methodology is used in this study is to analyze the environmental burdens associated with the Indian oil sardine fishery extracted in three different types of same species targeted fishery (ring seine) in detailed and compared. This will be done using material wise output analysis for each fishing systems in detailed and it is the first of that kind in India. In fact, hot spots identification and improvement opportunities for the three ring seine fishing systems are important discussion point in this paper.

Results and Discussion

The total landing from the study area was 4127.89MT and 4146.46MT in 2013 and 2014 respectively. The percentage share of mechanized ring seine which was 51.30% during 2002 has been increasing ever since (Fig. 3). In 2014, 96% of ring seine production in the area was by the mechanized ring seine fishing craft. The contribution of motorized fishery to the total ring seine landings reduced during the period from 49% in 2002 to 4% in 2014. This was because, the number of mechanized ring seiners increased by 83% during the period whereas, the number of motorized ring seiners increased only by 25% and the size and power of the craft, gear and engine increased two to three times with respect to mechanized ring seine units. By virtue of their increased horse power and large gear size, the mechanized fishing fleets exploit more areas and the high landing of this fishery attract more investors to this fishery. The size of the gear has increased gradually from 250m length and 30m (max.) depth to a length of more than 1000 m and a depth of 100m (Edwin et al., 2014b).

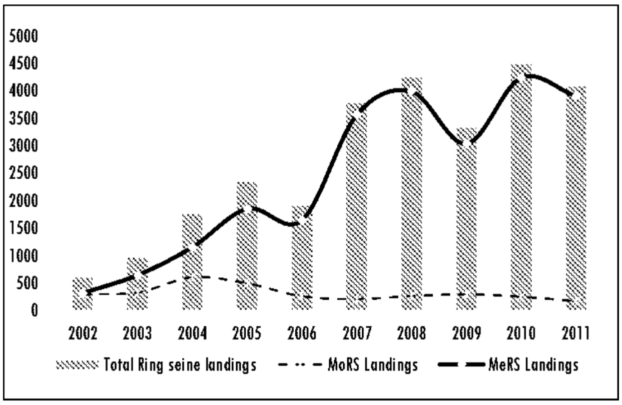

Fig. 3. Ring seine fish landing of the study area (in tonnes)

The fleet size and capacity increase drastically over the years and now the investment in a single mechanized ring seine has reached up to eight million rupees. The labour required for operation and the operational expenses have also increased (Das et al., 2012).

With reference to subsystem 1, the environmental impact of material used for the construction procedure and the repair and maintenance of the vessel during its life time have been assessed (Fig. 4). In case of steel fishing vessel under FS-1 and out of 10 environmental factors studied eight showed more than 74% contribution toward the construction material steel (HTP 86.58%, MAETP, 82.85%, EP 82.85%, GWP 82.80%, POPC 80.66%, TETP 79.67%, ADP fossil 76.44% and AP 74.65%). In FRP fishing vessel FS-2, FRP materials contribute major share of ADP element (86.47%), ADP fossil (82.12%), EP (80.47%), ODP (79.24%), GWP (75.65%) and AP (56.64%). In wooden fishing vessel under FS-3, Copper nails used for the hull construction contributed maximum to 97.67% of ADP elements, 54.62% of HTP, 40.41% of ODP; paints including antifouling paints contributed to 51.24% of TETP, 44.44% of AP, 40.27% of ADP fossil; steel contributed 40.68% of MAETP and cotton used for caulking contributed 45.51% of EP. Wood contributed maximum to the biomass for construction but contribution to the environmental factors were comparatively less (POCP contributed 37.34 %), GWP contribution shown negative value (-64.52%).

In motorized FRP fishing vessel under FS-4, FRP material contributed maximum to the ADP element 98.63% followed by ADP fossil 74.58%, ODP 73.33%, EP 69.68%, GWP 50.53% and steel contributed 48.08% to HTP, MAETP 47.62% and TETP 43.39%. Contribution of wood is negligible to all environmental factors and in GWP it showed negative value (-21.26%). In wooden fishing vessel under FS-5, copper nails used for the hull construction contributed maximum of 98.25% to ADP elements and 42.92% to HTP cotton used for caulking contributed 68.68% of EP. Steel contributed 56.03% of MAETP and paints including antifouling paints contributed to 50.43% of AP, 50.21% of TETP and wood contribute 35% of POCP and -63.30% of GWP. In motorized traditional FRP fishing vessel under FS-6, FRP material contributed maximum to all the environmental factors (ADP element 99.87% followed by ADP fossil 96.12%, ODP 95.39%, EP 90.71%, AP 86.66%, GWP 79.97%, HTP 73.25%, POCP 68.24%, TETP 61.04% and MAETP 41.15%).

In the case of subsystem-2 fishing gear under RS-1, RS-2 and RS-3 the synthetic materials used, construction, maintenance and repair were taken into consideration while assessing the contribution to environmental factors. In case of fishing gear coming under the subsystem-2 Polyamide webbing contributed maximum to ODP, EP, GWP, ADP fossil, POCP, AP and TETP with an average of 83.94, 81.43, 77.94, 69.49, 57.69, 44.57 and 44.96% respectively in all fishing gear coming under subsystem-2. Lead was the second most important factor that contributed to environmental impact accounting for 94.63%

Table 6. Inventory for fishing sub systems-III (data for one tonne of landed Indian oil sardine)

	FS-1 Steel	FS-2 FRP	FS-3 Wood	FS-4 FRP	FS-5 Wood	FS-6 FRP
Diesel	89.50684	85.56297	87.85965			
Petrol	4. 945890	4.890945	5. 094589	8.114803	8.899482	9.341826
Kerosene	32.44179	31.94401	33. 02941	141.9945	141.0218	74.73461
Lub oil	1.316277	1.383796	1.402016			

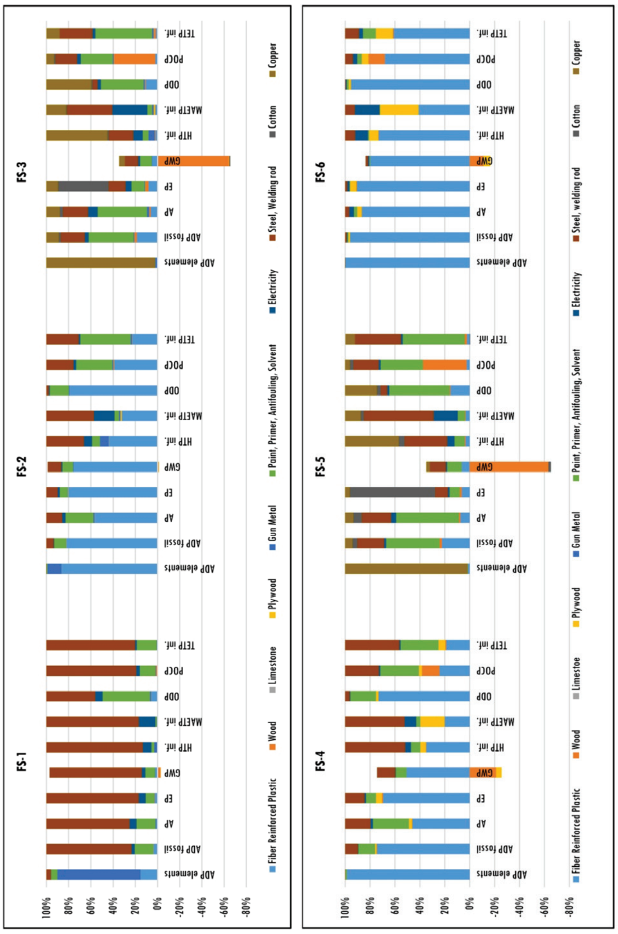

Fig. 4. Relative contribution to environmental impact associated with the subsystem-1 fishing craft

of ADP elements, 45.18% of HTP and 40.46% of AP. HDPE webbing contributed 62.23% of MAETP (Fig. 5).

In the case of subsystem-3 fishing operation under FS-1, FS-2 and FS-3 the fuel used by the main vessel, skiff vessel and lubricant oil were taken into consideration while assessing the contribution to environmental factors. In case of fishing operation coming under the subsystem-3 diesel contributed 74.26 to 78.75% of all the environmental parameters, kerosene contributed 19.92 to 18.66% to the environmental parameters. Contribution of lubricant and petrol were less than 4%. In fishing operation under FS-4 and FS-5 the contribution of kerosene to the environmental factors are from 93.61 to 98.69% where as in FS-6 it is 88.81 to 97.39% and the petrol contribution is 1.31 to 6.39% in FS-4 and FS-5 where as in FS-6 it is 2.61 to11.18%. (Fig. 6)

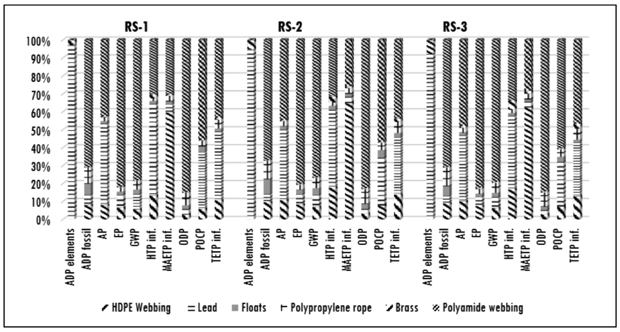

Fig. 5. Relative contribution to environmental impact associated with the subsystem-2 Fishing gear RS-1, RS-2, RS-3

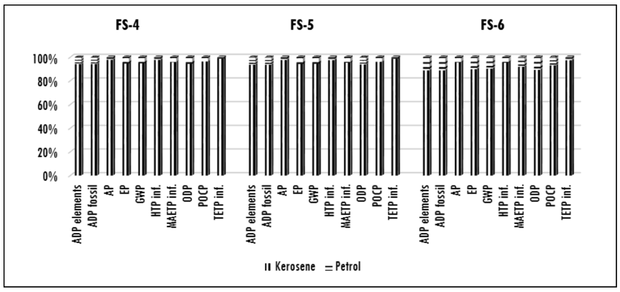

Fig. 6. Relative contribution to environmental impact associated with the subsystem-3 Fishing operation FS-4, FS-5 and FS-6

While considering the environmental performance of oil sardine fishery of Kerala landed by ring seines, gear contributes maximum to ADP element and ODP and fishing operation contributed maximum to all other environmental factors considered in this study. Maximum contribution to ADP elements was by the fishing gear due to the presence of lead used in the sinker line and the gear used in the mechanized fishing systems contributed maximum to ADP and the minimum contribution was by the traditional gear. Similar pattern was observed in the case of ODP where the environmental impact is due to the polyamide webbing used studied by Vázquez-Rowe et al., (2010) while assessing the LCA of horse mackerel in Galicia.

Maximum contribution to ADP fossil was through fishing operation which is due to the presence of fossil fuel used for the vessel operation (Table 7). Among the fishing systems motorized fishing vessels operation contribute more to the ADP fossil which is due to the heavy fossil fuel used by the outboard engines. The minimum contribution was by traditional fishing vessels. Second highest con-

Table 7. Environmental performance of different ring seine fishing systems operated along the Kerala coast (data for one tonne of landed Indian oil sardine)

	Fishing System 1			Fishing System 2			Fishing System 3		
	Operation	Craft	Gear	Operation	Craft	Gear	Operation	Craft	Gear
ADP elements	1.13E-05	1.45E-04	2.91E-03	1.13E-05	1.75E-04	3.06E-03	1.12E-05	8.98E-04	3.26E-03
ADP fossil	4.55E+03	7.33E+01	3.48E+02	4.51E+03	1.22E+02	3.67E+02	4.49E+03	5.76E+01	3.91E+02
AP	1.12E+00	3.18E-02	8.61E-02	1.11E+00	5.32E-02	9.07E-02	1.11E+00	2.39E-02	9.65E-02
EP	5.03E-02	2.30E-03	6.61E-03	4.99E-02	3.58E-03	6.96E-03	4.96E-02	2.59E-03	7.41E-03
GWP	3.74E+02	4.15E+00	1.96E+01	3.71E+02	7.83E+00	2.06E+01	3.69E+02	-3.21E+00	2.19E+01
HTP	2.57E+01	8.51E-01	1.68E+00	2.55E+01	1.44E+00	1.77E+00	2.53E+01	7.38E-01	1.89E+00
MAETP	6.87E+03	1.94E+03	1.59E+03	6.82E+03	3.36E+03	1.70E+03	6.78E+03	9.18E+02	1.79E+03
ODP	3.45E-10	9.29E-11	2.58E-09	3.43E-10	1.45E-10	2.72E-09	3.41E-10	1.49E-10	2.89E-09
POCP	7.49E-02	3.47E-03	1.00E-02	7.44E-02	5.66E-03	1.05E-02	7.39E-02	3.53E-03	1.12E-02
TETP	1.63E-01	3.08E-02	1.68E-02	1.62E-01	5.25E-02	1.77E-02	1.61E-01	1.95E-02	1.88E-02
	Fishing System 4			**Fishing System 5**			**Fishing System 6**		
	Operation	Craft	Gear	Operation	Craft	Gear	Operation	Craft	Gear
ADP elements	1.52E-05	1.13E-04	1.80E-03	1.52E-05	2.82E-04	1.65E-03	7.98E-06	1.14E-04	1.46E-03
ADP fossil	6.09E+03	1.22E+02	2.70E+02	6.08E+03	8.61E+01	2.48E+02	3.20E+03	1.01E+02	2.31E+02
AP	1.49E+00	2.95E-02	6.02E-02	1.48E+00	2.44E-02	5.52E-02	7.56E-01	1.96E-02	5.06E-02
EP	6.78E-02	2.46E-03	4.93E-03	6.77E-02	2.68E-03	4.53E-03	3.55E-02	2.14E-03	4.34E-03
GWP	5.05E+02	4.85E+00	1.46E+01	5.04E+02	1.23E+00	1.34E+01	2.63E+02	4.64E+00	1.28E+01
HTP	3.42E+01	3.20E-01	1.19E+00	3.40E+01	3.62E-01	1.10E+00	1.73E+01	2.02E-01	9.98E-01
MAETP	9.14E+03	7.41E+02	1.37E+03	9.12E+03	6.28E+02	1.26E+03	4.73E+03	4.73E+02	1.13E+03
ODP	4.52E-10	1.67E-10	1.94E-09	4.51E-10	1.40E-10	1.78E-09	2.37E-10	1.25E-10	1.72E-09
POCP	9.99E-02	6.76E-03	7.18E-03	9.96E-02	4.92E-03	6.59E-03	5.14E-02	5.73E-03	6.10E-03
TETP	2.14E-01	1.24E-02	1.21E-02	2.13E-01	1.25E-02	1.11E-02	1.08E-01	5.01E-03	1.03E-02

tributor to the ADP fossil was fishing vessel followed by fishing gear. In steel mechanized fishing vessel steel contributed maximum, in FRP mechanized fishing vessel FRP material contribute maximum and in wooden mechanized fishing vessel paint including surface primer, base coat, antifouling, paint contributed maximum followed by FRP constituents and steel. In fishing gear polyamide webbing contribute maximum to ADP fossil.

Maximum contribution to ADP fossil, AP, EP, GWP, HTP, MAETP, POCP and TETP was by fishing operation due to the presence of fossil fuel used for the vessel operation. Previous works by Edwardson, (1976); Watanabe & Okubo, (1989); Tyedmers, (2001); Ziegler et al. (2003); Tyedmers et al. (2005); Thrane, (2004); Hospido & Tyedmers, (2005); Schau et al. (2009) and Vázquez-Rowe et al. (2010) have reported similar trends. Nonetheless, it is interesting to point out that among the fishing systems studied, motorized fishing vessel operations contribute more to the above environmental factors, except MAETP. Fishing system-2 mechanized FRP craft has higher MAETP contribution than motorized fishing system which is due to the FRP material used for construction.

The high environmental impact of the motorized fleets (Table 8) are mainly due to the, operational issues like the intensive use of kerosene as fuel by highly inefficient outboard engines, whereas mechanized ring seines are propelled by inboard engines run by diesel. The motorized unit uses 150 liters of fuel for producing one tonne of oil sardine whereas mechanized and traditional vessels consume 112 and 84 liters respectively per tonne of fish landed. A study conducted by Schau et al. (2009) in Norwegian fleet shows that 90 kg fuel was consumed per tonne of mackerel landed. Similar study by Vázquez-Rowe et al. (2010) in Galicia on the horse mackerel fishery reports that 176 kg of fuel is used for the production of one tonne of fish. Studies by Hospido & Tyedmers (2005) on Spanish tuna fishery shows 420 kg of fuel usage per tonne of production. To our knowledge there are no environmental impact studies for motorized and mechanized fishing fleet for oil sardine fishery in India.

Results show that oil sardine landed by motorized ring seine fleet is having higher impact compared to mechanized ring seine fleet except ADP element and ODP due to the high use of lead weight and polyamide webbing in mechanized fleets. While comparing motorized fleets (Table 9), impact of ADP fossil, AP, EP, GWP, HTP and POCP shows more than 20% higher impact than mechanized fleet with a higher value of 24% in GWP.

Different hot spots have been identified in the study of oil sardine fishery through motorized and mechanized ring seine activities. Through this study some important interventions can be proposed for the improved efficiency of the fishery. The reduction of fuel through reduction of speed can bring about a major change. Gulbrandsen (2012) has opined that 10% reduction of engine rotation per minute (rpm) will reduce 20% fuel consumption and 20% reduction in rpm will reduce 40% fuel consumption. Proper maintenance of vessel hull also contributes a major role in fuel use. In tropical conditions hull fouling increases fuel consumption at 7% in first month of operation and up to 44% after six month of operation if antifouling paint is not used (Gulbrandsen, 2012). Vessel drag reduction through improvised hull shape will help in energy efficiency up to 20% (Schau et al., 2009). In motorized fleets, replacement of high energy consuming 2-stroke out board engine to inboard engines will reduce the fuel usage. According to Gulbrandsen (2012) when compared with 2-stroke out board petrol engines inboard diesel engine consume 62% less fuel at same speed. Ring seine operations are conducted based on the occurrence of small pelagic fish shoals. The chance of occurrence of fish as small pelagic shoals mainly depends on the sea surface temperature and chlorophyll concentration (Pillai & Nair, 2010). Boopendranath & Hameed (2012) observed that Kerala ring seine fuel consumption per kg fish landed varied with lower fuel consumption during the month of May to December and higher in January to April. The high fuel consumption during this period is due to the movement of oil sardine shoals towards deeper depth (Pillai & Nair, 2010) which make the fishing more difficult and increase the total fish shoal searching time and leads to the wastage of fuel. During the study period it is observed that an average ring seine fishing trip takes 12.28 ± 2.06 h of operation, including the cruising time to the fishing ground and the fishing operation takes less than 45% of the total fishing time and major time was spent for searching the fish shoals for which maximum fuel is consumed. Knowledge

Table 8. Combined environmental performance of different ring seine fishing systems operated along the Kerala coast (data for one tonne of landed Indian oil sardine)

	FS-1	FS-2	FS-3	FS-4	FS-5	FS-6
ADP elements	3.07E-03	3.25E-03	4.17E-03	1.93E-03	1.95E-03	1.58E-03
ADP fossil	4.97E+03	5.00E+03	4.94E+03	6.48E+03	6.41E+03	3.53E+03
AP	1.24E+00	1.25E+00	1.23E+00	1.58E+00	1.56E+00	8.26E-01
EP	5.92E-02	6.04E-02	5.96E-02f	7.52E-02	7.49E-02	4.20E-02
GWP	3.98E+02	3.99E+02	3.88E+02	5.24E+02	5.19E+02	2.80E+02
HTP	2.82E+01	2.87E+01	2.79E+01	3.57E+01	3.55E+01	1.85E+01
MAETP	1.04E+04	1.19E+04	9.49E+03	1.13E+04	1.10E+04	6.33E+03
ODP	3.02E-09	3.21E-09	3.38E-09	2.56E-09	2.37E-09	2.08E-09
POCP	8.84E-02	9.06E-02	8.86E-02	1.14E-01	1.11E-01	6.32E-02
TETP	2.11E-01	2.32E-01	1.99E-01	2.39E-01	2.37E-01	1.23E-01

Table 9. Mass allocation of impact categories in terms of 1 tonne sardine landing

Impact Category	Mechanised	Motorised	% difference motorized / mechanized landings
ADP elements	3.50E-03	1.94E-03	-80.24%
ADP fossil	4.97E+03	6.45E+03	22.89%
AP	1.24E+00	1.57E+00	21.02%
EP	5.97E-02	7.51E-02	20.41%
GWP	3.95E+02	5.22E+02	24.26%
HTP	2.83E+01	3.56E+01	20.60%
MAETP	1.06E+04	1.12E+04	4.96%
ODP	3.20E-09	2.47E-09	-29.95%
POCP	8.92E-02	1.13E-01	20.71%
TETP	2.14E-01	2.38E-01	10.08%

about the spatial distribution of fish over the time and the effective use of Potential Fishing Zone (PFZ) forecast based on sea surface temperature and or surface chlorophyll concentrations can help to reduce the searching time and environmental impact.

Replacement of low durable polyamide webbing with highly durable Ultra-High Molecular Weight Polyethylene (UHMWPE) will help to increase the life span of webbing (Thomas & Edwin, 2012) which may lead to reduction in detrimental effect on environmental impact factors. Appropriate use of lead sinkers will reduce the number of sinker per meter of sinker line which will also reflect in environmental factors like ODP. Compared to mechanized and motorized ring seine units, traditional ring seine units contribute least to the environmental factors. L_{OA} of motorized ring seine units restricted to 15 m for near shore operation with smaller size of ring seine gear and mechanized ring seine units with optimized gear for off shore operation will help to reduce the environmental impacts.

The two hot spots identified in the Indian oil sardine fishery (mechanized and motorized ring seine) were fuel usage for fishing operation and material for fishing craft and gear. Compared to mechanized fleet, environmental impacts of motorized fleet are high. Fishing vessel hull optimization, reduction of engine rpm, periodic maintenance of hull and replacement of two stroke petrol engine to inboard diesel engine is recommended in order to reduce environmental impact related to fishing operation and knowledge about pelagic fish spatial distribution reduce the environmental impact by reduced shoal searching time. Use of high durable alternative webbing materials and appropriate use of lead sinkers will increase the life of gear and reduce the environmental impacts.

Acknowledgments

The study was carried out as part of the project "Green Fishing Systems for Tropical Seas" funded by the National Fund for Basic, Strategic and Frontier Application Research in Agriculture (NFBSFARA)" ICAR. The authors are thankful to the Director, Central Institute of Fisheries Technology, Cochin for providing the necessary facilities.

Reference

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

Boopendranath, M. R. and Hameed, M. S. (2009) Energy analysis of traditional non-motorised gill net operations in Vembanadlake, Kerala, India. Fish. Technol. 46: 15-20

Boopendranath, M. R. and Hameed, M. S. (2010) Energy Analysis of stake net operations in Vembanadlake, Kerala, India. Fish. Technol. 47: 35-40

Boopendranath, M. R. and Hameed, M. S. (2012) Energy analysis of the ring seine operations, off Cochin, Kerala. Fish. Technol. 49: 141-146

CMFRI (2013) Annual Report 2012-13. 200 p, Central Marine Fisheries Research Institute, Cochin

Das, P. H. D., Gopal, N. and Edwin, L. (2012) Labour Deployment and Wage Distribution in Ring Seine Fishery of Central Kerala, In: Agricultural Economics Research Review Year, 25(1): 107-114

Driscoll, J. and Tyedmers, P. (2010) Fuel use and greenhouse gas emission implications of ûsheries management: the case of the new England Atlantic herring ûshery. Mar. Pol. 34: 353-359

Edwardson, W. (1976) The energy cost of ûshing. Fishing News Int. 15(2): 36-39

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., Pravin, P., Madhu, V. R., Thomas, S. N., Remesan, M. P., Baiju, M. V., Ravi, R., Das, D. P. H., Boopendranath, M. R. and Meenakumari, B. (2014a) Mechanised Marine Fishing Systems: India, 277 p, Central Institute of Fisheries Technology, Kochi

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

Guinee, J. B., Gorre´e, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Weneger, A., Suh, S., Udo de Haes, H. A., de Bruijn, H., van Duin, R. and Huijbregts, M. (2001) Life Cycle Assessment: An Operational Guide to the ISO Standards, Part 2. Ministry of Housing, Spatial Planning and Environment, The Hague, The Netherlands

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

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

ISO (2006) ISO 14040 Environmental Management – Life Cycle Assessment – Princi- ples and Framework

Pillai, V. N. and Nair, P. G. (2010) Potential Fishing Zone advisories- are they beneficial to the coastal fisherfolk? A case study along Kerala coast. South Ind. J. Biol. Forum. 2(2): 46-55

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

SER Kerala (2005) State of Environment Report Kerala 2005, Govt. of Kerala, Kerala State Council for Science, Technology and Environment; 349

Thomas S. N. and Edwin L. (2012) UHMWPE - The Strongest Fibre Enters the Fisheries Sector of India, Fish Technology Newsletter, Central Institute of Fisheries Technology, Cochin, Vol. XXIII (4) October - December 2012

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

Tyedmers, P. (2001) Energy consumed by North Atlantic fisheries. In: Fiseries impacts on North Atlantic ecosystems: catch, effort and national/regional datasets (Zeller, D., Watson, R. and Pauly, D., Eds), Fisheries Center Research Report, Vancouver, British Columbia 9(3): 12-34

Tyedmers, P., Watson, R. and Pauly, D. (2005) Fuelling global fishing fleets. AMBIO 34(8): 619-622

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

Vivekanandan, E., Singh,V. V. and Kizhakudan, J. K. (2013) Carbon footprint by marine fishing boats of India. Curr. Sci. 105 (15): 361-366

Watanabe, H. and Okubo, M. (1989) Energy input in marine fisheries in Japan. Jpn. Soc. Sci. Fish. B 53: 1525-1531

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