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Research Paper

Carbon footprint in aquaculture –A review

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ABSTRACT
Protein demand from animal sources is increasing significantly as global population increases. The recent supply of fish from aquaculture is running behind the demand of the global market. According to the FAO, the demand for protein requirements from the aquaculture sector may increase up to 96 percent by 2050. The raising demand accelerates the rate of greenhouse gas emission from increased level of aquaculture production. Life Cycle Assessment (LCA) method is often employed to calculate carbon footprint of each operational phase during culture period right from raw material source to consumption and final disposal. The carbon footprint value needs to be evaluated in all kinds of species specific and region specific culture so that suitable mitigation strategies can be framed to reduce environmental impacts. The emission from aquaculture sector can boost global warming and climate change consequences. Reducing emissions from food production will be one of the greatest challenges in the coming decades. Shortening supply chains and building regional markets could reduce GHG emissions at the same time, potentially contributing to greater food security. Thus, the present paper mainly aims to give an overview about carbon footprint and its significance in aquaculture.
KEY WORDS: *Aquaculture, Carbon, Climate change, GHG, Emission*

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I. INTRODUCTION

According to the International Energy Agency, global carbon dioxide emissions from fuel combustion reached a new record of 36.3 billion tons (36.3 Gt) in 2021. Overall, greenhouse gas emissions fell 9% from 2019 to 2020, largely as a result of COVID-19-related lockdowns, which limited the use of motor vehicles (and in turn greatly reduced the emission of GHGs in vehicle exhaust). However, early data indicate that GHG emissions not only rose in 2021, but reached the highest global level yet recorded. Both coal and renewable powerrose to their highest recorded levels of consumption in 2021.Intergovernmental Panel on Climate Change (IPCC) research suggests that the world needs to reduce global greenhouse gas emissions by 45% by around 2030, and achieve net-zero emissions by 2050, in order to avert the worst impacts of climate change. However, meeting such long-term goals will require deep cuts in emissions in the coming decades, including in transportation where emissions are projected to increase significantly by 2050, absent new actions. The Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C.In order to achieve the set goals, carbon footprint concept was established. The carbon footprint method helps to quantify the amount of greenhouse gases released into the environment from all kinds of government and private production and consumption sectors. The concept of a carbon footprint captures the interest of businesses, consumers, and policy makers alike. Investors watch the carbon footprint of their portfolios as an indicator of investment risks. Purchasing managers are curious about the carbon footprint of their supply chains, and consumers are increasingly offered carbon-labeled products (Hertwich, E.G. and Peters, G.P., 2009). The carbon footprint of food products needs to be given special importance since food significantly contributes to global emissions. Among all food varieties, production quantity of aquatic food especially from aquaculture sector is keep on increasing year after year. The results of overexploitation by capture fishery leads to construction of numerous large and small scale aquaculture farms. Aquaculture sector greatly compensates the global protein demand and food security. Protein demand from animal sources is increasing significantly as global population increases. The recent supply of fish from aquaculture is running behind the demand of the global market. According to the FAO, the demand for protein requirements from the aquaculture sector may increase up to 96 percent by 2050. The IFIF (International Feed Industry Federation) report reveals that currently livestock and fisheries consume 1 billion t of formulated feed in the world, resulting in an indirect addition of 16 million t of carbon into aquaculture systems. These emissions will increase with the growth in the aquaculture industry. The estimated damage by GHG emissions to ecosystems and human health is about US$ 0.679 trillion and US$ 13 billion, respectively. Thus, there is a need for accurate and comprehensive estimation of GHG emissions from different aquaculture systems and the different mechanisms of gas production so that future strategic mitigation measures can be taken up for sustainable growth of the aquaculture sector. So, the present paper aims to give a review about carbon footprint in aquaculture industry and its emission status.

II. CARBON FOOTPRINT

A carbon footprint is a measure of the total greenhouse gas emissions (primarily carbon dioxide and methane) caused by an individual, community, event, organization, service, product, or nation. These emissions are caused directly and indirectly by an individual, organization, event and product. The main GHGs in the Earth's atmosphere are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone. A life cycle product carbon footprint measures the total greenhouse gas emissions generated by a product, from extraction of raw-materials, to end-of-life. It is measured in carbon dioxide equivalents (CO_2e). The carbon dioxide equivalent for a gas is derived by multiplying the tonnes of the gas by the associated GWP:

MMTCDE = (million metric tonnes of a gas) * (GWP of the gas).

For example, the GWP for methane is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tonnes of methane and nitrous oxide respectively is equivalent to emissions of 25 and 298 million metric tonnes of carbon dioxide.

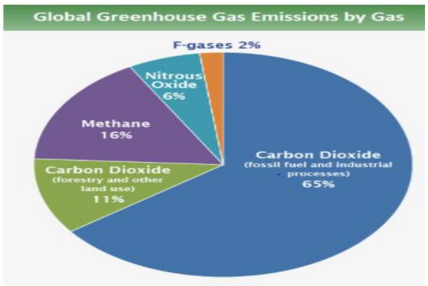

Figure 1: Percentage of GHG emissions in U.S. 2020 (EPA)

Global Warming Potential (GWP): The Global Warming Potential (GWP) of a GHG indicates the amount of warming a gas causes over a given period of time (normally taken as100 years). It is a term used to describe the relative potency, of a greenhouse gas, taking account of how long it remains active in the atmosphere. GWP is an index, with CO_2 having the index value of 1, and the GWP for all other GHGs is the number of times more warming they cause compared to CO_2.Carbon dioxide is taken as the gas of reference and given a 100-year GWP of 1.The GWP values of important GHG gases are shown in Fig. 2. The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy and how long they stay in the atmosphere (lifetime) (US EPA, 2022)

	Greenhouse Gas	Global Warming Potential (GWP)
1.	Carbon dioxide (CO_2)	1
2.	Methane (CH_4)	25
3.	Nitrous oxide(N_2O)	298
4.	Hydrofluorocarbons (HFCs)	124 – 14,800
5.	Perfluorocarbons (PFCs)	7,390 – 12,200
6.	Sulfur hexafluoride (SF_6)	22,800
7.	Nitrogen trifluoride (NF_3)[3]	17,200

Figure 2: GWP for important GHGs in atmosphere

III. HISTORY OF CARBON FOOTPRINT:

The carbon footprint concept is related to and grew out of the older idea of ecological footprint, a concept invented in the early 1990s by Canadian ecologist William Rees and Swiss-born regional planner Mathis Wackernagel at the University of British Columbia.An ecological footprint is the total area of land required to sustain an activity or population. It includes environmental impacts, such as water use and the amount of land used for food production.British Petroleum (BP), the second largest non-state owned Oil Company in the world, with 18,700 gas and service stations worldwide, hired the public relations professionals to promote the slant that climate change is not the fault of an oil giant, but that of individuals. It was BP that revealed the phrase "carbon footprint". The company unveiled its carbon footprint calculator in 2004 so one could assess how their normal daily life going to work, buying food and traveling is largely responsible for heating the globe.BP made no attempt to reduce its own carbon footprint, instead expanding its oil drilling into the 2020s. However, the strategy had some success, with a rise in consumers concerned about their own personal actions, and creation of multiple carbon footprint calculators.

IV. TYPES OF CARBON FOOTPRINT

There are two types of carbon footprint(Czerkauer-Yamu et al. 2010) which are explained below:
Primary footprint–It is the sum of direct emissions of greenhouse gases from the burning of fossil fuels for energy consumption and transportation. These emissions can be brought under control. For example: When one drive a car, the greenhouse gases would be considered Primary because you are the one burning the fossil fuels.
Secondary footprint–It is the sum of indirect emissions of greenhouse gases during the life cycle of products used by an individual or organization. These kind of emissions are not under the control since secondary footprint is the greenhouse gases that are released into the atmosphere indirectly. For example: If one buy food that was imported from another country, those greenhouse gases would be secondary because the consumer is not burning anything directly, that food had to travel more than 1,000 miles to get to the market store

V. INDIAN STATUS IN GREENHOUSE GAS EMISSIONS

India is the world's third largest emitter (2,310 MMT) of greenhouse gases (GHGs), after China (9,877 MMT) and the US (4,745 MMT).India In 2018, India contributed about 7.2% to global greenhouse gas emissions and about 6.9% to global CO_2 emissions.India's current CO_2 emissions (2021) are 2.88 Gt. According to the Centre for Science and Environment (CSE)'s projections, India's generation in a business-as-usual scenario will be 4.48 Gt in 2030.The mean carbon footprint of every Indian was estimated at 0.56 tonne per year.

VI. FOOD'S CARBON FOOTPRINT

By 2050 the world's population will reach 9.1 billion, which is a 34 percent increase from today. In order to feed this larger population, food production must increase by 70 percent. The world produces about 4 billion metric tons of food per year. Food production is responsible for a quarter of anthropogenic greenhouse gas (GHG) emissions globally (Parker et al. 2018).The carbon footprint of a food product is the total amount of GHG emitted throughout its lifecycle, expressed in kilograms of CO_2 equivalents.Food's carbon footprint or foodprint, is the greenhouse gas emissions produced by growing, rearing, farming, processing, transporting, storing, cooking and disposing of the food you eat.

It is most appropriately calculated using Life-Cycle Assessment (LCA) method – used to estimate emission of GHGs during the Food Product's Life Cycle. LCA is an internationally accepted method and the guidelines for conducting the assessment were provided by ISO standards (ISO 14040 and 14044) - These standards describe the method and basic requirements for undertaking an LCA.Principally four stages of the life cycle of various food products are important. Those include production, processing, transportation and preparation of a product. The supply chain of fishery products has increased that led to the long distance trade consuming significantly more fossil-fuel energy for transportation.

In Fig. 3, it was shown that food alone constituted 26% of global greenhouse gas emissions. Thus, its very important to study the carbon emissions released from food sector especially fisheries since it acts as a fuel to compensate global protein demand. The volume of global fish production amounted to 178.5 million metric tons in 2019-20 (SOFIA, 2020). Per capita food fish consumption grew from 9.0 kg (live weight equivalent) in 1961 to 20.5 kg in 2018 (Statista, 2022). India is the 3rd largest fish producing and 2nd largest aquaculture nation in the world after China. In India, total marine fish production was 3.72 MMT (2019-20) and 10.43 MMT (2019-20) for Inland fish production (Handbook on Fisheries Statistics, 2020).

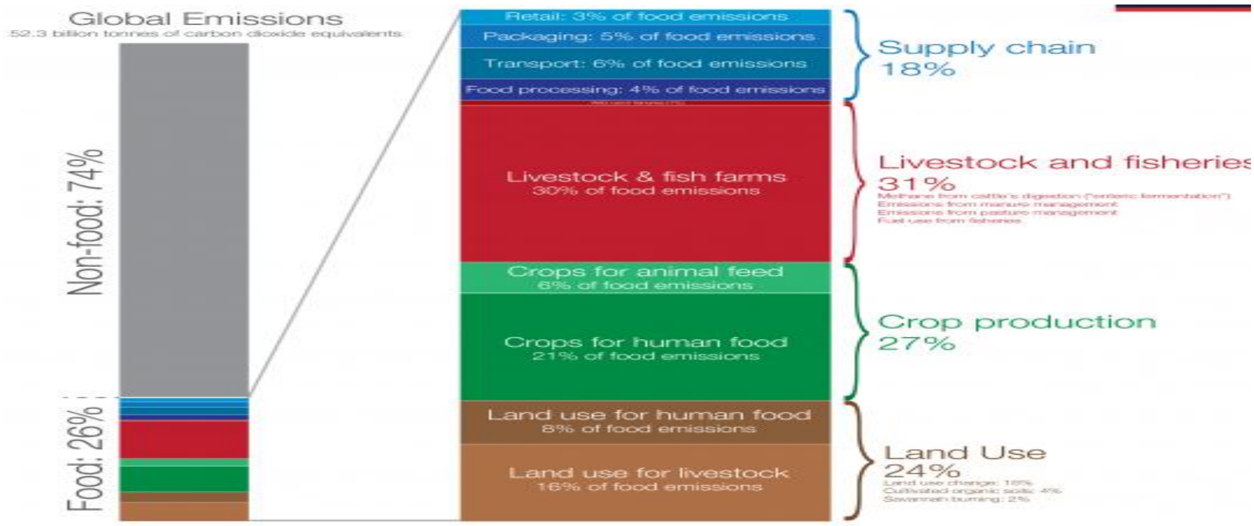

Figure 3: Global food emission and its constituents (Poore and Nemecek, 2018)

VII. CARBON FOOTPRINT ANALYSIS IN THE AQUACULTURE INDUSTRY

Global aquaculture makes an important contribution to food security directly (by increasing food availability and accessibility) and indirectly (as a driver of economic development). In order to enable sustainable expansion of aquaculture, we need to understand aquaculture's contribution to global greenhouse gas (GHG) emissions and how it can be mitigated.Aquaculture produces 0.49% of man-made greenhouse gases or 263 million tonnes of carbon dioxide equivalent ($MtCO_2e$) (FAO, 2017). A method called Life Cycle Assessment (LCA) is used for quantifying the GHG emissions arising from the culture of the main aquatic animals reared for human consumption, i.e.: bivalves, shrimps/prawns and finfish (catfish, cyprinids, Indian major carps, salmonids and tilapias). This method quantifies the main GHG emissions arising "cradle to farm-gate", from the following activities: the production of feed raw materials; processing and transport of feed materials; production of compound feed in feed mills and transport to the fish farm; rearing of fish in water.

The economic, ecological and social issues mentioned above have raised serious concerns over the sustainability of shrimp aquaculture production and consumption. Some previous studies have looked into different stages and activities within the shrimp production chains but, as far as the author is aware, no study of the whole life cycle of the shrimp production and consumption has been earned out so far. Mungkung (2005) takes a life cycle approach to assess the environmental sustainability of the shrimp aquaculture from "cradle to grave". Life Cycle Assessment (LCA) has been used to compile the inventories of raw materials and energy used as well as emissions and wastes generated along the production chains.By using LCA, the key life cycle stages and most significant impacts have been identified to enable a more effective approach to reducing the environmental footprint of shrimp farming. Comparison of different farming systems has also been carried out to identify better farming practices in terms of environmental performance. Moreover, the balance between environmental interventions, social impacts and economic benefits has been investigated across the whole life cycle to provide an understanding of the level of sustainability of the sector and how it might be improved.

Sources of Greenhouse Gas Emissions from Aquaculture Systems

Carbon Dioxide: Respiration by biological components - mineralization of organic matter (Chen et al. 2015). Heterotrophic bacteria mainly produce CO_2 during the mineralization of organic matter. Feed residues, faecal matter of fishes, manure applications, as well as dead phytoplankton biomass, also contribute to the organic matter content in most aquaculture systems.

Methane: Methanogenic bacteria produce methane gas by utilizing dissolved organic carbon (DOC) in anaerobic conditions. Bottom sediment is the major site for methanogenic bacteria activity as it resides at the least aerated site of the pond environment. An increase in temperature stimulates methanogenesis activities, which would contribute to higher CH_4 emission.

Nitrous Oxide: Nitrifying and denitrifying bacteria produce nitrous oxide gas through autotrophic aerobic nitrification, anaerobic denitrification process - These bacteria utilize ammonia, which is released from the degradation of the uneaten protein-rich aquafeed and faecal excreta of fishes - Algal photosynthesis also releases NO_3 - 90 percent of N_2O is produced by denitrification and 10 percent by nitrification (Yang et al. 2015).

Emissions from tentative operations used in aquaculture practices

Aquaculture consists of several operational phases such as pond construction, water filling, weed control, stocking, feeding, water quality management and harvesting. All these operations are either directly or indirectly involved in releases of greenhouse gases into environment. Until now there are no clear-cut figures of total GHGs emissions from the aquaculture sector nor individual data about different culture systems (Adhikari, 2013). Data are available for area-wise culture systems, species-specific culture systems, and emissions from water bodies of different countries.

The emission from aquaculture in 2009 was estimated to be 9.30×10^{10} g eq CO_2 and will increase to 3.83×10^{11} g eq CO_2 by 2030 (Hu et al. 2012). Globally, the annual utilization of compound feed is 1 billion tons for all livestock and fisheries, from which annually 16.6 million tons of carbon is buried in the aquaculture industry in the form of aquafeed (IFIA, 2019). As fish feed is protein rich, the leftover feed and faecal matter are the ultimate sources for the release of greenhouse gases during microbial mineralization. Therefore, the aquaculture sector is also responsible for global warming by emitting greenhouse gases, but the actual figure is unknown. Different world organizations are conducting research for quantifying GHGs from the aquaculture sector and its possible mitigation.Life cycle assessment begins with the extraction of raw materials and end with the delivery of gutted fish to the retailers or for further processing (Gronroos et al. 2006).

Aquatic foods have high nutritional value, are important as a food source for human nutrition, food security, and generation of income, while contributing to greenhouse gases, although this impact is often underestimated (FAO, 2009).But to enable sustainable expansion of aquaculture, we need to understand its contribution to global greenhouse gas emissions and how it can be mitigated.One way to reduce the impact of aquaculture production systems is by having thorough knowledge of the production system, which allows implementation of corrective measures or adjustment of the technologies used to improve the consumption of natural resources and the disposal of production residues.The search for environmentally sustainable aquiculture is a constant process that can only be achieved using environmental management tools that identify the potential environmental impacts and factors associated to the production systems

There are lots of ways to reduce emissions, including developing genetically improved breeds suitable for lower feed conversion rates, improving health, using more precise feeding methods, and improving on-farm energy efficiency. Feed is the main source of emissions in most systems, so some of the reduction can be achieved before we even get to the fish farm, in the production of feed materials.Across the blue foods, farmed seaweeds and bivalves generate the lowest emissions, followed by small pelagic capture fisheries, while flatfish and crustacean fisheries produce the highest.Farmed bivalves and shrimp produce lower average emissions than their capture counterparts (bivalves, 1,414 versus 11,400 $kgCO_2e\ t^{-1}$ (kilograms of CO_2 equivalent per tonne); shrimps, 9,428 versus 11,956 $kgCO_2e\ t^{-1}$), while salmon/trout are similar whether farmed or fished (5,101–5,410 versus 6,881 $kgCO_2e\ t^{-1}$). Among farmed finfish and crustaceans, silver and bighead carps have the lowest greenhouse gas, nitrogen and phosphorus emissions, but highest water use, while farmed salmon and trout use the least land and water. Boyd et al. (2011) reported CO_2 emission for aquacultured channel catfish as 3.14 kg CO_2/kg fish compared to aquacultured salmon as 2.45 kg CO_2/kg fish. Mungkung (2005) reported the environmental LCA (life cycle analysis) of shrimp farming in Thailand, which included hatchery, farming, processing, distribution, consumption and waste management phases (Sun, 2009).

Application of LCA to Finnish cultivated rainbow trout production was conducted by Gronroos et al. (2006), but similar information is not available regarding aquaculture, particularly in India.A study reported that Raceway Aquaculture System (RAS) production of Atlantic salmon in the US generated a carbon footprint of 7.01, compared to only 3.39 for offshore net-pen production in Norway. However, when both products were placed in front of consumers in a North American city the carbon footprints were 7.41 and 15.22, respectively. From this, it is obvious that amount of emission directly depends on mode of transportation and distance covered. Transport costs are significantly lower for frozen product than fresh and in fact, the relative impact of fresh vs frozen on carbon footprints has been debated for some time. While frozen product incurs more greenhouse gas releases due to the energy required for initial freezing and subsequently maintaining sub-zero temperatures (as well as refrigerant leakage and more packaging in most instances), fresh product often results in more spoilage and waste.

As carbon footprints play a more important role in policy, economics and consumer preference in the coming years, the importance of producing seafood close to major markets will grow. This may bode well for proponents of RAS, but the technology will need to evolve to further reduce costs.In addition to that, carbon loss from mangrove deforestation for shrimp culture is not included in aquaculture carbon footprint studies. One study made by Boone et al. 2017 included carbon loss from mangrove areas for shrimp aquaculture. They presented the land-use carbon footprints arising from the conversion of intact mangroves and tropical forests to extensive (low-input) shrimp farms and cattle pastures. On the basis of measurements of ecosystem carbon stocks from 30 relatively undisturbed mangrove forests and 21 adjacent shrimp ponds or cattle pastures, we determined that mangrove conversion results in GHG emissions ranging between 1067 and 3003 megagrams of carbon dioxide equivalent (CO_2e) per hectare. There is a land-use carbon footprint of 1440 kg CO_2e for every kilogram of beef and 1603 kg CO_2e for every kilogram of shrimp produced on lands formerly occupied by mangroves. This is approximately the same quantity of GHGs produced by driving a fuel-efficient automobile from Los Angeles to New York City. 84% of the estimated emissions from shrimp pond conversion were attributed to declines in soil C pools. So, it is very essential to include land use carbon footprint because failure to include deforestation in life-cycle assessments greatly underestimates the GHG emissions from food production

Belettini et al. 2018 conducted a life-cycle assessment during semi-intensive and super-intensive commercial cultivation of marine shrimp from December 2011 to June 2012, considering all phases from the preparation of the nursery to harvesting of the shrimp, to determine the carbon footprints of each process (Fig. 4). Conventional shrimp production systems are characterized by extensive flooded areas that require a large volume of water, mainly during the grow-out period because of loss from evaporation and periodical water renewal, while super-intensive systems operate in smaller areas and only replace water lost by evaporation.

Factor for CO_2 emission	Super-intensive system		Semi-intensive system	
	kg CO_2 eq.	%	kg CO_2 eq.	%
Preparation of the nursery				
Water use	0.0041	0.0086	0.3019	30.0519
Planing wood	-	-	0.0009	0.0955
Lime	-	-	0.0141	1.4030
Urea	-	-	0.0386	3.8495
Triple superphosphate	-	-	0.0014	0.1422
Agricultural tractor	-	-	0.0197	1.9668
Transportation of inputs	-	-	0.0425	4.2304
Shrimp cultivation				
Shrimp culture	-	-	0.0170	1.6921
Water use	3.6906E-06		0.4832	48.0997
Super-intensive electric power system	44.5268	92.7699	-	-
Electric power generator	0.0875	0.1824	0.0009	0.0984
Electric power aerators	-	-	0.0499	4.9697
Post-larva – juvenile	0.0093	0.0196	0.0084	0.8022
Shrimp feed	3.1683E-05	0.0001	1.7429E-06	0.0002
Hydrated lime	0.0234	0.0488	-	-
Molasses	3.1828E-06	0.0000	-	-
Rice bran	0.0096	0.0200	-	-
Transportation of inputs	3.3360	6.9506	-	-
Agricultural tractor	-		0.0055	0.5573
Harvesting of the shrimp				
Shrimp harvest			0.022	2.1898
Harvesting equipment	-	-	−0.0018	−0.1876
kg CO_2 eq. total	47.9967		1.0042	

Figure 4: Contribution for CO_2 emissions and percentage of impact factors in a commercial cultivation of marine shrimp Litopenaeusvannamei in semi-intensive system and super-intensive system with bioflocs (Source: Belettini et al. 2018)

Based on the findings, it can be seen that most of the factors that contribute to global warming are found in the steps for preparation of the nurseries and in the grow-out phase of shrimp. The grow-out phase contributed the most to the final results in super-intensive culture, which had a higher carbon footprint, 47.9967 kg of CO_2 eq., which was 1.0042 kg of CO_2 eq. in the semi-intensive culture.The most important impacting factor is the use of electrical energy, which is required to maintain dissolved oxygen and the biofloc particles in suspension in the super-intensive culture and for movement of large volumes of water in the semi-intensive system.More than 95% of the result in the life-cycle analysis is related with this step of the marine shrimp production process in the super-intensive system and just over 55% of the total in the semi-intensive system. This is mainly due to the use of electricity in these production systems, although for different purposes. In the super-intensive system, electricity is needed to maintain the dissolved oxygen at normal levels and maintain the bioflocs suspended, while in the semi-intensive system, electricity is used more for pumping the large volumes of water needed, whether to replace loss from evaporation or for the renewal of water during cultivation. The use of electricity also contributed the most in the phase for preparation of the nurseries in the semi-intensive system; 30% of the potential for global warming was calculated to be in this step.

Carbon emission in Mariculture

Jones et al. (2022) examined the major sources of GHG emissions and assess both the opportunities for emissions reduction and the potential for carbon sequestration from three key marine aquaculture (mariculture) sectors: seaweed, bivalve, and fed finfish. Based on the results (Fig. 5), it was obvious that finfish mariculture emitted more amount of emissions when compared with bivalve and seaweed culture. Because downstream processes (Fig. 6), such as transport throughout supply chains, can have a large impact on overall GHG emissions (Parker et al. 2018), it can be difficult to generalize an emissions footprint to a sector or species level. Air transport has been shown to cause GHG emissions three to five times that of road freight, and 31 times greater than sea freight (Buchspies et al. 2011). A specific example from Tamil Nadu (India) found that transport by ship, rail, or road increased the climate impact of maricultured seaweed by 14%, 51%, and 139% respectively, compared with the product's emissions footprint before leaving the farm (Ghosh et al. 2015). Therefore, downstream accounting heavily depends on where and how the product reaches the market.

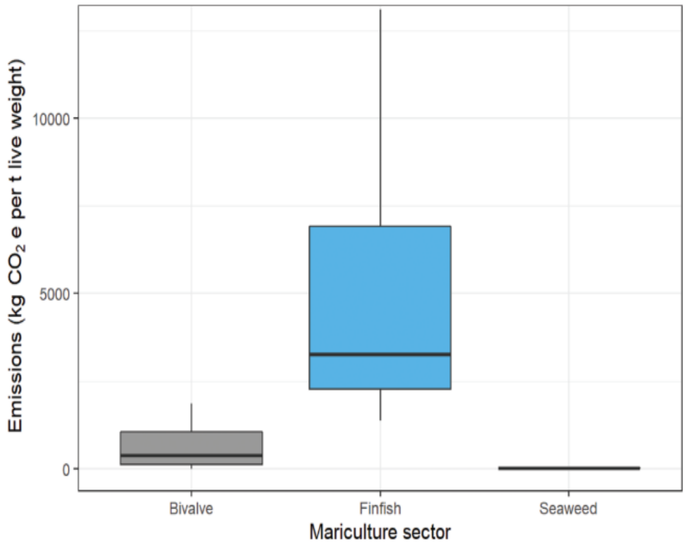

Figure 5: GHG emissions from selected mariculture sectors (Source: Jones et al. 2022)

Production stage	Source of emissions	Finfish	Bivalves	Seaweed
Upstream	Production and supply of eggs, larvae, or propagules	✓	~	~
	Terrestrial land-use change and degradation (e.g., for crops or livestock used in feed)	✓	×	×
	Feed production and processing (e.g., direct emissions from crop and livestock farms and wild caught fisheries)	✓	×	×
	Transport of feed to wholesale and mariculture operations	✓	×	×
On farm	Fuel use	✓	✓	✓
	Energy use	✓	✓	✓
	Infrastructure or maintenance	✓	✓	✓
	Coastal and subtidal land-use change and degradation	✓	~	~
	Nutrient or effluent impact and water treatment	✓	~	~
	Liquid oxygen and other chemicals used in production	✓	~	~
Downstream	Processing	✓	✓	✓
	Packaging and ice	✓	✓	✓
	Refrigeration	✓	✓	✓
	Transport	✓	✓	✓

Note: ✓ and × indicate relevance to each sector, with ~ showing where an emissions source is not typical when best practices are implemented, but may be relevant under some circumstances.

Figure 6: Major greenhouse gas emissions sources at different stages of the production cycle for the three key mariculture sectors (Source: Jones et al. 2022)

VIII. MITIGATION STRATEGIES FOR GREENHOUSE GAS EMISSIONS FROM AQUACULTURE:

Among greenhouse gases, methane and nitrous oxide draw more attention because the global warming potential is much higher and they are very difficult to sequester after being released to the atmosphere, as compared to carbon dioxide. Atmospheric CO_2 can be sequestered as blue carbon (plant biomass). Possible mitigation strategies for reduction of GHGs from aquaculture systems given by Raul et al. 2020 include:

1. Prevention of Aquaculture in Sites of High Carbon Sequestration: Ecologically sensitive sites like mangroves, salt marshes, estuaries and other wetlands are natural sites for carbon sequestration. Huge quantities of carbon and nutrients get sequestered in these sites from terrestrial runoff and also from the autochthonous dead biomass. Many countries, especially developing countries, are disturbing these sites by practicing commercially important shrimp and fish aquaculture for generating high profit. Habitat transformation of these wetlands can increase emissions of GHGs from organic matter already stored in the system. Many studies have demonstrated greater emissions of greenhouse gases from sites converted to aquaculture ponds. Countries should have strict legislation to limit intensive aquaculture in areas of high carbon sequestration and encourage aquaculture in degraded soil environments like inland saline areas where the carbon pool is much less.

2. Practising herbivorous fish polyculture system: Commercial aquaculture of carnivorous fishes mostly uses protein-rich formulated feeds, which is a major contributor of GHG formation in aquaculture. In herbivorous fish polyculture systems, candidate species are selected on the basis of feeding habits and niches, including phytoplankton, attached algae, and submerged weeds in different depth of pond water. Primary producers utilize nutrients, preventing the GHGs substrate for microbes. The bottom submerged weed and bioturbation by detritivorous fishes create aerobic conditions and positive redox potential in the bottom sediment, leading to a decrease in the activity of methanogens and denitrifiers. In this aquaculture system, formulated feed supplementation is relatively less. This also reduces the requirement for fishmeal, hence making the feed cost-effective. This system should be attempted in all countries for better utilization of pond bottom sediments.

3. Integrated Multitrophic Aquaculture (IMTA): The system comprises species of each trophic level having different requirements like finfish, bivalve shellfish and seaweed. The waste generated from the fed trophic level component (i.e. finfish) serves as a source of organic matter for bivalve shellfish and nutrients for seaweeds. In this process, an integrated system is formed that minimizes emissions from the aquaculture system. Systems like seaweed-fish polyculture are already practiced in many countries as a component of coastal aquaculture and cage culture. IMTA could be established by carefully selecting candidate species for different trophic levels.

4. Aquaponics: This is a hybrid system of aquaculture and hydroponics in which the fish culture unit and plant farming unit remain in two separate systems or in a combined system. Fish like tilapia and pangasius that utilize feed efficiently produce waste that is used for the growth of foliage plants like lettuce, spinach, and other leafygreen vegetables. This can intensify the culture system with high production and better output without harming the environment. High stocking density fish culture that produces nutrient-rich wastewater utilized by plants for growth hence reduces the emission of GHGs through sequestration in plant biomass.

5. Using Fish Feed Additives: The yucca plant extract feed additive contains saponin which is the major bioactive component present in the steroidal form (Mao et al. 2010). Saponin physically binds to ammonia, thereby reducing its concentration. It also reduces methane emission by controlling the protozoa population as saponin damages the cell wall. This is because protozoa harbors an active population of methanogenic archaea on their external and internal surfaces. Yucca extract can be used to improve water quality by reducing the concentration of total ammonia nitrogen and nitrate in fresh and marine water used for aquaculture. Yucca can reduce methane by 8.5 to 69 percent, total ammonia nitrogen by 50 to 100 percent, and nitrous oxide by 75 percent.

6. Pond Bottom Sediment Management: The pond bottom sediment is the chemical laboratory for all biochemical degradation of carbon substrate and production of GHGs. The anoxic condition of pond sediment and negative redox potential favour the activity of methanogenic bacteria and denitrifiers. The application of biochar to bond bottom sediment prior to culture practice can reduce GHGs emissions significantly. Although there has been no direct report of biochar applications reducing GHGs in aquaculture systems, a meta-analysis of 296 observations in agriculture fields and laboratory incubation of different biochars shows a reduction of 5 percent CO_2 , 20 percent N_2 O, and 19 percent CH_4 after a crop cycle (Song et al. 2016). Other than biochar, regulation of C:N ratio in pond sediment of intensive aquaculture systems with the addition of carbohydrate source increases the growth of heterotrophic bacteria. It inhibits the growth of nitrifying bacteria, due to competition for nutrients between heterotrophic and nitrifying bacteria, hence reducing N_2O emission from the aquaculture system (Hu et al. 2014). These kind of strategies should be employed in real time process and operational culture period. Proper implementation of strategies will greatly reduce the emission amount into environment.

IX. LIMITATIONS OF CF ANALYSIS IN AQUACULTURE

The production of aquatic plants and its emission data are not available. Because aquatic plants also constitute a significant proportion of global aquaculture production. Inclusion of this data will give a correct figure about emission. Apart from that, feed used in culture for all fed species is also an important GHG emitter. However, feed composition is constantly changing as nutritional knowledge and its application develop in response to commercial demand. There is lack of data for regional assumptions of feed formulations and raw material origins for the main species in the key regions. Next, most of the analyses do not include losses and emissions occurring post-farm. Depending on the post-farm supply chain (e.g. mode of transport, distance transported, mode of processing, storage conditions), significant emissions can arise from energy use in transportation or from refrigerant leakage in cold chains. Aquaculture produces processing by-products (such as trimmings) that are often used in other sectors and the associated emissions should be allocated to these sectors to get a complete carbon footprint value.The estimates of aquatic N_2O should be treated with caution, as the rate at which N is converted to N_2O in aquatic systems can vary greatly, depending on the environmental conditions sincenitrifcation and denitrifcation processes are influenced by many parameters such as dissolved oxygen concentration, pH and temperature. Finally, to perform empirical studies, primary data need to be gathered on key parameters to properly validate the results.

X. CONCLUSION

The climate change issues are important environmental problem since uncontrolled and abundant release of GHG accelerate global warming rate. This paper explained the GHG emission scenario from food sector especially aquaculture. The importance of determining carbon foot print value from each culture phase using LCA was briefed. Feed is the major contributor for aquaculture emission. But, sufficient data are not available regarding feed emission which is a major drawback in carbon footprintcalculation from this sector. So, there is a need for accurate and comprehensive estimation of GHG emissions from different aquaculture systems and the different mechanisms of gas production so that future strategic mitigation measures can be taken up for sustainable growth of the aquaculture sector.

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