Fish Waste: Understanding the Pollution Potential and Sustainable Mitigation Strategies

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Abstract Fish production expansion around the world has increased waste output, which has become a stressor to the environment, despite meeting the expanding protein need and can be considered as the other side of a coin. Similar to other waste, fish waste has the potential to cause environmental pollution if not properly disposed of. This chapter provides baseline information in this regard, and the main inferences are as follows: (1) Fish waste, both solid and liquid, has the potential to cause all types of pollution, with water pollution receiving the most attention because fish waste and effluent from fish processing industries are commonly discarded into water systems (2) Fish waste pollution has drastic effects starts with water quality alteration and ends with jeopardizing biodiversity (3) Cleaner production, valorizing fish waste, raising awareness, and implementing rules and regulations are a few ways to reduce fish waste pollution, with the transformation of fish waste into marketable products being particularly attractive from an environmental and economic standpoint. Finally, while fish waste is a cause of pollution in the ecosystem, it may be reduced with the proper procedures.

Keywords Air pollution · Byproducts · Fish waste · Fish processing · Generation · Marine · Ocean dumping · Valuable products · Wastewater · Water quality

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1 Introduction

Due to the healthy lifestyle, fish product consumption has dramatically increased in recent years. Fisheries and aquaculture productivity have expanded significantly between 1954 and 2014, according to the Food and Agricultural Organization (FAO), because of rapid advances in aquaculture and rapid innovations in fishing technology in the United States (Coppola et al. 2021). to meet the growing demand of the increasing world population. In 2020, the world's total production of fisheries and aquaculture was 177.8 million tons out of which 157.4 million tons were used for human consumption (Fao 2022). A certain amount of fish is routinely lost during both capture and aquaculture, with the total amount expected to be 30 million tons in 2018, accounting for 23% of global catches (Guillen et al. 2018). Fish discards can make up 20 to 70 percent of the total weight of the fish, depending on the species, product, and processing methods (Jaiswal et al. 2014). In the fishing industry, "discards" refers to any organic material of animal origin in the catch that is dumped at water bodies, notably the sea. Discarding was deemed a severe problem by the FAO, and it was advised to reduce its code of conduct for ethical fishing (Guillen et al. 2018). Beyond this, intensified processing of caught fish into various products also could discard a considerable amount of waste which has little to no economic value (Dauda et al. 2019). Yorio and Caille as cited by Islam, Khan and Tanaka (2004b) stated that waste generated from processing plants was 58% of the total landings from 1989 to 2001 in coastal cities of Argentina.

When fish waste is improperly disposed of, it can endanger the environment and have an adverse effect on a larger coastal zone on a variety of ecological levels (Fig. 1). The amount of fish waste produced globally has increased dramatically; it is estimated that over two-thirds of all fish is discarded, which poses significant economic and environmental problems (Caruso et al. 2020). Small, non-food fish known as marine trash fishes are frequently abandoned in coastal environments, landfills, and neighbourhood fish markets, attracting flies and insects, emitting harmful fumes, giving off disagreeable odours at the dumps, and contaminating the soil and groundwater as a result of organic waste decomposing (Gayathri et al. 2018). Additionally, the effluent from the processing plants also causes adverse changes to the environment due to the presence of high levels of organic chemicals including salt, nitrogen, oil and fat, and the biochemical and chemical oxygen demands (BOD and COD). The release of such organic wastes affects the biodiversity and community structure of benthic assemblages (Arvanitoyannis and Kassaveti 2008). Since liquid waste from the fish processing industry is swiftly destroyed by microbes, it has the potential to be hazardous to both the environment and human health (Kurniasih et al. 2018). Consequently, the public's concern has increased regarding fish farming's detrimental effects thus necessitating that waste management must be recognized by the fish processing industry to reduce pollution whereas the industry's recovery of usable byproducts from fish wastes is known as a popular waste reduction approach because of their nutritive values. Fish waste has a higher concentration of n-3 polyunsaturated fatty acids than other organic waste products (PUFAs) (Barroso et al. 2019).

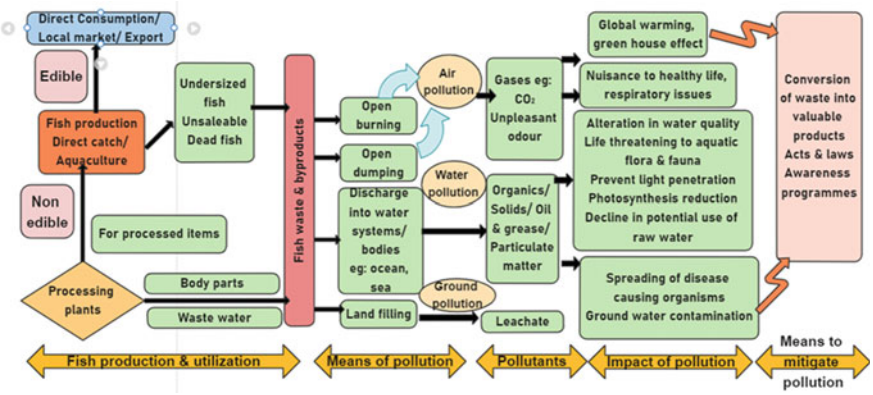

Fig. 1 Schematic presentation of fish waste as a source of pollution

The literature that is now available indicates that fish waste has been used to produce a variety of compounds, each with a potential value, including feed, biofuels, natural colours, food packaging (chitosan), cosmetics, and soil fertilizer (Arvanitoyannis and Kassaveti 2008). In this context, this chapter comprehensively overviews and discusses various means of how fish waste and byproducts act as a source of pollution in the ocean, air and land, and what is their impact on humans and the environment. Consequently, baseline information provided through this chapter would serve as a guide and reference source in the production as well as management of fish and fish waste in the future.

2 Global Fish Production, Utilization and Waste Generation

Overall 179 tons of fish were produced globally in 2018, whereas China as a leading fish producer contributed 35% of the production (Amoakwah et al. 2020). A major portion of manufacturing in 2018—outside of China—came from Asia (34%), followed by North America (14%), Europe (10%), and Africa (7%). The Food and Agriculture Organization (FAO) declared that the yearly catch of fish, crustaceans, and mollusks from inland waters around the world had surpassed 10 million tons for the first time in 2008 (Amoakwah et al. 2020). Africa's inland fisheries generate 2.1 million tons of fish annually, accounting for 24% of the world's overall production (Janko 2014). Even today, aquaculture provides over 25% of the world's seafood supply, and the FAO estimates that by 2030, that proportion will be close to 50% (Jayasankar 2001).

The caught and farmed fish can be eaten either as fresh or processed. Only about 30–40% of fisheries products are consumed fresh around the world; the rest 60–70% are processed for human utilization as well as other uses (Islam et al. 2004a). In 2016, 53% of fisheries products were intended for human use (Boyd and Davis 2020). Hence, the world's fish consumption has increased by 3.1% per year on average,

where it was 9 kg in 1961 and 20.5 kg in 2018 (Coppola et al. 2021). However, the average yearly consumption of fishery products in North America, Europe, Asia, and Oceania was similar at 21.6–25 kg per capita, while it was just 9.9 kg per capita in Africa. In low-income, food-insecure nations, the average annual intake per person was 7.7 kg, as compared to 20.5 kg in other developing nations and 24.9 kg in developed nations. On the other hand, a great number of capture fisheries, about 20 million tons, account for 12% of the total production, were used to produce non-food products each year, mainly fish meal and oil. The remaining amount (roughly 4 million tons) was used to raise ornamental fish for use as bait in pharmaceutical applications, for feeding in aquaculture, as well as for raising livestock and furry animals, the latter of which was largely reduced to fish meal and fish oil by about 80% (18 million tons) (Arvanitoyannis and Kassaveti 2008).

In the fish industry, it is generally accepted that the edible flesh portion is the "main product" and that the remaining components, such as the head, skin, trimmings, scale, viscera, and bone, are known as waste (Dauda et al. 2019) (Fig. 2). The manufacture of processed fish generates enormous volumes of solid waste (30–85%) globally, reliant on the species, stage of processing (gutting, scaling, filleting), as well as the kind of fishery that is discarded (Surasani 2018). In general, more than 20 million tons of fish waste including non-target" species, byproducts, and waste from the processing of fish, are generated yearly throughout the world where about 5.2 million tons are discarded annually by European Union (Barroso et al. 2019) and this was later on used for various purposes. China's annual fish waste products from fish processing, or about half of the nation's aquaculture sector, may supply between 420,000 and 650,000 tons of fishmeal, according to Cao et al. (2015).

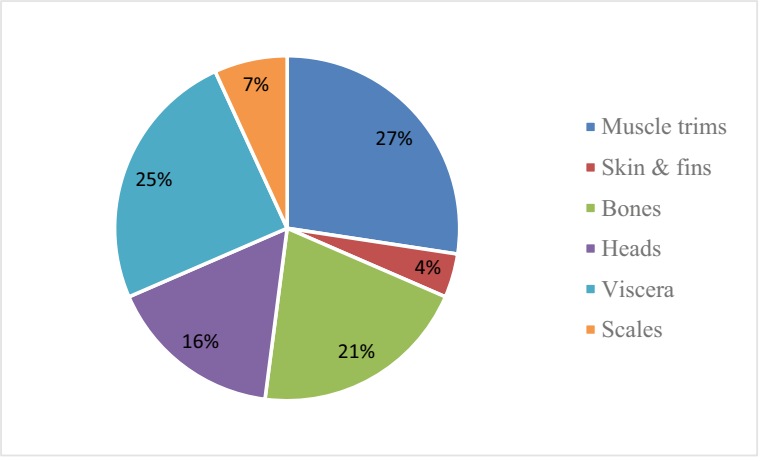

Fig. 2 Fraction of fish waste

3 Means of Pollution by Fish Waste

Fish waste either in the form of liquid or solid is known to cause environmental pollution due to the characteristics of pollutants' richness. High levels of organic substances, nitrogen, salt, oil and fat are present in fishery waste (Islam et al. 2004b). Liquid waste primarily water used during fish processing stages such as washing, thawing, cleaning, and cooking has the potential to cause water pollution when it is discharged improperly without treatment into the water systems. Small volumes of wastewater (effluent) from fish processing enterprises contaminate a large number of water bodies, leading to water pollution (Mihret et al. 2015). The pollutants in the wastewater inclusive of organics, solids, salts, oil, grease, ammonia, and cleaning agents (e.g., chlorine, surfactants) should be lesser than the standard limits released into the water bodies, otherwise, they alter the conditions at water-bodies and adversely affects aquatic living beings (Karkal and Kudre 2020). Islam et al. (2004b) well documented the characteristics of effluents of fish processing industries, for instance, the wastewater from the tuna processing industry had 125–300 m^3/day water flow and with 700, 1600, 500, 250 mg/l BOD, COD, TSS, FOG respectively. Hence, Kurniasih et al. (2018) stated that the water quality parameters of BOD and COD concentration in wastewater at the fishery industry area of the fishing port of Nizam Zachman Jakarta—North Jakarta were 7 times higher than the water quality standards. Ahumada et al. (2004) mentioned that the highest organic load received from fish processing altered the dissolved oxygen level of coastal water from Lota Bay. All these findings imply that fish waste has the potential to cause pollution. Furthermore, the volume of wastewater generated and concentration of pollutants and their consequences depend on several factors such as type and quantity of fish processed, climate, type of fish processing industry (e.g., fish meal, fish oil), hydrological condition of water systems. For example, effluents generated with processing oily fish can be rich in pollutants due to higher oil content than white fish species. Comparatively higher BOD, COD, TSS, Oil and fat were observed in effluent resulted from fish meal production than surimi production in Japan (Islam et al. 2004b). Beyond the waste water, whole fish either spoiled or non-spoiled can cause marine pollution. In Bangladesh, the practice of pitch back of by catch (unintended catch of non-target species) as well as dumping of fish parts into the sea as there are no facilities to store them in fishing boats affect the marine ecosystem (Mozumder et al. 2022). Moreover, the disposal of plastic materials (e.g., vessels, containers) and chemicals used during fish processing also can pollute the marine environment (Abdel-Shafy and Mansour 2018).

Next to water pollution, there is a possibility of air pollution from fish waste. Perishable fish waste left in the open air emits the gases like NH_3, and H_2S, giving an unpleasant odour when enzymatic and or microbial degradation occurs. As these gases have low threshold limits, for instance, 2.1×10^{-4} ppm for NH_3 and 21.4 ppm for H_2S, even a small amount of gases escaping into the surrounding atmosphere, is quiet enough to cause air pollution (Khan et al. 2017). Besides, strong odours are frequently produced from various stages of the fish meal process at fish processing

factories. According to Schmidtsdorff (1974), the odour emission was high during drying (60–80%), while it was low in pneumatic meal conveying (2–5%). Hence, the processes of raw material conveying, cooking also emit fairly considerable amount of odour (10–20%). The disgusting odour of rotten fish is a major problem that can cause respiratory irritation and health issues in residential neighbourhoods. Moreover, Wu (1995) stated that sediments settled on the sea bed also can produce hazardous gases such as ammonia, methane, and hydrogen sulfide due to anoxic and reducing conditions.

On the other hand, solid wastes comprising of various fish parts like heads, bones, skin, and plastic evolved during cleaning, skinning, and packing are disposed of unsafely at an open dump site in general, which could serve as a breeding site for insects like mosquito, flies and attract animals, thus leading to the exposed land surface get polluted (Cao et al. 2007). Further, fish waste disposed of at landfill sites generates leachate upon decomposition of organic waste and its subsequent infiltration and percolation with rain water, have the potential to contaminate the groundwater and soil. Fish waste and leftovers improperly disposed of and dumped on the soil result in land pollution, thus making the environment uncomfortable (Abdel-Shafy and Mansour 2018).

Fish waste cause pollution not only as raw when it is left open in the environment but the management techniques also have a chance to cause pollution. For instance, thermal treatments, composting of fish waste and byproducts as a management approach release the greenhouse gases of CH_4 and CO_2, thus having the chance to pollute the air where the concentration of these gases is much concern. Compared to incineration, composting fish waste emitted high CO_2 and CH_4 (Hristov et al. 2017)). Meanwhile, landfilling as a management option for fish waste found with higher values of global warming potential (579.66 kg CO_2 eq/ton) and carbon footprint accounted for greater emissions of greenhouse gas CH_4 (Hristov et al. 2017). Furthermore, huge quantities of fish waste are dumped and typically burned to increase the management process's energy use, cost, and environmental impact (Arvanitoyannis and Kassaveti 2008).

4 Impact of Pollution on Living Beings and the Environment

Disposal of fish waste as solid wastes generated either at fishing ports or processing centres is a noxious and pervasive issue not only in many developing nations but even in developed countries as it has adverse effects on various components of ecosystems.

4.1 Impact on Humans and Living Beings

The abundance of animals in fish waste dumps close to human areas increases the risk of animal attack on humans and livestock theft. A large population of Hamadryas baboons *(Papio hamadryas)* coupled with fish waste and chicken meat waste dumps close to cities caused frequent clashes with people because they encroached on crops in agricultural areas (Plaza and Lambertucci 2017). Dingoes (*Canis lupus dingo*) attacked people in Australia while feeding on organic (fish) waste, and have even been known to result in deaths (Thompson 2005). In Ethiopia, hyena predation on cattle is more severe close to fish and organic waste dumps (Mihret et al. 2015). Additionally, fish waste dumps have an impact on bird populations because of the foul odours that cause serious environmental problems (Novaes and Cintra 2013) and Plaza and Lambertucci (2017) stated that the chance of an aircraft crash increases if birds are close to airports, All of these incidents of conflicts resulting from the disposal of fish wastes and other organic wastes.

Furthermore, fish waste dumped at open sites harbours flies, mosquitoes, and pathogenic microbes consequently causing health issues for people living around. Hence, the obnoxious smell from either raw or decomposing fish waste creates an unwillingness to reside closer to these sites and makes the people shift their places. Most residents believed that air disturbances caused by rotting, toxic material signified the possibility of contamination because of the overwhelming odour (Doron 2021).

4.2 Impact on Environment

On the other hand, wastewater discharge from fish processing plants attributes to negative effects on the environment. The release of wastewater primarily into the surface water bodies (e.g., sea, ocean, rivers, canals) alters the water quality, and as a result, makes it unsafe for the survival of aquatic flora and fauna. In particular, the entry of wastewater with heavy loads of organic matter from fish processing industries lowers the dissolved oxygen level, which in turn, creates an anaerobic condition which retard the growth and functioning of aquatic organisms. Oil and grease-contaminated wastewater prevents photosynthesis, inhibits direct oxygen exchange at the air–water interface, lowers light penetration, and reduces water column oxygenation (Ahumada et al. 2004). Hence, carbon dioxide resulting from organic waste conversion and its subsequent dissolution within water alters the acidity of saltwater, which has an impact on marine life (Gregory et al. 2019). The biomass, density, and variety of the benthos, plankton, and nekton are all decreased as a result of fish farm waste, and the natural food webs are also altered. This has an effect on a greater coastal zone on numerous ecological levels (Arvanitoyannis and Kassaveti 2008). In contrast, the possibility of increased algae and bacteria feeding on fish excrement

also concerns scientists, where few species of algae may create toxic substances that are dangerous to humans, fish, and marine mammals (Guillen et al. 2018).

5 Means to Minimize the Pollution

One of the problems most detrimental to the environment has been the production of fish waste. The negative impacts of fish waste particularly on the marine ecosystem have drawn attention to the search for a solution to combat the pollution effect. Here are some means to minimize such adverse effects encountered with fish waste-based pollution.

5.1 Minimization of Fish Waste Generation/Cleaner Production

Prevention and or minimization of generation is the first and foremost management strategy for any type of waste. Cleaner production, which in this context is defined as the ongoing application of integrated, preventive environmental measures to processes, goods, and services, helps to reduce pollution by preventing the formation of unnecessary waste. It aims to improve the overall effectiveness and lower hazards to both people and the environment. Improved housekeeping practices, process optimization and raw material substitution are a few techniques that can be used to achieve cleaner production. Since the water and effluent from fish processing plants are the main sources of pollution, a reduction in water consumption and pollution load of effluent would help to minimize the pollution. Below listed are a few examples of strategies to be adopted to reduce water consumption and pollution load.

- Installation of devices to limit or regulate water flow for manual cleaning procedures
- Cleaning surfaces with high pressures as opposed to large volumes
- Utilizing reasonably clean wastewater for other purposes; for instance, thawing wastewater might be utilized for offal fuming or as the first stage in cleaning unclean regions
- Utilizing cooling systems with closed circuits
- Soaking equipment and floors beforehand to remove grime before the final clean
- Removing solid waste from the ground and using it as a byproduct rather than flushing it down the toilet
- Using an offal hopper instead of the effluent system to collect the blood and offal after vacuum-cleaning dressed fish
- Installing screens or traps in drains to stop solids from entering the wastewater system

- Employing dry cleaning methods, scraping equipment before cleaning, pre-cleaning using air guns, and mopping up spills on the floor with squeegees.

6 Valorization of Fish Waste and Byproducts

Rather than disposing of the waste considering the hazards associated with it, the utilization of waste known as "waste valorization" become popular in the present era as a sustainable waste management strategy, leading to reducing environmental pollution. Utilizing byproducts can help the industry produce goods more sustainably because it may be able to increase income while also lowering disposal expenses for the materials involved (Mo et al. 2018). The conversion of undesired fish wastes from aquaculture and fishing into usable products has gained increasing attention due to its intrinsic characteristics and serves as an alternative for high-cost products. For example, fish waste is recycled into fish feed and fish oil is being utilized as a feed ingredient in fish and poultry farming because of its higher protein content. Reutilization of fish waste lowers the cost of animal production and provides a useful basis of rich-quality protein and energy (Arvanitoyannis and Kassaveti 2008). Utilizing this waste helps address issues with environmental contamination while increasing food security (Surasani 2018). A hydroxyapatite adsorbent prepared from fish waste has been found effective in the removal of lead from water, which in turn reduces heavy metal pollution in the environment (Omar et al. 2019). Similarly, several value-added products have been derived from fish waste and Table 1 summarizes the widely developed products and their potential uses. As a crucial strategy for waste reduction, there is an increasing desire for the industry to recover marketable byproducts from fish waste (Guillen et al. 2018).

Besides, reusing and recycling wastewater from fish processing plants is another means of reducing pollution. The UNEP (2000) advised using vacuum pumps and relatively clean effluent from cooling systems for washing animals and fish. Recycled water could be used to wash the transport vehicles and the floors of the pens (Bailone et al. 2021).

Furthermore, the conversion of fish waste into valuable products as valorization not only indicates environmental pollution but also boosts the economy of a country. Specifically, a country like Bangladesh which is self-sufficient in fish production and generates 93 thousand tons of waste in a year, finds its way to reduce the negative effects caused by the generated huge waste via selling the raw and or dried fish waste collected from local market and processing centres either to retailers or exporters like China, Indonesia, Thailand. A kilogram of fish waste is valued at 70–90 BDT and it was estimated to earn 80 million BDT in a year by exporting 1/3 of the fish waste generated in Bangladesh (Mozumder et al. 2022). However, the production of good quality products from fish waste is challenged by the poor hygienic nature of fish waste, lack of awareness about the potential of fish waste to be utilized, lesser involvement of public and stakeholders, lack of processing facilities etc. In this context, proper segregation of degradable and non-degradable components of waste,

Table 1 Fish waste reduction or utilization approaches

Fish waste-based products		Advantage	Reference
Feed supplement	Animal feed	Cost-effective, waste reduction	Arvanitoyannis and Kassaveti (2008)
	Feedstuff	Protein substitute for swine	Gasco et al. (2020)
	Fish silage	Decreasing feeding costs, Animal protein	Ferraz De Arruda et al. (2007)
	Poultry feed	Sardine fish waste is used for poultry feeding	Shabani et al. (2018)
	Fish or mink food	Reducing the amount of salmon cannery waste solids	Gregory et al. (2019)
Fuel	Biodiesel/biogas	Alternative source of fuel, cost-effective	Arvanitoyannis and Kassaveti (2008)
Miscellaneous uses	Natural pigments (e.g., astaxanthin or βcarotene),	Additional revenue, reduce the disposal cost	Alfio et al. (2021)
Fertilizer	Fertilizer	Improve the soil fertility	Radziemska et al. (2019)
	Soil amendment - Fish offal (heads, skin, viscera and skeletons of rainbow trout	Improve the soil fertility	Arvanitoyannis & Kassaveti (2008)
Enzymes	Pepsin	Caviar production of fish	Coppola et al. (2021)
	Proteases	Pepsin soluble collagen extraction	Coppola et al. (2021)
	Lipases	Defatting of fish skin	Sae-leaw and Benjakul (2018)

awareness enhancement, and the establishment and update of processing facilities, of existing would help address these challenges.

7 Laws and Legislations

People in many developing countries like Bangladesh are of lack awareness and poor knowledge regarding the adverse impacts of waste disposal on the environment and the benefits of reutilizing the waste (Mozumder et al. 2022). Hence, in the absence of laws and regulations, any legal actions cannot be carried out against the people or industries for dumping the waste into the ocean. In this context, proper awareness among people and stakeholders through social and mass media as well as

the establishment of laws and legislation would be helpful to minimize the pollution caused. Several countries have passed various acts, laws and regulations restricting the dumping of waste into water bodies to prevent and or minimize water pollution. Accordingly, the Marine Environmental Protection Law (MEPL), a fundamental law formed in 1982, has regulations on the disposal of fish wastes at sea and governs the protection of marine environments in China (Keyuan 2006). China has the East Asian region's longest coastline, and its coastal environmental laws and practices have an impact on the entire East Asian Sea region. Additionally, the Ministry of Agriculture in China issued regulations for fishery loss calculation of accidents of water pollution as well as regulations and procedures for investigating and handling pollution accidents in fishery waters in 1997 to put the investigation and management of pollution accidents in aquaculture on a legal footing (Cao et al. 2007). Similar to this, the marine ecosystem in the USA is preserved by the Ocean Dumping Ban Act of 1988, an addition to the Marine Protection, Research, and Sanctuaries Act of 1972. An international convention for the prevention of pollution from ships (MARPOL), enforced by over 150 countries around the globe, controls the marine pollution by ships including fishing vessels.

Only a few countries, including Norway, the Faroe Islands, Iceland, Chile, New Zealand, and now the EU, have discard bans in place, which outlaw the practice and mandate that all catches of species subject to the restrictions be landed (Guillen et al. 2018). The discard prohibition for European Union fisheries is a key component of the most current overhaul of the Common Fisheries Policy (Guillen et al. 2018). As a result of these acts and laws, the quantity of waste thrown away could be decreased, meanwhile, violations also occur. At this juncture, penalties and punishment should be made. People who disobey the laws, rules, and regulations governing the sea, administration of marine scientific research, and foreign affairs are punished by the ocean administrative penalty enforcement authority (Fu 2005). However, it is still unclear how cutting back on discards would affect the environment in the short- and long-term, as well as the economic and social implications that go along with them.

Besides the above-mentioned main ways, the establishment of modern and innovative processing centres closer to landing sites, installation of own wastewater treatment plants inside the processing factories, collaborative activities between public and private sectors for promoting better utilization of fish waste, conducting empirical studies and improving the existing waste management systems also would help in pollution control.

8 Conclusion

Fish waste and leftovers discarded carelessly onto the ground and waterbodies have the potential to pollute the resources of the environment, especially water because of the heavy pollutant load. Meanwhile, there are possibilities for pollution when fish wastes are managed properly via composting, landfilling and incineration due to emission of greenhouse gases such as CH_4 and CO_2. Therefore, fish waste, as a

source of pollution, is a serious environmental issue and causes substantial economic losses. As a result, there is currently a push for the creation of a sustainable fish waste management system that strives to minimize waste output and maximize its potential use, whereas recycling of fish waste into usable products and reuse of wastewater with or without minimal treatments could be better means for managing the fish waste, while those minimize the pollution. Further, several factors namely awareness, social acceptability, facilities available, processing conditions and facilities and costs incurred may challenge fish waste management via a reutilization approach. These can be overcome with awareness campaigns, government and non-government sector collaboration for fish waste reutilization, establishment and update of processing facilities. Even though fish waste has been found potential for pollution, the studies conducted in this regard are limited and it should be explored more in the future.

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