
Photo by Juan Vilata

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FOOD SAFETY SITUATIONAL ANALYSIS OF THE ARTISANAL SEAFOOD SECTOR IN SENEGAL

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Dirty seawater in Soumbédioune Bay, Dakar Peninsula. Seawater polluted with sewage is one of the main sources of seafood-borne health hazards in artisanal fisheries in Senegal. Source: Juan Vilata.

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ACKNOWLEDGEMENTS

Artisanal and small-scale fisheries are complex sectors to work in, and also of high economic importance in a county like Senegal where a vast number of communities and livelihoods depend on them. This complexity makes it essential to consider the experience, knowledge and insight of the local stakeholders, as well as the local and international experts in the fisheries sector.

First of all, Food Enterprise Solutions (FES) wants to thank Dr. Babacar Sene, whose input on seafood-borne health hazards within Senegal's artisanal fisheries supply chain was invaluable to better understand the intricacies of the topic. The author and FES would also like to thank the local participants who kindly and patiently answered our interview questions; and provided first-hand testimonies of the increasingly harder conditions in which the artisanal dried, salted, and smoked fish are produced. FES thanks as well Drs. Karen Kent and Kathy Castro from the University of Rhode Island (URI) for their generous sharing of the information related to the associations of women fish processors and fish gatherers in Senegal and The Gambia; and also for their efforts reviewing a first draft of this report. Dr. Lahsen Ababouch from FAO's *Coastal Fisheries Initiative* (CFI) also provided his insight to the review of the initial draft. Jenna Borberg (FES) provided invaluable help to draft the final layout of the report.

Lastly, due to lack of space it is not possible to include here the names of all the fishers, fish vendors, and fish processors whom we talked to. They are the main actors of the artisanal fish supply chain; it is them that bring the fish to the consumers with their hard and thankless work, and they are also the first and most affected when fish is scarce, as in the recent covid-19 pandemic. Big thanks to all. We hope that this study will contribute to safeguard their livelihoods.

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ABBREVIATIONS AND ACRONYMS

ASCOSEN	Senegalese Consumer Association
BD4FS	Feed the Future Business Drivers for Food Safety
COMFISH	USAID-funded Collaborative Management for a Sustainable Fisheries Future Project
CONIPAS	National Council of Artisanal Fisheries in Senegal
CLPA	Local Artisanal Fisheries Councils
CNPS	National Collective of the Artisanal Fishermen of Senegal
CRODT	Oceanographic Research Centre at Dakar-Thiaroye (Senegal)
DPM	Marine Fisheries Directorate
DTIP	Directorate for seafood processing industries
EEZ	Exclusive Economic Zone
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FENAGIE-PECHE	National Federation of Fishery stakeholders of Senegal
FENAMS	National Federation of Senegalese vessel owners (artisanal fisheries)
FENATRAMS	National Federation of Women Fish Processors of Senegal
FSSA	Food Safety Situational Analysis
GAIPES	Association of Senegalese Ship-owners and Seafood Processors
GDP	gross domestic product
HDI	Human Development Index
ILRI	International Livestock Research Institute
ISRA	Senegalese Institute for Agricultural Research
IUU	Illegal, unreported and unregulated (fisheries)
MCS	Monitoring, Control and Surveillance
MPEM	Ministry of Fisheries and Maritime Economy
SMFE	Small and Medium Food Enterprises
OECD	Organization for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
t	tonne (1,000 kg)
UPAMES	Union of Senegalese Fishers and Exporters
USAID	United States Agency for International Development
USD	United States Dollar
VCA	Value Chain Analysis

1. EXECUTIVE SUMMARY

Fisheries, and especially the artisanal fisheries sector, are crucial to Senegal's economy. They provide livelihoods for hundreds of thousands of its citizens; and fish represent a crucial source of protein for most of the population. Additionally, fish products are widely traded with neighbouring countries in West Africa. While there are many health benefits to seafood consumption, seafood can carry a large variety of health hazards, potentially affecting millions of consumers in Senegal and its neighbour countries.

During 2020, Feed the Future Business Driver for Food Safety (BD4FS) funded by USAID and implemented by Food Enterprise Solutions (FES), undertook a Food Safety Situational Analysis (FSSA) of the artisanal seafood sector in Senegal. The FSSA was a combination of a desk-based literature review, insight-gathering field missions, and interviews with fishery supply chain actors. The main findings of the FSSA were as follows:

- The desk study revealed that foodborne health hazards in Senegal's seafood sector are manifold and widespread. They can be classified into nine main categories: (1) bacterial pathogens, (2) viruses, (3) parasites, (4) heavy metals, (5) microplastics, (6) histamine and scombroid fish poisoning, (7) biotoxins, (8) organic chemical pollutants (POPs, PCBs, OCPs, PBDEs), and (9) Polycyclic Aromatic Hydrocarbons (PAHs).
- The key factors impacting food safety were as follows:
    - Cleanliness - The main reason for the ubiquity of food safety issues in the seafood sector is lack of access to safe water facilities, as well as the prevalence of poor hygiene and poor handling practices at all main nodes of the artisanal fisheries supply chain.
    - Toxic contamination – Smoked fish is widely traded and consumed in Senegal, and traditional processing methods result in high levels of PAHs – a known carcinogen.
    - Cold chain logistics – Most seafood destined for local consumption through retail vendors (with the exception of supermarket chains) is not adequately chilled due to deficiencies in infrastructure and lack of proper cooling equipment throughout the supply chain.
    - Access to finance – Most small and growing food businesses (GFBs) in the artisanal seafood sector operate with minimal capital investments and very low margins.
- There is a lack of demand by consumers for safer food products; and in turn, a lack of incentives for businesses to improve food safety practices. While hygiene and handling improvements are gradually being brought into the artisanal seafood supply chain aimed for export and higher-end markets, those improvements are for the most part still absent in the artisanal seafood supply chain destined for local consumption by lower-income consumers.
- Despite considerable investment efforts by international donors over the last couple of decades, the artisanal seafood sector in Senegal needs additional support to overcome barriers and improve food safety. Among the areas in need of food safety improvements, BD4FS initiated the following studies: (1) an assessment of water, sanitation, and hygiene (WASH) conditions at artisanal seafood processing sites; (2) a study on the risks of PAHs, alternative smoking techniques, and consumer awareness; and (3) a financial landscape assessment to better understand business needs and potential resources for improving food safety practices.

2. INTRODUCTION

Seafood is a critical source of nutrition in Senegal, especially among populations with low incomes. Post-catch processing, distribution, and retailing are also a source of employment and income; in addition to fresh seafood sold near the point of catch, a significant amount gets processed (salted and smoked) and sold further inland and cross-border to neighbouring countries. This important commodity for Senegal's food security comes with public health and food safety challenges. Many handling practices along the supply chain – cleaning, smoking, salting, drying, transporting, and retailing – can contribute to loss of potential nutrients for consumers as well as losses of income and profit to businesses. In addition, poor food safety practices set the stage for transmission of foodborne pathogens.

From March – July 2020, Feed the Future Business Drivers for Food Safety (BD4FS) carried out an assessment of conditions in Senegal that affect the ability of supply-chain actors – fisherfolk, fish processors, fishmongers, vendors, technology suppliers, and transporters – to adopt food safety practices. The initial focus for this Food Safety Situational Analysis (FSSA) was the artisanal fisheries sector, although some of our key findings also have relevance for other perishable food groups popular to Senegalese consumers. The steps in this analysis include desk research, appraisal of the artisanal fishery supply chain from post-capture to retail, field observations, interviews with local stakeholders, and review of previous interventions in the sector.

In addition to documenting the threats to public health presented by traditional handling of seafood catch, BD4FS also interviewed key actors in the private sector to better understand the constraints that businesses face to adopting food safety practices – financial, technological, regulatory, etc. These findings are the subject of this report and will be used in the next phase of the BD4FS Senegal project implementation. BD4FS will co-design possible solutions and explore the "drivers" for adopting food safety improvements alongside formal and informal supply-chain actors. BD4FS will monitor the implementation, adoption, and outcomes of varying solutions to assess which have the greatest potential for impacting the development of food systems – by reducing loss and incidence of foodborne pathogens – that provide consumers with safe and nutritious food choices.

3. SEAFOOD IN SENEGAL

3.1. Economic importance

Senegal is a coastal West African country bordering with Guinea-Bissau, Guinea-Conakry, Mali, Mauritania and The Gambia. It has a land area of 196,712 km² and an Economic Exclusive Zone (EEZ) of 158,358 km² (Mpatlas 2020). The population in 2019 was estimated at almost 17.5 million inhabitants (Countrymeters 2020), about 52% of whom live in rural areas (World Bank 2020a). Per capita income in 2018 was US$1,522 (World Bank 2020b). Senegal's Human Development Index (HDI) was 0.514 in 2018, which put the country in the low human development category (it ranked 166th out of 185 countries) (Human Development Report 2019). In recent years it had one of the fastest-growing economies in Sub-Saharan Africa (WBG 2018, World Bank 2020c). However, about 47% of the population lives below the poverty line (World Bank 2020c; 2011 estimates), while 46% of households are vulnerable to food insecurity (URI 2018). The major sources of revenue are remittances, foreign financial assistance, and tourism, together with agriculture and fisheries (WBG 2018).

As a coastal developing country, Senegal relies heavily on its marine resources. Senegal's EEZ is encompassed by the Canary Current Large Marine Ecosystem (CCLME), which sustains highly productive marine ecosystems and fisheries (Diop *et al.* 2016). Fisheries catch reaches on average 400,000 t/yr and provides about 75% of the animal protein intake of the population (Belhabib *et al* 2014, Diop *et al.* 2016). Small pelagic species (small fish of the sardine and anchovy families) like sardinella constitute a key source of protein for most of the population.

Besides being crucial for the country's food security, fisheries also provide livelihoods, employing directly some 70,000 artisanal fishermen and sustaining an estimated 600,000 to 800,000 indirect jobs (Africa Progress Panel 2014, Belhabib *et al.* 2014; Section 3.4). The fishing fleet comprises approximately 20,000 pirogues (artisanal wooden canoes) and about 100 large-scale industrial fishing vessels (CEA 2014, Belhabib *et al* 2014). The industrial sector is responsible for about 20% of total fish catch volume, while artisanal fisheries represent the remainder 80% and an even larger share of the workforce (Bank and Thiam 2018).

Seafood production and trade constitute a main source of revenue representing about 3% of Senegal's GDP (Bank and Thiam 2018). Generally speaking, the industrial fishery focuses on the provisioning of processing facilities with raw material aimed to export, while the artisanal fishery supplies the needs of the local market. However, the artisanal fishery sector is also increasingly supplying the export industry with raw material for processing, and it supplies, as well, high-end markets like restaurants and hotels in Dakar and touristic areas. This fraction of the artisanal fishery targets highly valued species such as crustaceans (shrimp, crabs, and lobsters), octopus, and demersal fish such as groupers and snappers.

The industrial fisheries sector is composed by three main fleets: a bottom trawling fleet, targeting demersal resources; a pelagic trawling fleet, targeting small pelagics; and a tuna fishing fleet, which targets tuna and other large pelagics such as swordfish, billfish and sharks (Belhabib *et al.* 2014). In all three cases, their catch is aimed for export, with the circumstance that the pelagic trawling fishery catches sardinella and similar species to be transformed into fishmeal and fish oil. The transformation may occur in Senegalese plants, but the catch may also be landed and processed abroad. While some of the industrial fishing vessels are owned by Senegalese companies, others are owned by joint venture companies financed with European or Asian capital. These joint ventures operate under different fisheries agreements that have been signed between Senegal and third parties (see subsection 3c, Fisheries sustainability).

As for the fraction of artisanal catch supplying domestic consumption, some of the main locally processed fish products are *keccax* (also spelled *kejax*) and *methora* (braised and smoked fish, respectively). Another important artisanal product is salted-dried (*salé-seché, "Sali"*) fish (CEA 2014). Sardinella is the main species used but other species may be similarly processed as well. Of these three main types of artisanally processed fish products, braised fish is generally the cheapest and is more consumed locally, especially in poor communities. Smoked and salted-dried fish are also exported to other West Africa nations such as Mali, Burkina Faso, Guinea Bissau, Guinea Conakry, Cote d'Ivoire, Benin, etc. (DPM 2019).

Braised, smoked, and dried fish are traditionally produced by associations of women fish processors located in coastal areas in proximity to the landing sites. Yet in recent years, industrial processors have also started to acquire large smoking ovens which allow for mass production. Thus, the traditional fish processing collectives are at risk of being outcompeted by the industrial producers (CEA 2014). Another threat to the artisanal fish processor collectives is the increasing competition by the fishmeal plants that also source sardinella and can pay higher prices for the fish (CCFD 2020).

3.2. Nutritional importance

Fish and seafood constitute an important part of the diet in many developing coastal countries. Fish provides proteins and micronutrients such as iron, zinc, magnesium, phosphorous, calcium, vitamin A, D, E, and B12, and iodine (Obodai *et al.* 2009, Mohiuddin 2019). It is especially important in diets dominated by intake of starch-rich but protein-poor vegetables (e.g., diets based on staple crops such as maize, cassava or rice), where it provides most of the essential amino acids. Fish (especially, small pelagics) is also rich in n-3 polyunsaturated long chain fatty acids (PUFAs), essential for children development, and thus also crucial for the diets of pregnant and lactating women (Mohiuddin 2019). Moreover, fish protein has been found to be easier to digest than other sources of animal protein, and high intake of fish and seafood have been linked to longer lifespan in human populations (Obodai *et al.* 2009).

Although FAO estimates that fish represents on average about 20 percent of animal proteins in the diet in Low-income food-deficit countries (LIFDCs), in reality for many coastal LIFDCs, this share is considerably higher (Entee 2015). Senegal has a per capita fish consumption ratio of 36 kg per year, among the highest in Africa (Belhabib *et al.* 2014). As fish is often cheaper than other sources of animal protein, it is crucial for the poorer sectors of the population (Entee 2015).

3.3. Stock sustainability

The Senegalese coastline spans 700 km and stretches from the mouth of the river Senegal at the border with Mauritania to the north, to the border with Guinea-Bissau in the south. About 50% of the Senegalese population lives in the coastal zone (Niang-Diop et al 2010). The main economic activities are linked with the coastal resources, such as fisheries, which mobilize about 20% of the active population (Thiao 2009). Almost 85% of artisanal fishermen operate in three areas: the Grande Côte (comprising Kayar and Saint-Louis), the Petite Côte (comprising Mbour and Joal), and the Cap Vert Peninsula (corresponding to the greater Dakar area) (Mbengue 2008).

Given this dependency on fisheries, a critical concern is that many fish stocks are exploited beyond the maximum sustainable yield (MSY) and required proper management to restore their reproductive capacity. These negative impacts are further exacerbated by climate change (Niang-Diop et al 2010).

A study funded by the CSRP (2012) identified specific measures that needed to be taken in order to achieve a sustainable exploitation of fisheries resources in Senegal. Despite the decade passed since, its conclusions are still valid. The identified measures are as follows:

a) An adjustment of marine fisheries capacities (capping any further growth of fishing effort);

b) Implementing effective control of access to fisheries resources (use of fishing permits and concessions of rights of access to resources);

c) The introduction of fisheries management plans;

d) The promotion of integrated management of coastal zones;

e) The strengthening of fisheries research; and

f) The optimization of fisheries monitoring, control and, surveillance (MCS) capacities.

A further issue which needs attention is the fact that inadvertently, international donor agencies might be contributing to the growth in overcapacity, through their funding of projects aimed to improve the infrastructures and logistics associated with export of high-quality species to the external markets; the EU, JICA, and other development agencies have supported a variety of measures such as the creation of landing docks, the distribution of refrigerated trucks, the establishment of ice plants, etc. (Thiao *et al.* 2012).

Overview of the resources

Fisheries resources in Senegal can be classified into four groups: coastal pelagic, coastal demersal, offshore pelagics, and estuarine resources. The first three groups depend mainly on the upwelling associated to the CCLME, while the last one benefits from the existence of many estuaries where nutrient-rich waters are slowly discharged into the sea (Niang-Diop et al 2002, CCLM 2020).

- Coastal small pelagics are the main fish resources in Senegal (75% of all landings). About 80% are constituted of sardinella (*Sardinella aurita* and *S. maderensis*). Other important small pelagic species are the Bonga shad (*Ethmalosa fimbriata*); Chub mackerel (*Scomber japonicus*); Horse mackerel (*Decapterus rhonchus* and *Trachurus trecae*); and anchovy (*Anchoa guineensis*) (Niang-Diop *et al.* 2002). Although the stocks of small pelagics are deemed to be highly dependent on environmental fluctuations (Zeeberg *et al.* 2008), they also can be overfished, especially when a period of high fishing effort overlaps a shift towards low stock productivity (Ba *et al.* 2006, Niasse and Seck 2011, Roux *et al.* 2013).

- Coastal demersal resources are found within the shelf area, between 0 and 200 m from shore. This group includes crustaceans (shrimps, lobsters, crabs), cephalopods (octopus, cuttlefish), and fishes (soles, groupers, seabreams, etc.). In general, they have a high commercial value and are increasingly exported. Most of these stocks suffer from overfishing, and some are, or have been, on the brink of collapse (Mbengue 2008, Fall 2009, Thiaw *et al.* 2015, Meissa *et al.* 2016).

- Offshore pelagic resources are mainly constituted of mackerel (*Scomber scombrus*); tuna such as albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), and skipjack (*Katsuwonus pelamis*); billfish; and swordfish. They are deemed at least fully exploited (Powers and Medley 2016).

- Estuarine resources are mainly constituted of fishes (about 250 species), shrimps (4 species), and mollusks, such as *Cymbium, Murex* sp., cockles, and oysters (Niang-Diop et al 2002, Ndaw et al 2014).

Both fishing with explosives and poison are officially banned by Senegalese authorities. However, these methods are still in use by the small-scale fishery sector, due to the authorities' insufficient enforcement capacities (Blédé *et al.* 2015).

Also, there are problems regarding the capacities to produce a reliable estimate of the artisanal catch volume. Belhabib *et al.* (2014) found that although the government had set up a registration system for the artisanal fleet, this was met with strong resistance from the fishermen and as a result, a significant number of pirogues may still unregistered. Thus, extrapolations based on the official number of pirogues can lead to under-estimating the real catch. It is unknown whether the situation has improved substantially since then.

The industrial fleet

The expansion in fishing capacity of the industrial fleet, in parallel to that of the artisanal fleet, has led to the overexploitation of several demersal stocks (Mbengue 2008). This overfishing has generated numerous conflicts between the artisanal and the industrial sectors (DuBois and Zografos 2012). It is to be noted that the impact of the bottom trawling fleet goes beyond the overfishing of commercial fish stocks: this fishing method has a critical impact through the destruction of vulnerable benthic habitats which often are also nursery grounds for many species (Meenakumari *et al.* 2008, Puig *et al.* 2012, Rossi 2013, Velip *et al.* 2015, Victorero *et al.* 2018, Das 2020, Lakshmanan *et al.* 2021).

A further factor involved in the depletion of the demersal resources was the widespread illegal, unreported and unregulated (IUU) fisheries activities by foreign demersal trawlers which started in the 1960s and continued even after Senegal claimed its EEZ (Belhabib *et al.* 2014). Increased surveillance in recent years seems to have partially decreased IUU fishing within Senegalese waters, with the IUU fleets shifting to operate in neighbor countries with weaker monitoring capacity than Senegal (Doumbouya *et al.* 2017). However, even when industrial vessels are assumedly operating in a legal way, they still represent a threat to artisanal fisheries. This is not only due to the competition for fishing resources, but also because they present a risk of collision with the pirogues, which has led to at least 100 deaths at sea registered so far (Belhabib *et al.* 2020).

Lastly, in the recent past, Senegal has signed several fishery agreements with the EU, Russia, China, and other partners. These agreements are a subject of great controversy among the Senegalese society given their unclear benefits to the country and the suspicions of corruption involved in the process (Sumaila *et al.* 2017). During 2020 massive social protests managed to make the government renounce the granting of 54 new fishing licenses for Turkish and Chinese vessels (CAPE CFFA 2020).

3.4. Summary

Key figures related to the fisheries sector in Senegal*

- *(maritime) Exclusive economic zone: 158,861 km²*
- *Land area: 196,712 km²*
- *Coast length: 718 km*
- *Artisanal vessels: approx. 20,000*[1]
- *Employment represented by the fisheries sector: 600,000, of which about 70,000 are fishers*[2].
- *Fish and seafood catch: In 2018 it was estimated at 517,000t of which 398,000t (77%) correspond to artisanal marine fisheries*[3]
- *Human Development Index: 0.466 (low -170th)*
- *Exports: USD$ 515 million in 2018*[3]
- *Fisheries share in export revenue: 21%*[4]
- *Fisheries share in GDP: 3,2% (Artisanal fisheries represent 2.5%)*[4]
- *Fish Consumption: 36 kg/hab/yr*[5]

*information retrieved from combined sources such as: CFI (2020), DPM (2019), Belhabib *et al* (2014, 2018), and others, as specified in the footnotes below.

[1] Based on Belhabib *et al.* (2014) and Belhabib *et al.* (2018).

[2] DPM (2019) estimates a total of 70,041 fishers. The figure of 600,000 workers involved in the fisheries sector (i.e. the addition of fishers, traditional fish processors, intermediaries, fish transporters, workers at processing plants, etc.) is somewhat uncertain: it is frequently quoted, but the original source could not be found. Some reports quoting this figure are considerably outdated (e.g. from the early 2010s); thus, the figure should be taken with caution. Nevertheless, as happens with the number of pirogues, the actual figure is likely to be as high as this estimate, if not higher. For instance, a recent report by Greenpeace (2019) suggests the real figure might be closer to 825,000 workers.

[3] DPM (2019)

[4] EUMOFA (2019).

[5] Belhabib *et al.* (2014)

4. SEAFOOD SAFETY CHALLENGES IN SENEGAL

4.1 Issues with food safety along the value chain from processing to pre-consumer

Food spoilage is a consequence of poor preservation conditions throughout the food supply chain. According to Porter and Reay (2016), globally, more than 30% of all food that is produced is ultimately lost and/or wasted through inefficiencies in the food supply chain. In developing countries, most food loss occurs due to spoilage at the early nodes of the food supply chain (production, harvesting and distribution; Fig. 1) (Porter and Reay 2016).

Figure 1. Food loss and wastage along the food supply chain

Source: Porter and Reay (2016)

Seafood supply chains can be very complex and often include more nodes than agricultural supply chains. This complexity increases the chances of seafood loss due to spoilage. The loss is also amplified by the fact that seafood is highly perishable. This fact increases the risk of product spoilage and value loss especially at the earlier nodes of the chain (Islam and Habib 2013).

A major concern for seafood loss in artisanal fisheries is that fish handling on board fishing boats, at the landing sites and/or during the transport stage are rudimentary and lead to quality loss. In addition, adequate storage facilities and ice in sufficient amounts might not be available for several steps of the supply chain. Quite often, seafood is transported over considerable distances in deficiently isolated transport vehicles. The sum of these and other factors damages the product and constitutes a food safety concern. On the other hand, the landing of low-quality products implies a loss of income for the fishers and fish sellers, since their products would fetch lower prices (Fig. 2).

Figure 2. Seabream infested with flies for sale in a landing site at Mbour, in Senegal's Petite Côte.

Source: J. Vilata.

Artisanal or small-scale fisheries in developing countries generate most of the world's fish landings yet are highly susceptible to post-harvest quality losses (Beran 2018). Post-harvest losses lead to reductions in the quantity, quality, monetary, and/or nutritional value of fish (Beran 2018). Fish (fresh or processed) is prone to microbial contamination enhanced by oxidation and enzymatic processes which lead to rancidity and rapid degradation. Degradation of fish compromises intake of nutrients such as protein, essential fatty acids, vitamin A, among others, and decreases its nutritive value. Loss of nutrients, associated to fish spoilage through bacterial growth, is caused by excessive exposure to high temperatures, poor hygiene, and poor handling during storage at-sea, on-board, and on shore (Beran 2018).

Superposed to the food spoilage is the issue of the *safety* of food – *i.e.*, that food is safe to consume and free of hazards to human health (Paudyal *et al.* 2017). It has been estimated that no less than 200 diseases are caused by or related to food. In some cases, they might be especially harmful to vulnerable sectors, such as the elderly, pregnant women, and infants (WHO

2020). Fish and seafood have been identified at the origin of many foodborne diseases and outbreaks worldwide (Chintagari *et al.* 2018). Food safety (including but not limited to seafood) is a crucial challenge for the public health sector in developing countries (Paudyal *et al.* 2017).

In Senegal, seafood products usually follow two main patterns of distribution: highly valued species aimed for export (e.g. tuna, octopus, lobster, groupers) are taken to the processing plants by modern refrigerated trucks; whereas fish destined to the domestic markets (usually small pelagics) are often transported in much poorer means of transport, for instance, horse-drawn carts or in open containers without ice. Hence the fish easily spoils, with the subsequent loss of value. Therefore, a specific area of action should be the modernization of the transport of fish aimed for the domestic markets. The central fish markets in Dakar and other main cities play an important role in Senegal's domestic fish supply chain, and substantial investments have been made on them in recent years. However, in rural areas, the situation is still of a lack of infrastructures (including ice plants and adequate storage facilities), means of transport, and adequately paved roads, which effectively prevent the conservation of the cold chain (CEA 2014).

4.2. Seafood-borne health hazards

Seafood-borne diseases can be caused by microorganisms (such as bacteria, viruses, and parasites) but also by heavy metals and a wide range of chemical compounds. Environmental conditions can influence or potentiate such hazards. In a minority of cases, the causes may be natural (e.g., bacteria naturally occurring; biotoxins produced by diatoms and dinoflagellates); but in the overwhelming majority of cases, seafood-borne health hazards are caused by lack of adequate hygiene during handling, processing, transport, and storage.

Fish and seafood are highly perishable and prone to become a health hazard if contaminated with pathogens or toxic compounds. They start spoiling soon after death due to enzymatic and microbial processes which foster the multiplication of pathogenic species within the fish tissues, thus becoming a high potential health hazard to the consumers (Obodai *et al.* 2009). Inadequate or non-sanitary handling, processing, storage, and transport of seafood increase hazards of microbial origin, including growth of pathogens already present in the fish and seafood tissues, but also contamination by food handlers or through cross-contamination (Chintagari *et al.* 2018).

The main seafood safety hazards can broadly be categorized according to their origins into pre-processing and post-processing groups. The first group contains all those potential pathogens and toxic compounds which may be present in the freshly caught seafood. The second group might appear only after seafood has undergone some processing method.

Pre-processing hazard group

Pre-processing is subject to bacterial pathogens (e.g., *coliforms, Vibrio*, etc.), viruses, parasites, heavy metals, microplastics, organic chemical pollutants, histamine, and biotoxins. Adequate processing and/or cooking might eliminate most viruses and bacteria and virtually all the parasites. However, some hazards (*i.e.,* some bacterial pathogens and histamine) might increase their concentration along the supply chain, if hygiene is deficient. Lastly, processing or cooking might not alter the levels of some other hazards (biotoxins, heavy metals, chemical pollutants, microplastics), which might render the final product unsafe even if adequate hygiene was kept along the entire supply chain.

Post-processing group

This hazard group encompasses PAHs (polycyclic aromatic hydrocarbons), which are highly carcinogenic and appear when fish has been processed under traditional braising and smoking methods.

Summary of categories

Hence, to summarise, the following types of seafood-borne health hazards have been identified by BD4FS: (1) Bacterial pathogens, (2) Viruses, (3) Parasites, (4) Heavy metals, (5) Microplastics, (6) Histamine and Scombroid fish poisoning, (7) Biotoxins, (8) Organic chemical pollutants (POPs, PCBs, OCPs, PBDEs), and (9) Polycyclic Aromatic Hydrocarbons (PAHs). These groups are assessed in detail in Annex 1.

4.3. Supply chain nodes where food safety issues occur

The sanitary conditions found across the artisanal seafood supply chain in Senegal are often inadequate. Poor handling and storage may begin at the fishing boats and continue along the seafood supply chain, encompassing landing sites, fish stocking stations, open markets, traditional processing sites, processing plants, and transport between these nodes.

The lack of adequate sanitary conditions in artisanal seafood supply chains appears to be a combination of two main factors: an insufficient awareness amongst the stakeholders and lack of means to implement adequate measures. Besides, the sanitary situation of fisherfolk (fishermen and processors) at the household level is also a core issue (K. Kent, pers. comm.).

The rate of fish spoilage after the moment of capture will depend on a number of variables such as the fishing gear used, the species of fish, environmental conditions (temperature), and handling (Entee 2015). Thus, adequate handling immediately after capture is essential to minimise spoilage. Fish stock abundance (or scarceness) also plays a role, since "*as catches reduce and economic pressures increase, fishermen go for fewer, longer trips since motoring in and out from shore burns the most fuel (one of the biggest costs of the trip). Thus fish [are] held on board longer*" (K. Kent, pers. comm.).

In order to prevent spoilage, adequate postharvest handling is needed. Fish should be quickly chilled at nearly 0°C. At this temperature the bacterial growth and enzymatic activity are slowed down, and the shelf life of seafood can be extended. Chilling should start onboard the vessel; fish should be kept at low temperature throughout the supply chain. Depending on the species, fish also may undergo some basic processing onboard the fishing boat before chilling. It can be bled, gutted, eviscerated, and gilled. The gutting and gilling are particularly important since these organs are potential sources of bacterial contamination (Kapute *et al*. 2013).

As basic as these procedures seem, they are not frequently followed. In the artisanal fleets present in Senegal, conditions onboard might vary considerably. Main factors influencing fish spoilage are the size of the fishing boat (i.e., with or without fish hold), number of crew, target species, fishing gear used, distance to the fishing grounds, and duration of the fishing trip. The largest pirogues that target sardinella, bonga shad, and other small pelagic species might have barely enough room to store the catch and the nets. In such cases, the catch is simply put on the bottom of the boat, exposed to the air, and the crew depends on a swift return to the landing site in order to keep the fish from spoiling. Some pirogues are better prepared and have a fish hold where the fish is stocked with ice.

In contrast, the smaller pirogues target demersal coastal species such as groupers, snappers, octopus, etc. Many carry a fish hold or fish boxes. At their simplest, they carry Styrofoam boxes, which might be strengthened with external fabric coating to increase their durability (Fig. 3). Larger fish holds may be old freezers recycled for this use. In both cases the fish hold or box will be stocked with ice.

Figure 3. Styrofoam boxes used by artisanal fishers in Senegal. Saint-Louis, Senegal.

Source: J. Vilata.

The type, quality, and quantity of the ice used for the chilling of the seafood catch is another variable that has direct effects on the fishers' ability to delay fish spoilage. According to Entee (2015*)*, different types of ice can be used for chilling fish, including liquid ice (ice slurry), flake ice, and block ice. Liquid ice has the highest cooling rate and has been identified as the best means to prevent fish spoilage onboard fishing vessels, followed by refrigerated seawater (Shawyer and Pizzali 2003, Kauffeld *et al*. 2010).

Once the fish catch is landed, it is either transferred to bigger plastic or wooden fish crates or kept in the original fish boxes. These crates and boxes are then carried in the means of transport to the next node. In any case, it is crucial that the cold chain is kept between the landing site and the point of last sale. Some export companies, high-end restaurants, and retailers that source from artisanal supply chains are very proactive in raising awareness amongst the fishers, and fish buyers, on the need to keep the fish chilled and in adequate conditions including during transport. They have strict buying rules by which fish that has not been adequately kept will not be bought. Exporters, restaurants, and retailers are appreciated clients for fish buyers; fish buyers, in turn, will adopt their fish handling requirements and transmit them to the fishers. Thus, the scheme for the artisanal fish catch destined to higher-end final buyers would schematically be:

However, a large fraction of the artisanal fish catch is destined to consumption by local customers. Regardless of whether its aim is to be sold "fresh" at local markets or traditionally processed, it is likely that ice will not be used in enough quantity, or not used at all, at several of the supply chain nodes. Thus, fishers may keep the fish with little or no ice until sold to the fish buyers, who in turn might not store the fish in adequate conditions until it is sold to the fish mongers or traditional fish processors. Fish mongers might also lack the means for adequate storage and transport of the fish until their final point of sale.

In the case of fish aimed for traditional processing, most of the bacterial pathogens might be destroyed (partially or totally) during the different processes used: sun-drying, salting, fermenting, braising, and smoking. However, the lack of hygiene at the processing sites means that whilst the original bacterial pathogens might be eliminated, contamination by other pathogens will occur anew during the fish handling and storage at intermediate or final stages of the processing. Besides, as mentioned earlier, braising and smoking involve the synthesis of carcinogenic PAHs, which will be present in the final product. And, to compound this situation, when the fish is set to sun-dry it is also a common practice to use insecticides such as DDT to prevent insect infestation. Hence, the final processed product might present a range of biological and chemical pollutants that make it a high health hazard to the final consumers.

5. CONSTRAINTS IN THE ADOPTION OF FOOD SAFETY

5.1 BD4FS findings

The findings by BD4FS are as follows: the weak capability of Senegalese seafood sector SMEs to adopt adequate food safety and handling practices (or foster their adoption throughout the seafood supply chain) is due to both internal and external causes. Internal causes may be a lack of awareness on the health hazards represented by inadequate sanitary conditions along the supply chain and a lack of access to funding by the small stakeholders to allow them to make improvements. External causes may include lack of incentives from the market (insufficient consumer demand) and also insufficient investment, monitoring, and enforcement from the pertinent authorities.

If the overall situation was summarized in one sentence (at the risk of being too simplistic), it could be said that good quality fresh fish goes to export or high-end markets and usually fetches a high price, while low quality, potentially spoiled fish goes to the domestic market or artisanal processing SMEs. BD4FS fieldwork and interviews with stakeholders allowed the team to learn the following: there is a positive feedback in the high quality/high price sub-chain that strengthens the process, but this positive feedback is absent from the low quality/low price sub-chain. Thus, fishers and fish buyers selling seafood to the better paying end buyers (e.g. exporters, retailers, and restaurants) are likely to obtain sufficient revenues, enabling them to reinvest part of these revenues in maintaining and improving the conditions that ensure their fish is of good quality. This means, for instance, that they can buy more and better quality ice, newer and cleaner fish storage implements, adequate transports means, or invest in any other weak point along the supply chain where they can intervene. In the case of highly capitalised fish buyers, they might even cover the costs of the fishing trip, thus having a strong leverage for demanding compliance by the crew with best handling practices in order to keep the highest possible quality of the fish.

None of this is doable by the SMEs and stakeholders in the low quality/low price seafood supply chain: they buy and sell their fish cheap, but they cannot ask the fishers and fish buyers to keep higher handling and storage standards, nor in most cases can apply these standards themselves, given that their revenues are often marginal. In extreme cases, this can lead to negative feedback loops: if fish supply becomes scarcer and/or more expensive, the poorest fish buyers, fishmongers, and fish processors might be constrained to buy less fish, and of worse quality, than under normal circumstances. This in turn will further decrease their revenues and will increase their vulnerability.

Incentives from the market

The BD4FS team learned that a main driver of the low-level implementation of food safety practices seems to be the lack of active consumer pressure for the sector to adopt such practices. This perception can change depending on the specific SMEs viewed and their respective customer pool. In principle, customers of high-end restaurants would seem more prone to demand warrants that the seafood they consume is safe, than the customers of street food vendors or traditional fish processors, for instance. Likewise, the awareness level of individual consumers purchasing seafood for their households might be influenced by their socioeconomic level and educational background.

A growing business driver for better quality in seafood products are retailer chains such as Auchan, the largest in the country. As was learned by the BD4FS project team during the project interviews, Auchan's policy for acquiring seafood products has recently been renewed. It now puts a strong emphasis on demanding a high-quality standard for the seafood it acquires through intermediary fish buyers, who get their supply from the artisanal fishers. Thus, pressure by Auchan might be helping to implement better hygiene and handling practices at the earlier nodes of the chain. Some exporting companies and hotels in Dakar and touristic areas such as the Petite Côte might be following similar lines of work. However, large international retailer chains, export companies, or hotels cannot qualify as SMEs.

Local restaurants, on the other hand, might be deemed medium-sized enterprises. An exhaustive analysis of the demand for high-quality seafood from the restaurant industry in Senegal is out of scope in this study. However, some input could be gathered from BD4FS fieldwork. This input points to a diverse array of situations: some restaurants seem interested in making proactive investments and aim to improve their seafood supply chain, while others seem satisfied with the current situation, and though they concede that seafood quality could be a general issue, they claim that they directly source their seafood themselves, and so are confident in its quality. The potential for involvement of local restaurants in creating demand for better seafood supply chain handling practices should be further investigated.

Lack of investment, monitoring and enforcement from the authorities

The DITP (*Direction des industries de transformation de la pêche*) is the national agency responsible for ensuring that any seafood entering the market meets safety and quality standards. However, DITP is focused on the export sector. In theory, it should also conduct inspections on artisanal fisheries landing sites, traditional fish processing sites, fish buyer stocking stations, traditional markets, etc. The responsibility for monitoring and enforcement in the artisanal fisheries supply chain is apparently shared with another state agency, the DPM (*Direction de la pêche maritime*). There seems to be an overlap of responsibilities between the two, where the agencies themselves do not always appear to have a clear understanding of their respective competencies and mandates. This situation is recognised by some members of the DITP (D. Thiop, pers. comm.).

In any case, regardless of which agency is performing the task, the fieldwork undertaken by the BD4FS team revealed that the personnel and financial means available for monitoring and enforcing adequate hygiene and handling practices in the artisanal seafood supply chains are very limited. Consequently, most nodes in the artisanal seafood supply chain are not regularly monitored or inspected, and even when they are and the need for improvements is made clear, the lack of financial support from the State thwarts any progress.

The input received from stakeholders interviewed during BD4FS fieldwork supports the position that monitoring, enforcement, and investment capacities by the pertinent agencies are very weak, and that they are also not capable of linking the investment-needed areas to potential investors, for instance other government agencies or public financing institutions.

Lack of awareness of food-related health hazards and illiteracy rates

In Senegal, in 2017, the average literacy level of people aged 15 years or more was 51.9% (UNESCO 2020). Illiteracy tends to increase as the socioeconomic level of the population decreases; thus, in the poorer sectors of the population, illiteracy levels tend to be higher (Bakare 2011). Fisheries-dependent coastal communities are at the lower range of metrics for average income and literacy in Senegal (World Bank 2018). In turn, low general literacy- especially in rural areas- affects health literacy (Andrzejewski *et al.* 2009, Ester *et al.* 2011). The existing lack of awareness of food-related health hazards in many coastal communities would appear to be related to the higher illiteracy rates found in these communities. Therefore, increasing the public's awareness on food-related health hazards requires a concomitant effort on improving literacy levels.

General conditions at the landing and processing sites

All the factors mentioned in section 5.1 converge to determine the actual conditions in which the artisanally caught fish is landed, handled, transported, and processed:

- A general lack of basic infrastructures at landing and processing sites: deficiencies in water supply, power supply, availability of ice, availability of cold storage for preserving the fish, etc.
- Obsolete transport vehicles (in contrast with those used by the export and high-end market seafood supply chain).
- A double lack of training and of financial means by supply chain actors to adopt basic sanitary and handling measures.

5.2 Interviews and field missions

Sixteen full interviews were carried out by the BD4FS team to gather input from a varied range of stakeholders. The interviewees worked at different levels in the seafood supply chain and related areas, such as private sector, fisheries stakeholder associations, fisheries management agencies, and food safety research institutions. Twelve interviews were held in March, prior to the declaration of the state of emergency due to the covid-19 pandemic, and the remaining four were held in June and early July, once travel restrictions within the country were lifted. Table 1 provides a summary of all the stakeholders contacted within and outside Senegal.

Table 1. Summary of organizations and individuals consulted during the FSSA.

Type or of organization/business	*Number*	*Individual/expertise*	*Number*
Fish processor associations	4	Supermarket and restaurant procurement	4
Seafood processing & export	2	International organizations & universities	4
National food safety institutions	3	National subject matter experts	10
National associations & federations	6	Private sector entrepreneurs	7
Donors	2	Public sector	5

Besides the interviews listed above, the BD4FS team undertook two field missions in Senegal, both in mid-2020, in order to assess the conditions prevalent in coastal communities relevant to the artisanal seafood supply chain (some of which had also been recipients of donor-funded projects in the past). The first mission targeted coastal communities in the Petite Côte region, south from Dakar, while the second targeted the northern coast.

In total, the following places were visited:

- Joal: landing site, fish terminal, and two artisanal processing sites.
- Ngaparou: a fish landing site and small fish terminal (Fig. 4).
- Mballing: two traditional processing sites.
- Mbour: landing site and the adjacent fish terminal.
- Richard Toll: ANA aquaculture station.
- Saint-Louis: artisanal fisheries landing site and traditional processing site.
- Lompoul: artisanal fisheries landing site and traditional processing site.

BD4FS findings from the interviews and the field missions are presented in the next section.

Figure 4. Cymbium set to sun-dry at the beach of Ngaparou, Petite Côte. It has been set upon a Styrofoam box, often used to keep the catch onboard the pirogues.

Source: J. Vilata

6. LESSONS LEARNED FROM OTHER FOOD SAFETY INITIATIVES IN SENEGAL

6.1. Findings and lessons learned

BD4FS field missions enabled the team to check *in situ* the current situation in several artisanal fisheries communities, including artisanal fish processing sites. In general, it was apparent a need for investment in the communities themselves and in the infrastructures belonging to the artisanal fisheries supply chain. And yet, this is at odds with the fact that, during at least two decades, several international donor agencies have been investing significant amounts of funds into Senegal's fisheries sector. Table 2 shows the estimated budgets invested by international donors on already terminated projects. It is split into two sub-tables, where Table 2a shows projects which were exclusively focused on Senegal, and Table 2b shows projects which targeted the wider West Africa region.

Despite considerable investment efforts, the artisanal seafood sector needs additional support in the following areas: technical, logistic, and infrastructure (e.g., availability of clean water, ice, and power); access to funding for businesses to improve food safety practices; and education and outreach to improve literacy levels in coastal communities, awareness of seafood safety and quality, and willingness to pay for higher quality seafood among consumers. For food security more broadly, Senegal would benefit from assistance in fishery resource management to address increasing competition for scarce resources while considering social, economic, and cultural aspects of fisheries.

A full description of the projects mentioned here is presented in Annex 2.

Table 2a. Total estimated budget invested by international donor agencies in projects concerning the Senegalese fisheries sector, 2000-2020 (Projects focused on Senegal).

Donor agency	Project title	Project timeline	Budget [USD]
JICA	Pilot project Petite Côte	2003-06	Not found
USAID (URI-implemented)	COMFISH Pencoo Gej	2011-16	$11.5M for 5 years
USAID (URI-implemented)	COMFISH Plus	2016-18	$4.5M
World Bank	GIRMaC + GDRH	2006-10	~$14 M
JICA	COGEPAS	2009-13	~$3.3M
JICA	PROCOVAL	2014-17	$4M
World Bank	WARFP – PRAO	2010-14	~$11.6M* (* to be split among the 9 countries encompassed by the project).
EU	ADuPeS	2013-17	4.5M
Total budget			**45.3M** (without PRAO), or **54.3M** (assuming 30% PRAO budget for Senegal)

Source: elaborated from the sources referred in Annex 2.

Table 2b. Total estimated budget invested by international donor agencies in projects concerning the Senegalese fisheries sector, 2000-2020. Projects focused in the wider West Africa region (not restricted to Senegal).

Donor agency	Project name	Project timeline	Budget [USD]
UNESCO / African countries	ODINAFRICA: Réseau d'Echange de Données et d'Informations Océanographiques pour l'Afrique	4 phases, 1998-2014	Not found
UNDP - EU	GOWAMER	2012-2017	~11.8 Million* (* to be split among the 6 participating countries)
EU	ACP FISH II	Not found	Not found
FAO / GEF Executed: CI, UNDP, UNEP, WB, WWF	Coastal Fisheries Initiative (CFI)	2015-ongoing	201.5M* (This is a global project. The budget for Senegal activities could not be found).

Source: elaborated from the sources referred in Annex 2.

Counting only the international donor-funded projects focused on Senegal fisheries (Table 2a), at least USD 45-54M has been allocated since the mid-2000s. The actual figure is likely higher, since Senegal's fisheries sector is included in multimillion-dollar initiatives such as GOWAMER (already ended) and FAO-GEF's CFI (started in 2015 but still ongoing). Therefore, "lack of funding" can hardly be poised to explain the poor situation of artisanal seafood supply chains in Senegal. This situation encompasses each possible aspect of fisheries interventions, from management of the stocks and the fishing effort, to the lack of adequate sanitary conditions throughout the fish supply chains.

Few of the donor initiatives presented above have addressed the issue of seafood safety (except, partially, in JICA and FAO-GEF CFI projects, where the value chain component included food safety; L. Ababouch, pers. comm.), even though this has clear relevance to the Senegalese population's wellbeing.

One project that has given full coverage to sanitation and seafood-borne health hazards is USAID's COMFISH and its continuation COMFISH Plus, both implemented by URI. The following is an excerpt from the independent USAID/COMFISH Mid-term Performance Evaluation (Cadmus Group 2015): "*Improved infrastructure and protocols for fish processing (especially hygiene and sanitation): The COMFISH program has contributed to increasing women's incomes by improving fish processing activities* (…). *Example outcomes include: Construction of the pilot processing unit for the women's association in Cayar;* t*raining in functional literacy for the women's association in Cayar; the provision of processors, cleaning material and equipment to women's processing groups in Mbour; capacity building on improved fish processing techniques for sanitation and hygiene in numerous coastal communities* (…)*; development of hygiene charters for eight communities* (…)".

Drawing from the insights gathered during BD4FS field missions, the input given by the interviewed stakeholders, and further analysis of project results in the available literature, BD4FS has identified the following **general** findings and **lessons learned**:

- Any **investment** should be made **directly in the communities**.
- The **projects**' expected outcomes, and the means to achieve them, should be **defined jointly with the local stakeholders**. Too often, donors do not take into account the local stakeholders' input, for instance, regarding the desirable characteristics of the facilities to be built. This leads to most facilities not being used or being used deficiently once the projects reach their deadline.
- **Local teams** should be set up to accompany any project developments.
- The projects results should be kept **monitored** in the **mid- and long-term**.
- A **holistic approach** is needed: for instance, achieving improvements in seafood-borne health hazard awareness is linked to improvements in literacy and in fostering the managerial and financial autonomy skills within the fishers, fish buyers, and associations of women fish processors.

- Projects focused on funding large infrastructures tend to be negligent on seemingly **peripheral aspects** which end up having a large influence on determining the **final results**. For instance, designing a brand new landing site or fish terminal without ensuring that there would also be an increased availability of affordable, good quality ice, might result in a high rate of fish spoilage still occurring after the completion of the project.
- Projects relying mostly on **high-tech fixes** or implementing exclusively technical approaches are prone to a **high failure risk** if they are not socioeconomically and/or culturally viable. For instance, one of the large donor projects identified that wooden pirogues offered a number of risks in terms of fish spoilage. Hence, the project proposed the large-scale replacement of the wooden pirogues by newly constructed fiber-glass boats. This approach failed to recognize that even if it were economically feasible to replace most of the 20,000 pirogues of Senegal's artisanal fleet, the fish would still be subject to high spoilage rates if no further measures were taken. Most prominent is raising awareness among the fishers on the need to observe adequate fish handling practices onboard.

Besides the general lessons learned presented above, there were also a number of **specific lessons learned**. Some of these may apply to one specific community or site, while others might be applicable to many sites.

- **Ice production** is a general constraint in the fresh fish supply chains: ice is in short supply in many of the areas visited. In some sites there are plants, but they do not produce enough ice, and their production is mostly bought by the touristic facilities. Besides, "*Cost of energy is also a constraint in most places*" (K. Kent, pers. comm.).
- **Traditional fish processing sites** vary greatly in their respective situations. The most urgent actions would be to ensure that all sites have clean **running water**, properly built **toilets**, and **shaded** working areas.
- **Further needed improvements** in fish processing sites would be the scaling up of the use of **solar fish driers** and adequate **fish smoking ovens**.

  -Currently, most fish is set to sun-dry in the open air, directly exposed to infestation by insects. It is a current practice to add insecticides (DDT) to the fish in order to avoid the infestation. Thus, the final fish products might become highly toxic for human consumption.

  -In turn, adequate fish smoking stoves are needed in order to avoid the synthesis of carcinogenic PAHs during the smoking process.
- **Power supply** was also mentioned often by the stakeholders as an important problem, especially at the traditional fish processing sites. Deficiencies in power supply might, in turn, facilitate theft of tools and materials and create a lack of safety for the workers, most of whom are women.
- **Lack of support facilities**: Infirmaries, childcare, warehouses, stores, etc.
- **Scarcity of fish** and competition from other buyers (e.g. fishmeal plants) over the main resources.
- The problem of **lack of access to finance** to start businesses and safeguard their resilience. For instance, to maintain the required improvements in order to ensure the quality of the product while withstanding temporary decreases in fish supply or demand.
- Related to the previous point, **lack of access to social insurance** (to cover for health coverage, schooling of children, retirement pensions, etc.).
- Lack of implementation of adequate **hygiene and handling practices** (except in the sites where the USAID-URI projects had been successful).
- Lack of **maintenance** of infrastructures, facilities, and equipment.
- **Low literacy** rate among the workers at the initial nodes of the chain (fishers, fish processors).
- **Lack of value-adding** processing that meets market requirements.
- Marketing and consumption: need to increase **seafood safety and quality awareness** and **willingness to pay** for higher quality of seafood, among the consumers.

Figure 5. A fish processor working in a traditional processing site located in Joal. In the background, the chimneys of the fish stoves (built by the Albert Schweitzer Foundation) were toppled after an episode of extremely strong wind. The stoves were thus rendered unusable, and follow-up action aimed to repair them had not been undertaken at the time when the picture was taken (June 2020).

Source: J. Vilata.

7. WAYS FORWARD FOR BD4FS

Three main lines of work were followed by BD4FS regarding seafood-borne health hazards in the artisanal fisheries supply chains of Senegal:

1) Identifying areas and actors where implementable actions can have the widest impact in terms of curbing serious health hazards for the largest possible share of the population. Priorities were identified by applying a matrix of hazards' risk level versus the feasibility of implementation of the actions. After applying this matrix, traditional smoked fish appeared as the highest priority.

2) Enabling the actions to curb the hazards. For instance, in the case of widely consumed and traded smoked fish, this means identifying which oven model could be best to reduce the identified hazards (carcinogenic PAHs created during the smoking process).

3) Providing economic self-sustainability to the actors through education and training, so that they can implement by themselves the enabling actions, while minimising their dependency on external sources of funding (e.g. international donor projects).

Pre- and post-processing seafood-borne health hazards were identified in Section 4b under the following nine general categories: (1) bacterial pathogens, (2) viruses, (3) parasites, (4) heavy metals, (5) microplastics, (6) histamine and scombroid fish poisoning, (7) biotoxins, (8) organic chemical pollutants (POPs, PCBs, OCPs, PBDEs), and (9) Polycyclic Aromatic Hydrocarbons (PAHs) (See Annex 1 for details on each group of hazards). Table 4 below classifies each hazard according to three criteria: ease of detection, risk level to the population, and feasibility to implement the actions aimed to curb them.

Table 3. Assessment of the identified seafood-borne health hazard categories against: a) ease of detection, b) risk level to the population, and c) feasibility to implement of hazard-curbing actions. Each criterion is scored from 1 to 3 depending on: detection and feasibility to implement the proposed actions (easy=1, difficult=3), risk (1=low, 3 =high).

Hazard	Pre-/Post processing	Detectability	Risk level to the population	Implementability
Bacteria	both	1	2	2
Viruses	both	3	2	2
Parasites	Pre-	1	2	1
Heavy metals	Pre-[1]	3	3	na[2]
Microplastics	Pre-	2	2	na[2]
Histamine	both	1	1	2
Biotoxins	Pre-	3	3	3
Chemical pollutants (POPs, PCBs, OCPs, PBDEs)	both (mostly Pre-)	2	3	3
PAHs	both (mostly Post-)	2	3	1

[1]they are already in the seafood tissues and cannot be eliminated by processing.
[2]the only implementable action would be to limit the consumption of the species found to have higher levels of heavy metals or microplastics.

7.1 Identifying the hazards and the feasibility of curbing actions

1) Bacterial pathogens are likely widespread throughout the artisanal supply chains in Senegal. Their detection is relatively easy (score 1 under "ease of detection" criterion), and in Senegal, there are microbiological research lab facilities that can perform this task. Poor country-wide statistical sanitary data prevent assessing how widespread are seafood-borne bacterial diseases within the country. However, it seems reasonable to assume that they are relatively common and that, at any given time, a significant share of the Senegalese population will suffer from them; hence their scoring as "medium risk" (score 2 under "risk" criterion). For a wide range of pathogenic seafood-borne bacteria, preventive measures do not necessarily require large investments (although cold chain investments would be required at the key nodes of the supply chain).

Implementing basic hygiene and handling guidelines in combination with an improvement of the cold chain throughout the supply chain would potentially have a wide impact, both in terms of improved health safety of the seafood and in reducing post-harvest losses due to fish spoilage. This is especially important in a context where fish resources are getting scarcer. Through the reduction of fish spoilage, net revenues per unit of fish catch volume could increase, thus reducing the pressure towards increasing fishing effort.

However, the overall feasibility to implement is assessed as "medium" (score 2), due to the vast scale at which the hygienic and handling guidelines and the cold chain improvements would have to be effectively implemented: artisanal fleet, landing sites, fish buyers' stocking stations, fish terminals, traditional markets where fresh fish is sold, etc. Still, some sites could be selected as pilot projects. One of such sites could be the landing site at Ngaparou, which is one of the more proactive sites in the country in terms of effective implementation of fisheries improvements.

2) Seafood-borne viruses are expected to be similarly widespread as seafood-borne bacterial pathogens (hence the risk level score of 2), although in contrast, their detection is more complex (3) than in the case of bacteria. Control measures would largely overlap with those applicable to bacterial pathogens (feasibility to implement score 2).

3) Parasites (multi- and unicellular) are also expected to be common, like bacteria and viruses. They are easily detectable (1). Their risk level is precautionarily assessed as medium (2). Still, in terms of ease of control, they are probably the easiest hazard to curb, since deep freezing combined with proper cooking would virtually kill all the parasites present in seafood (feasibility to implement score of 1).

4) Heavy metals (HM) are, in most aspects, the opposite to parasites. Their detection requires well-equipped laboratories (hence, detectability score of 3). A 3 risk level score was assigned due to their deleterious effects upon the human health and the poor availability of health statistics on their prevalence. Unfortunately, the leeway for preventing HM in seafood is very small: insofar, the main source of HM on seafood (industrial pollution) is not curbed; the only effective way to reduce population's exposure to them is by offering guidance on limiting consumption of higher-risk seafood products. Consumer guidelines providing recommended maximum intakes of the species at higher risk of carrying HM are already available in several countries.

5) Microplastics represent an intermediate score (2) for consumers' risk. They are similarly difficult to avoid as heavy metals and would also require a well-developed monitoring system.

6) Histamine poisoning is a rather common hazard, but it is also relatively mild, at least when compared with most of the other categories. Unfortunately, histamine is heat-stable and thus is not eliminated by cooking. Still, adequate sanitary and handling conditions along the seafood supply chain are likely to reduce greatly the population's exposure to histamine poisoning.

7) Biotoxins are peculiar in that they are almost exclusively found on bivalves (the only exception is Ciguatera poisoning, which affects fish, but it has not yet been detected in Senegal). Their detection is not easy since each type of biotoxin requires a specific protocol. As for the risk they pose to the population, there are two considerations: in the one hand, in Senegal, bivalve consumption is not high at the national level. However, locally, bivalves may be commonly consumed (for instance, in the coastal communities in the south of the country, such as the Sine-Saloum delta). On the other hand, several biotoxin syndromes are potentially fatal, with no cure or antidote.

Thus, in terms of public health it should be a priority to establish a strict monitoring system aimed to readily detect biotoxin outbreaks and issue rapid alerts to prevent any collection, trade, or consumption of bivalves during the duration of the outbreak. Such a system is both expensive and complex to manage, and it does not exist in the country. It is also true that Senegal seems to have been spared of any lethal biotoxin outbreak. However, the risk exists.

8) Organic chemical pollutants derived from industrial and agricultural contamination (POPs, PCBs, OCPs and PBDEs, and others) are amongst the most dangerous seafood-borne hazards in terms of their potential effects on the human health. However, unfortunately, they are similar to heavy metals in that the feasibility of curbing them is very limited. The only way of protecting the population (other than by stopping the spill of industrial and agricultural sewage) is to implement a thorough monitoring system, able to detect and to raise rapid alerts whenever any seafood product was found to surpass the concentration thresholds.

9) Lastly, there is the category of carcinogenic and teratogenic PAHs. They are in the category of very serious health hazards along with heavy metals, chemical pollutants, and biotoxins. And they're widespread: traditionally smoked fish (with high PAH levels) is widely consumed not only within Senegal but also in the wider West Africa region, constituting a serious threat to consumers.

In contrast with the other hazards, PAH levels in smoked fish can be greatly reduced by implementing low-complexity technology – essentially, modern models of fish smoking stoves. PAHs are the only hazard category where a high-risk score (3) is opposed to an easy feasibility to implement score (1), as shown in Table 3.

Therefore, PAHs constitute the one hazard category where BD4FS may reach the maximum positive effect, spilling over to benefit a large share of population and with potential for scalability throughout the region Nevertheless, it also must be acknowledged that scaling up stove technologies has not proven easy (K. Kent, pers. comm.).

7.2 Enabling the actions

In small scale fisheries, successful projects aimed to improve hygiene and handling practices within the seafood supply chain have focused in four areas: a) improving access to potable water and ice at affordable costs; b) disseminating best handling practices on board and after landing, including the use of insulated containers; c) training the actors: increasing awareness by using appropriate methods and local language; and d) promoting safe and quality products to fetch higher prices (L. Ababouch, pers. comm.).

While all four areas of work are valid, they share a disadvantage: they require application on a massive scale to produce significant results at the country level. Also, they have all been tried already, with results too uncertain or too slowly developing to be observable at present. There is a serious mismatch between the large sums invested by the different donors through different projects during the previous two decades and the apparent results on the field.

So, while the four areas of work listed above are also contemplated and included in BD4FS approach, the program chose to focus on a novel aspect with high potential to translate into direct health benefits for the stakeholders involved and the general public: the adoption of fish smoker models that avoid production of carcinogenic PAHs and that also offer better working conditions and health benefits for the artisanal fish processors (they reduce the workers' exposure to the smoke produced in the process).

Several authors (Beran 2018, Robadue *et al.* 2019) have presented the different existing models of fish smoking stokes. The comparative advantages and disadvantages of the four main stove models (Chorkor, Morrison, Ahotor and FTT) can be summarized as follows:

-Chorkor and Morrison stoves are relatively cheap, but inefficient in their use of fuel, and produce inacceptable high levels of PAHs. They also cause a high exposure of workers to the smoke.

-Ahotor stoves are more expensive (around $USD 400, Robadue *et al.* 2019), but are more fuel efficient. Their PAHs are around the maximum threshold set by the EU.

-FAO-Thiaroye (FFT) stoves are the most expensive (between $USD 500 and $USD 800, according to Robadue *et al.* 2019; however, higher costs are mentioned in the literature), are fuel efficient, and they yield the lowest PAH values. Larger FTT models have an important disadvantage: in order to be used at the maximum efficiency, they need to smoke 3 tons of fish in each turn. Still, it may be worth exploring the possibility to test and disseminate smaller FFT ovens, with the aim to produce large numbers which can bring economy of scale and ease of use (L. Ababouch, pers. comm.)

A number of questions are posed, e.g.:

What is the margin for reducing costs in the Ahotor and (especially) FTT stove?

Can the PAH levels in Ahotor stoves be further reduced?

How long does it take for the relative savings in fuel to offset the costs of both Ahotor and FTT stoves, compared to the basic Chorkor and Morrison models?

And fundamentally: can a consumer demand be developed for safer (=lowest possible PAH levels) smoked fish, so that it would become the main factor driving the processors to adopt the safer stove models, instead of depending on donors' external funding?

7.3 Providing economic self-sustainability

Based on the input given by the interviewed stakeholders and the results from the literature search, current consumer demand for safer (low PAH content) smoked fish seems to be very low or inexistent in Senegal and in the West Africa region. It might be linked to the issues already presented in Section 5. This proves to be a strong barrier to incentivise producers (the associations of women fish processors) to replace their stoves with safer but more expensive models. In other words, in the absence of external funding provided by an international donor, the government, an NGO, or any other external source, the artisanal fish processors would not seem able to tackle the considerable expenses involved in acquiring the safer fish stove models. Actually, the Ahotor and FTT models may represent savings in the long-term, given their greater fuel efficiency as found by Beran (2018). But Beran (2018) also admits that it is not easy for the processors to perceive and gauge this additional long-term advantage of the safer stove models when faced with the reality of having to disburse a large amount of money in the present to acquire them.

In summary, "*The key issue is often that for any additional improvement in quality (and safety), the costs has to be reflected in the price of the finished products. Any pilot project should include the promotion of a market with a willingness to pay for quality*." (L. Ababouch, pers. comm.).

Such a market may exist, primarily among the more educated urban classes in Senegal (mostly in Dakar) and in the main cities of the countries where smoked fish is exported. But also, complementarily, the West African diaspora in the US might constitute a promising market. BD4FS is currently looking at this: a dialogue has been started with representatives of the West African diaspora in US eastern coast states. The notion of supporting a strengthened trade of safe (low PAH or PAH-free), high-quality smoked fish, was well received. Further steps might include assessing the potential for Senegal's artisanally-smoked fish to be certified under Fair Trade label scheme or similar initiatives.

Figure 6. Sardinella fishers pushing a pirogue out of the water at their landing site in Cayar beach north of Dakar.

Source: J. Vilata

ANNEX 1. SEAFOOD-BORNE HEALTH HAZARDS

1.1 Bacterial pathogens

Several bacterial pathogens are transmitted through seafood: *Salmonella* sp., *Staphylococcus aureus*, *Vibrio cholerae*, *Vibrio parahaemolyticus*, *Listeria monocytogenes*, and *Escherichia coli*, among others (Raymond and Ramachandran 2019). Poor sanitary conditions onboard the boats, at landing sites, and at the fresh fish markets amplify the contamination. The actual incidence of bacterial disease outbreaks linked to seafood consumption in Senegal is difficult to track, as is often the case in many developing countries, due to the absence of adequate statistics records (Raymond & Ramachandran 2019).

Seafood contamination with bacterial pathogens occurs naturally from the environment where fish and other seafood products are gathered and also during their processing (Shikongo-Nambabi *et al.* 2011). In some cases, pathogenic bacteria levels initially present in the seafood may not be high enough as to pose a health hazard to consumers, but they are amplified throughout the supply and processing chains due to inadequate handling (poor general and /or personal hygiene) and inadequate temperature, which enables them to reach infective levels by the time the product is consumed (Shikongo-Nambabi et al. 2011).

Salmonella spp.

Several strands (serovars) of *Salmonella* spp. cause acute gastroenteritis, whilst other strands cause an enteric infection also called typhoid. Both constitute a global public health concern and represent a significant cost to society in many countries (Raymond and Ramachandran 2019). In most cases the cause is the consumption of water or food contaminated by fecal wastes from infected animals and humans. African and central Pacific countries show a high incidence of Salmonella-infected seafood (Chintagari *et al.* 2018).

Nontyphoid Salmonella: Infection with nontyphoid *Salmonella* results in typical gastroenteritis symptoms: abdominal pain, watery diarrhea, nausea, and vomiting with a low-grade fever. Typical infections are self-limiting with symptoms lasting 48 hours. More severe symptoms may occur in infants and the elderly. Fatality rates are low (~1%). (Waite and Yousef 2010).

Typhoid and paratyphoid Salmonella: Enteric fevers (typhoid and paratyphoid fevers) are major health problems in developing countries with an annual incidence estimated at 17-20 million cases, with 600,000 deaths (Waite and Yousef 2010). In Southeast Asia, typhoid fever is endemic (1,000 cases/100,000 population) and is considered the fifth leading cause of death. *Salmonella typhi* and *paratyphi* can infiltrate beyond the epithelial layers of the intestine, leading to bacteremia and other severe complications including intestinal perforation and death (Waite and Yousef 2010). Some individuals are asymptomatic carriers and may shed these organisms in fecal material for more than 1 year, potentially infecting many others. Humans are the only reservoir for *Salmonella typhi* and *paratyphi* and thus are the source of contamination of food and water (Waite and Yousef 2010).

Seafood contamination with *Salmonella* strands (of any type) is facilitated by the fact that these bacteria are often present in coastal and estuarine waters. However, it is not well established whether this presence is either naturally occurring or due to contamination from untreated sewage water, or both (Chintagari *et al.* 2018). Besides, *Salmonella* contamination can also occur along the supply chain due to the use of contaminated water and through cross-contamination by the workers (Raymond and Ramachandran 2019).

During a 9-year study (1990-1998) the US Food and Drug Administration noted an overall incidence of Salmonella in 7.2% of 11,312 samples from imported and 1.3% of 768 samples from domestic U.S. seafood. Bakr *et al.* (2011) identified Salmonella from 8% of bivalve samples and 14% of shrimp samples in the U.S. In comparison, Shabarinath *et al.* (2007) detected Salmonella in 70% of fish, 59% of shrimp and 30% of oyster samples from fresh markets and fish landing sites in India. While no results are available from Senegal, it is expectable that prevalence levels might be closer to India's than in the US.

Vibrio spp.

Vibrio species such as *Vibrio parahaemolyticus* and *Vibrio vulnificus* are part of the biota naturally found in estuarine and coastal marine habitats worldwide (Figure 1). Both species have been isolated from seawater in tropical and temperate regions, sediments, and a wide range of seafood; they are especially common in shellfish and bivalve mollusks. Bivalve mollusks (e.g. clams, mussels, and oysters) are especially prone to bacterial contamination because they are filter feeders. They concentrate these bacteria in their filtration systems and thus can potentially trap all bacteria and viruses, pathogenic or otherwise, that are present in their habitat (Bakr *et al.* 2011).

Figure 1. A 3D image of a number of oblong–shaped *Vibrio parahaemolyticus* bacteria.

Source: Public Health Image Library, Centers for Disease Control and Prevention.

Pathogenic *Vibrios* are a public health concern worldwide since they have been found to be one of the most important causes of human food poisoning (Raymond and Ramachandran 2019). Out of the 65 species of the genus Vibrio, only 3 species (*V. parahaemolyticus, V. cholerae* and *V. vulnificus*) are responsible for most cases of foodborne illnesses. Other *Vibrio* spp. can cause illness, but their prevalence is much smaller (Raymond and Ramachandran 2019).

Most varieties of *V. parahaemolyticus* are non-virulent; however, the virulent ones are a major cause of gastroenteritis linked to seafood ingestion (Bakr *et al.* 2011). Besides gastroenteritis, *V. parahaemolyticus* can also cause wound infections and septicemia. Although it is considered halophilic (and thus linked to marine and brackish water), it has also been found in freshwater environments. Many studies have isolated the species from fresh and frozen seafood (Raymond and Ramachandran 2019).

V. cholerae causes cholera, a potentially epidemic and life-threatening secretory diarrhea. Outbreaks of seafoodborne cholera are common (Raymond and Ramachandran 2019). Cholera may result in death, primarily due to dehydration. Fecal contamination of water is the primary source of infection during outbreaks; however, seafood has recently been implicated as a vehicle of transmission. Fish, crabs, oysters, and clams have been identified as the cause of cholera outbreaks (Waite and Yousef 2010).

Vibrio vulnificus is also widely distributed in coastal and estuarine waters throughout the world (Raymond and Ramachandran 2019). It poses "*a significant health threat to humans who suffer from immune disorders, liver disease, or hemochromatosis*" (Bakr *et al.* 2011). The infection occurs through open wounds or by consumption of raw bivalves, and if left untreated, can cause septicemia and death in vulnerable individuals (Harwood *et al.* 2004). The rate of mortality is higher than in any of the other pathologies caused by Vibrio species (Raymond and Ramachandran 2019).

Bakr *et al.* (2011) took 150 samples of seafood (oyster, mussel, and shrimp) from food markets in Alexandria, Egypt. *Vibrio* was recovered from 52% of samples on average (88%, 36%, and 32% of oyster, mussel, and shrimp, respectively). *Vibrio* bacteria present a trait that multiplies their potential to become a health hazard: these species are able to form an exopolysaccharide biofilm that protects them from the surrounding environment (Shikongo-Nambabi *et al.* 2011). Embedded in this biofilm, *Vibrio* can proliferate and reach high densities (Shikongo-Nambabi et al. 2011).

Whilst the presence of *V. cholerae* and other Vibrios in fish and shellfish products can be deemed difficult to avoid, the health hazard they represent can be offset by hygienic handling, adequate processing, and cooking (Raymond and Ramachandran 2019).

Escherichia coli

E. coli is a primary indicator for fecal contamination. Given that is natural habitat is the gastrointestinal tract of warm-blooded vertebrates, *E. coli* only survives for a relatively short period in the environment. It can be rapidly destroyed by freezing (Visnuvinayagam *et al.* 2017). However, active *E. coli* can be present in sewage-polluted water, from where it can be transferred to fish and shellfish (for instance, when polluted seawater is used to rinse freshly landed fish at the beach). Thus, most seafood contamination with *E. coli* is of secondary origin; it stems from inadequate practices during post-harvest handling (Chintagari *et al.* 2018). Repeated use of water for cleaning the fish in open markets is one of the main sources of seafood contamination with *E. coli* (Visnuvinayagam *et al.* 2017), as is the use of ice produced with polluted water (Chintagari *et al.* 2018). When Visnuvinayagam *et al.* (2017) analysed seafood samples from traditional wet fish markets in India they found that 22.4% of the samples were unfit for human consumption due to excess levels of *E. coli*. Kombat *et al.* (2013) analysed samples of anchovy (*Engraulis encrasicolus*) and round sardinella (*Sardinella aurita*) in Ghana and ran microbiological quality analysis at each of the following stages of the supply chain: at sea, immediately after capture; on landing at landing beach; and at local retail markets. Whilst the fish samples at the two first stages were shown to be within the legal limits, fresh samples obtained from the markets were all above national and international standards, and thus were unsafe for consumption.

Streptococcus spp.

Like *E. coli*, fecal streptococci are also an indicator of water contamination through untreated sewage discharge (Visnuvinayagam *et al.* 2017). In contrast to *E. coli*, though, they have better survivability in the open environment and are more resilient at cold temperatures. Both factors increase their potential as seafoodborne pathogens. The term fecal streptococci and Enterococci are used alternatively because Enterococci are considered as subset of fecal streptococci. They are deemed true fecal indicators because they have been found to be present in most samples from sewage-polluted water (Visnuvinayagam *et al.* 2017). Within the group, two species stand out for their pathogenic potential: *Enterococcus fecalis* and *Enterococcus faecium* are responsible for endocarditis, intra-abdominal infection, and urinary tract infections in humans (Visnuvinayagam *et al.* 2017). Their presence in seafood is due to secondary contamination, as in the case of *E. coli*.

Listeria monocytogenes

Listeriosis is a serious bacterial disease caused by the intracellular pathogen *Listeria monocytogenes* and has been recognized as a food-borne disease since 1981. It is capable of surviving under refrigeration conditions, low pH and in high salt concentration, but is killed by cooking (Raymond and Ramachandran 2019). Early stages of infection by *L. monocytogenes* causes relatively mild flu-like symptoms, but untreated cases may lead to septicemia, meningitis, encephalitis, miscarriage and may also cause death (Barbuddhe *et al.* 2008 cited in Raymond and Ramachandran 2019). In fact, *L. monocytogenes* has the highest fatality rate of the foodborne bacterial pathogens, commonly between 30% and 40%. The incidence rate of *L. monocytogenes* is between 2 and 15 cases per million people worldwide (Waite and Yousef 2010).

L. monocytogenes is naturally ubiquitous in the environment. It can be found in both soil and aquatic environments, as well as in animal and human feces. Since it is present in water, primary contamination is possible, and so it can be potentially present in pre-harvested seafood (Chintagari *et al.* 2018). However, secondary contamination is probably is a higher risk. *Listeria* has been found in restaurant kitchens and processing facilities. Similarly to *Vibrio*, *Listeria* sp. can exude protective biofilms that buffer them from the environment. This capacity greatly increases its hazard potential. It has been isolated from domestic and imported fresh, frozen, and processed seafood products, including crustaceans, molluskan shellfish, and fish (Chintagari *et al.* 2018).

Summary: Bacterial pathogens in seafood

Regardless of whether they are species naturally occurring in freshwater and marine habitats or their presence is due to pollution by untreated sewage water, bacterial pathogens stand out as the primary source of seafoodborne health hazards to seafood consumers all over the world. In countries such as Senegal where sewage water is insufficiently treated or not treated at all (Troussellier *et al.* 2004, Bouvy *et al.* 2008), the prevalence of seafoodborne bacterial pathogens is very likely to be much higher than in Global North countries where higher levels of sewage treatment are attained.

Bacterial pathogens in coastal waters are not present isolated from each other. Any given sample of coastal and estuarine water collected in the country will present a combination of pathogens, ranging from mild to severe hazards, and it is this mix of hazards that will be transmitted (and in some cases amplified) throughout the artisanal fisheries supply chain.

A few studies from other developing countries have highlighted the health hazard posed by the "cocktail" of seafoodborne potential pathogens. For instance, Jahan *et al.* (2019) sampled fish species caught at the Bakkhali River estuary in Bangladesh. These authors found high concentrations of pathogenic bacteria such as *E. coli, Salmonella* sp, *Shigella* sp, and *Vibrio* sp. These were shown to be linked to multiple sources of water pollution such as untreated sewage dumping, municipal waste, and industrial wastewater.

In Nigeria, Eze *et al.* (2011) sampled frozen mackerel (*Scomber scombrus*) from local markets. They found that *S. aureus*, *E. coli,* and *Lactobacillus plantarum* were the predominant pathogenic bacteria species present in the samples. In the specific case of *S. aureus,* its presence was attributed to secondary contamination through improper handling and poor hygienic conditions along the supply chain, since it is a species naturally present in the nose, throat, and skin of humans. The presence of *E. coli* also revealed that at some point(s) along the supply chain, the mackerel samples had been exposed to fecal water pollution.

Bacterial pathogens found in seafood show a wide spectrum of traits in terms of their resilience to environmental factors, which in turn determine their relative threat to the consumers. They also show a large variability in terms of the gravity of the diseases and syndromes they cause, ranging from very mild and short-termed to long-lasting and, in some cases, life-threatening.

Unfortunately, the absence of large-scale efforts aimed at collecting medical data on the prevalence of these diseases within the Senegalese population does not allow diagnosing the situation in the country. Thus, it is clear that there is a need for enforcement of disease surveillance and monitoring programmes (Raymond and Ramachandran 2019), along with an even greater need to implement hygienic conduct codes and best practices across the supply chains of seafood products.

1.2 Viruses

The main group of viral hazards associated with consumption of fish and seafood are enteric viruses, a wide group that encompasses norovirus and Hepatitis viruses A and E (Waite and Yousef 2010, Chintagari *et al.* 2018).

Enteric viruses

Enteric viruses pollute water through the discharge of treated and untreated sewage contaminated with human and animal waste. When compared to bacteria, waterborne enteric viruses *"pose a greater health risk due to the low infectious dose, which may be as little as one virion* [a virus particle]." (Chintagari *et al.* 2018). Noroviruses and hepatitis A are the most common enteric viruses transmitted by fish and seafood (Chintagari *et al.* 2018).

Bivalve mollusks play an important role as reservoirs of enteric viruses. They can accumulate virus and other microorganisms with a concentration factor up to 99-fold (Chintagari *et al.* 2018). Unlike bacterial pathogens which can be effectively purged from the bivalve's tissues after a period of depuration in clean water, viruses may be retained for a long time. Thus, conventional depuration does not eliminate the risk of virus infection through consumption of raw or undercooked bivalves (Chintagari *et al.* 2018).

Norovirus

Noroviruses (Fig. 2) belong to the Caliciviridae family. They have been identified as the causative agent of several viral gastroenteritis outbreaks across the world (Donaldson *et al.* 2010). In fact, norovirus infection appears to be the most common cause of gastroenteritis in humans and is highly infectious. Infection usually occurs by the ingestion of contaminated food or water, but person-to-person transmission has also been documented (Anbazhagi and Kamatchiammal 2010). It is linked to up to 200,000 deaths per year in children younger than five in developing countries (Chintagari *et al.* 2018). Norovirus infection is considered to be *"the second leading cause of morbidity and mortality among children under five with severe diarrheal infection in Africa*" (Louya *et al.* 2019).

Noroviruses can be transmitted to humans through consumption of raw or undercooked bivalves. They enter the ocean or estuaries through the discharge of domestic sewage and sewage-contaminated rivers and streams, as do all other enteric viruses. Anbazhagi and Kamatchiammal (2010) analysed 50 bivalve samples from several locations in India. The samples tested positive for noroviruses in 24% of the cases. In contrast, they also analysed samples from finfish tissues, but none tested positive for noroviruses.

Figure 2. 3D image of a number of norovirus virions. Representation based on original electron microscopic (EM) imagery. *Source*: Public Health Image Library, Centers for Disease Control and Prevention.

Hepatitis A and E

As stated by Waite and Yousef (2010), Hepatitis viruses A (HAV) and E (HEV) cause acute hepatitis and are transmitted via the fecal-oral route, person-to- person contact, and contaminated food and water. HAV may survive in water for weeks to months. Boiling, ultraviolet light, formaldehyde, and chlorine treatments are effective to inactivate HAV particles. (Waite and Yousef 2010). These authors also state that "*the fatality rate* [of HAV] *is low* (…). *Only 5% are considered to be foodborne. HAV is considered to be a preventable disease in developed countries due to access to an effective vaccine*." According to Chintagari *et al.* (2018), "*Hepatitis A infection is the leading worldwide cause of acute viral hepatitis (…) Outbreaks of hepatitis A virus caused by the consumption of raw shellfish have been reported regularly (…) and raw or undercooked clams or oysters were implicated as the most frequent vehicles of infection. Hepatitis A virus appears to be extremely stable in the environment*." Apparently, HAV can survive up to 12 months in fresh or salt water (Chintagari *et al.* 2018).

Regarding HEV, Waite and Yousef (2010) note that "*HEV causes a disease (hepatitis E) with a low-mortality rate (0.5%–3%);*" however, it is much higher in women in the third trimester of pregnancy (20%). According to the authors, HEV outbreaks are largely caused by drinking contaminated water, but "*only small foodborne outbreaks have been identified. HEV is endemic in Southeast Asia, the Indian subcontinent, and Africa*." (Waite and Yousef 2010).

Senegal is vulnerable to viral gastroenteritis outbreaks, given that *"countries that have inadequate infrastructure to support a growing population, coupled with poor wastewater treatment facilities and improper sanitation mechanisms or systems, will always be prone to gastroenteritis infection*" (Anbazhagi and Kamatchiammal 2010). In general, the results from the literature highlight the risk of consuming raw or insufficiently cooked bivalves as a main risk of infection by enteric viruses. This risk results from the bio-accumulative capacity of bivalves, combined with the high resilience of enteric viruses and the difficulty of purging them from the bivalves' tissues. Enteric viruses can survive for a long time in the water and in association with sediments, which act as reservoirs of infective viral particles (Anbazhagi and Kamatchiammal 2010). Besides implementing a tight monitoring system able to detect possible outbreaks, the main way to curb noroviruses-related health hazards is to avoid consumption of uncooked bivalves.

1.3 Parasites

Parasitic organisms representing seafoodborne health hazards to humans can be split into two main groups: animal or metazoan (multicellular) parasites and protozoan (unicellular) parasites.

Animal parasites

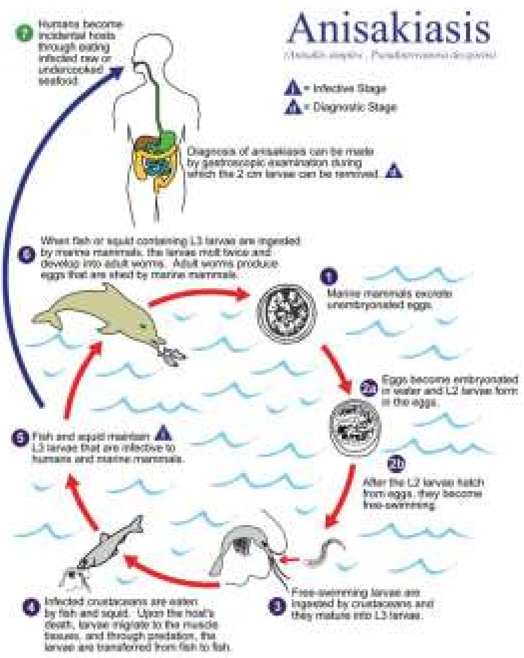
Animal parasites commonly found in fish and seafood include Nematoda species, also known as round worms (e.g. *Anisakis* spp., *Pseudoterranova* spp., *Eustrongylides* spp., *Gnathostoma* spp.), Cestoda species (tapeworms), such as *Diphyllobothrium* spp., and Trematoda species or flukes (*Clonorchis sinensis, Opisthorchis* spp., *Heterophyes* spp., *Metagonimus* spp., among others) (Chintagari *et al.* 2018). Although in developed countries outbreaks are generally low, in developing countries millions of people are infected annually (Waite and Yousef 2010, Lima dos Santos and Howgate 2011).

Seafood-borne Nematoda (e.g. anisakiasis, Fig. 3) infections can cause a range of symptoms varying from mild to acute allergic reactions (Foti *et al.* 2002, Audicana and Kennedy 2008). Within the Cestoda, the worst diseases (e.g. taeniosis and cysticercosis) are caused by consumption of infected raw or undercooked meat, but not seafood. Fishborne trematode (FBT) infections, or fishborne trematodiasis, are, however, a cause of concern due to the morbidities of their associated diseases and their prevalence in certain regions, such as South East Asia (Lima dos Santos and Howgate 2011).

Another taxa of marine parasitic worms, the Acanthocephala, can also infect humans via ingestion of their primary hosts (fish, cephalopods). The incidence of Acanthocephala worms causing human infections seems to be low, as most of these species are not well-adapted to be human parasites (Adams *et al*. 1997).

A rarer group of animal parasites transmitted through seafood belong to the Cnidaria (*Myxobolus, Kudoa* and *Unicapsula*). They cause diarrhea, but no lethality has been reported. Very little is known about them and their transmission to humans (Shamsi 2019).

Figure 3. Life cycle of the nematodes, *Anisakis simplex* and *Pseudoterranova decipiens*, the causal agents of anisakiasis.



Source: Public Health Image Library, Centers for Disease Control and Prevention.

Specifically in Senegal, Dione *et al.* (2014) researched the prevalence of Nematode parasites (*Anisakis* sp. and *Contracaecum* sp.) in mugilid fish (frequently fished and consumed by humans) from different locations in the country. They found a high occurrence of larvae in the sampled fish. Larvae infestation was positively correlated to the size of fish; thus, larger fish presented more larvae than smaller specimens. From a public health perspective, it might imply that consumption of smaller mugilid fish should be preferred.

Protozoan parasites

Giardia duodenalis has been isolated from dolphins, sharks, and farmed and wild fish in Western Australia, implying that fish may act as a reservoir for waterborne giardiasis and also present a source of infection for foodborne giardiasis and a public health risk (Shamsi 2019).

In short, most if not all outbreaks caused by marine parasites have been associated with eating raw or undercooked fish and seafood. The hazard is eliminated by cooking the seafood at a temperature high enough to destroy the parasites (Chintagari *et al.* 2018).

1.4 Heavy metals

According to Waite and Yousef (2010), the term "Heavy metals" refer to "*metals, or metalloids, having a specific density greater than 5 g/cm3.*" They are present in the environment at relatively low levels, but are *"purposefully concentrated for industrial production,"* whereby their intensive use and production has led to increased environmental contamination (Waite and Yousef 2010). The main heavy metals of concern in the food supply are lead, cadmium, mercury, and arsenic (a metalloid). Arsenic, lead, and mercury top the 2007 United States priority list of hazardous substances, with cadmium at number seven (Waite and Yousef 2010). Direct health impacts due to exposure to heavy metals are shown in Table A1.

Table A1. Adverse health effects of heavy metals.

Adverse Health Effects of Heavy Metals

Heavy Metal	Sources of Exposure	Health Effects	Provisional Tolerable Weekly Intake (PTWI)	U.S. FDA Action Levels in Shellfish
Cadmium	Cigarettes and food (potatoes, cereals, shrimp, fish, and shellfish)	Acute gastroenteritis, renal, liver, testicle, and prostate disorders, anemia, hypertension, cardiovascular changes, pregnancy complications, skeletal damage (Itai–itai disease: osteomalacia and osteoporosis), lung cancer (pulmonary adenocarcinomas)	7 µg/kg/week	3 ppm in crustacean
Mercury	Food (fish and shellfish) and dental amalgam	*Inorganic mercury:* lung damage (acute), neurological and psychological symptoms (chronic), kidney damage *Organic mercury (methyl- or ethyl-mercury):* renal, pulmonary, reproductive, and cardiovascular toxicity, nervous system damage, neurotoxic effects, gingivitis, insomnia, memory loss, anorexia, paresthesias, blindness, coma, death *Fetal damage:* mental retardation, cerebral palsy, congenital Minamata disease	5 µg/kg/week (total mercury)	4 ppm in mollusks 1.0 ppm methyl-mercury in all fish
Lead	Food (plants) and air	*Acute lead poisoning:* headache, irritability, abdominal pain, nervous system dysfunction, dark blue lead sulfide line at gingiva, disturbance of hemoglobin synthesis (anemia), kidney damage, death *Lead encephalopathy:* sleeplessness and restlessness, psychosis, confusion, reduced consciousness, memory deterioration Congenital defects *Children:* behavioral problems, learning and concentration difficulties, diminished intellectual capacity	25 µg/kg/week	1.5 ppm in crustacea 1.7 ppm in mollusks
Arsenic	Food (fish and seafood) and drinking water (Bangladesh, Chile, and China)	*Inorganic arsenic:* gastrointestinal symptoms, cardiovascular and central nervous system damage, death, bone marrow depression, hemolysis, hepatomegaly, melanosis, polyneuropathy, encephalopathy, peripheral vascular disease (black foot disease) *Drinking water:* lung, bladder, and kidney cancer, skin cancer and other skin lesions (hyperkeratosis and pigmentation changes)	15 µg/kg/week (inorganic arsenic)	76 ppm in crustacea 86 ppm in mollusks

Sources: Adapted from Bakir, F. et al., *Science*, 181, 230, 1973; Järup, L., *Br. Med. Bull.*, 68, 167, 2003; Protasowicki, M., *Toxins in Foods*, eds., Dabrowski, W.M. and Sikorski, Z.E., CRC Press, New York, 2005; Zukowska, J. and Biziuk, M., *J. Food Sci.*, 73, R21, 2008.

Source: Waite and Yousef 2010.

Heavy metals are a health concern for the entire population, but they are even more so for certain age sectors due to the fact that human body's ability to absorb and excrete heavy metals varies with age. For instance, children absorb 50% of the lead present in their diet, but in adults this percentage is only 10%-15%. Methyl-mercury poisoning is a primary health hazard for pregnant women due to the damage it causes to the fetus (Waite and Yousef 2010). As highlighted by Gbogbo *et al.* (2018), heavy metals "*have been linked to a number of pathological conditions including neurological disorders, kidney damage, skin damage,* *circulatory system problems, and increased risk of cancer*." Also, some other heavy metals such as Zn, Fe and Cu, which are essential to keep normal human cellular functions, can become toxic at elevated tissue concentrations (Gbogbo *et al.* 2018).

Moreover, many heavy metals are bioaccumulative, especially in aquatic trophic webs (Waite and Yousef 2010). Thus, fish at higher trophic levels (i.e. carnivore fish) are likely to bioaccumulate heavy metals within their tissues, reaching levels toxic to humans (Waite and Yousef 2010). There is evidence of toxic levels of heavy metals, especially mercury (Hg) and Cadmium (Cd), in the tissues of top predator species such as sharks, tuna, and swordfish. For instance, Storelli and Marcotrigiano (2001) found total mercury concentrations that exceeded the limits in 44.3% of bluefin tuna (*Thunnus thynnus*) samples caught in the Mediterranean Sea; Blanco et al (2008) found that 22% of samples from sharks and swordfish (*Xiphias gladius*) landed in Galicia, Spain had mercury levels above the legal limits; and Araújo and Cedeño-Macías (2016) detected unsafe levels of Cd and Hg in samples of yellowfin tuna (*Thunnus albacares*) and common dolphinfish (*Coryphaena hippurus*) landed on the Ecuadorian coast.

Gbogbo *et al.* (2018) studied heavy metal levels in a number of fish species from Ghana. Ghana shares many traits with Senegal in the sense that both are developing West African countries with growing industrial sectors but little capacity for toxic waste processing; this means that, in both countries the sources of heavy metal pollution (agricultural runoff, electronic waste processing, mining, smelters, oil refineries, chemical industry, shipyards, untreated sewage sludge, and diffuse contamination) are unlikely to be curbed, and the resulting heavy metal pollution will be released to the environment. These authors assessed and compared the concentrations of mercury, arsenic, lead, cadmium, selenium, zinc, and copper in two commercial fish species: the bigeye grunt (*Brachydeuterus auritus*) and Bagrid catfish (*Chrysichthys nigrodigitatus*). Overall, the values found did not raise immediate health hazard concerns, although the levels of arsenic and mercury were close to the thresholds used as a reference by the authors.

Net *et al.* (2015) studied concentrations of mercury and other pollutants in seven marine species sampled from different locations within Dakar's peninsula. They found that the highest levels of mercury were detected in Senegalese sole (*Solea senegalensis).* Mercury levels in round sardinella (*Sardinella aurita)* were comparable to values reported for the same species collected off Mauritania. They concluded that the mercury levels did not exceed the limits fixed by the European Union. However, they also stated that "*it is now urgent to adopt adequate pollution control strategies* (…) *before the problem becomes irreversible given (…) continuous discharges of domestic and industrial effluents*."

Also in Senegal, Diop *et al.* (2016) quantified the concentrations of 11 elements (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Se, V, and Zn) in the body tissues of round sardinella (*Sardinella aurita*) and Senegalese sole (*S. senegalensis*). They found that the concentrations of Cd, Fe, and Pb were significantly higher in sardinella whereas concentration of As, Cu, Cr, Mn, and Se were highest in sole. These authors also found high concentrations of arsenic in the liver and muscle of both sole and sardinella, but as they note, EC Regulations do not provide a legal limit for this element (Diop *et al.* 2016). Currently the regulation of the European Union recognises three metals (Pb, Cd, and Hg) as dangerous for human consumption, but As is excluded (Bodin *et al.* 2013).

Bivalves also possess a high potential to accumulate heavy metals due to their filter-feeding biology, their capacity for bioaccumulation, and their low capacity for depuring the heavy metals from their tissues. Bodin *et al.* (2013) studied heavy metals bioaccumulated by different species of mollusks sampled from estuarine areas in the south of Senegal (Petite Côte and the Sine-Saloum Estuary). The species sampled were two bivalves (*Arca senilis* and *Crassostera gasar*) and three gastropods (*Conus* spp., *Hexaplex duplex,* and *Pugilina morio*), all of which are edible and gathered by women from the local communities both for self-consumption and trade. These authors found that lead and mercury did not exceed the maximum acceptable limits. In contrast, Cd levels surpassed the legal limits and thus posed a hazard for the population. They concluded that *"a proper evaluation of the sources of Cd contamination of the Senegalese coastal marine environment, as well as of the exposure and effects of this trace metal on coastal fisheries is necessary*."

1.5 Microplastics

According to Lusher *et al.* (2017) "*Plastic production has increased exponentially since the early 1950s and reached 322 million tonnes in 2015 (…). Inadequate management of plastic waste has led to increased contamination of freshwater, estuarine and marine environments. It has been estimated that in 2010 between 4.8 million to 12.7 million tonnes of plastic waste entered the oceans*."

Lusher *et al.* (2017) define microplastics as "*plastic items which measure less than 5 mm in their longest dimension; this definition includes also nanoplastics which are particles less than 100 nanometres (nm) in their longest dimension*." These authors highlight that "*Microplastic contamination of aquatic environments will continue to increase in the foreseeable future and at present there are significant knowledge gaps on the occurrence in aquatic environments and organisms of the smaller sized microplastics (less than 150 µm), and their possible effects on seafood safety.*"

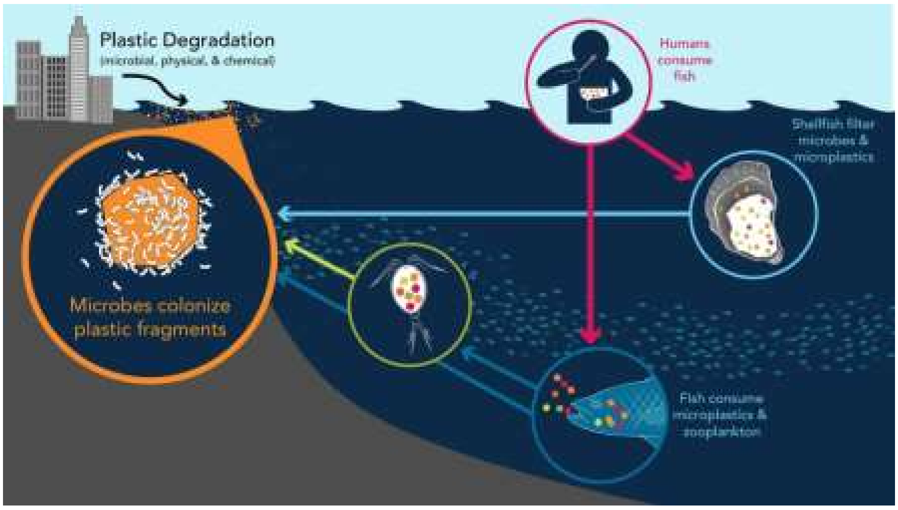
The ingestion of microplastics by aquatic organisms (including commercial fish species) has been documented: microplastics have been observed in the gastro-intestinal tract in 11 out of the 20 most important species and genera of finfish that contribute to global marine fisheries (Lusher *et al.* 2017). Fish collected from fish markets contained microplastics, including 25 percent of fish caught off the west coast of the United States of America and 28 percent of fish caught in Indonesian waters (Rochman 2015 *in* Lusher *et al.* 2017) (Figs. 4 and 5).

Figure 4. Plastic debris at the beach of Mballing, Petite Côte, Senegal.

Source: J. Vilata.

Microplastics contain additives, amongst which there are persistent, bioaccumulative (fat-soluble) and toxic contaminants (PBTs) (Lusher *et al.* 2017). Thus, microplastics' adverse effects may be two-folded: they may cause harm as foreign bodies within the organism (the smallest microplastic fraction (size ≤20 μm) may penetrate into organs and cause systemic exposure; Lusher *et al.* 2017), and then they may act as vehicles for PBT contaminants.

Figure 5. Plastics that get into the ocean often degrade into microplastics that are ingested by fish and shellfish and can go up the food chain to be ingested by humans.



Source: https://www.whoi.edu/oceanus/feature/junk-food

In humans, the risk of microplastic ingestion is reduced by the removal of the intestines and viscera in most species of fish before consumption. However, bivalves and small fish (e.g. anchovies) are consumed whole. Unfortunately, very little research has been conducted so far, and the existing reports of microplastic accumulation in bivalves are restricted to Europe, North America, Brazil, and China (Lusher *et al.* 2017).

In summary, the quantities of microplastics ingested by humans via seafood and their effects on human health are unknown. Specifically, toxicological data for the ingestion of nanoplastics either from seafood or from other origins are completely lacking. The only certainty is that there will be an increase of micro- and nanoplastics in the future as a result of degradation of plastics already released in the environment as well as future inputs (Lusher *et al.* 2017).

1.6 Histamine and Scombroid fish poisoning

Scombroid syndrome/histamine poisoning occurs worldwide and is considered one of the most common forms of toxicity caused by fish consumption (Colombo *et al.* 2018). Scombroid fish poisoning results from the consumption of spoiled scombroid fish (e.g. tuna, bonito, mackerel, swordfish, marlin, etc.). The cause of the syndrome is that dark meat in scombroid fish is rich in the aminoacid histidine, which is metabolized into histamine by bacterial contaminants (Jantschitsch *et al.* 2011).

Typical symptoms include erythema, sweating, nausea, diarrhea, a peppery taste or burning sensation in the mouth, dizziness, headaches, and palpitations. These symptoms are mediated mainly by histamine and appear several minutes to one hour after the ingestion of contaminated fish. The condition is usually self-limited and may last between a few and 24 hours (Jantschitsch *et al.* 2011).

Histamine-associated toxins are heat stable, which means that cooking the tainted fish will not prevent histamine poisoning. Hence, the main preventive measure is proper handling and storage of the fish (Jantschitsch *et al.* 2011). Colombo *et al.* (2018) conducted a global review of fish poisoning cases and found that fresh or frozen fish, diversely prepared and cooked, and fish products differently processed (not canned) were cause of poisoning in 79 episodes out of a total of 101 cases. Only 22 cases could be attributed to consumption of histamine-tainted canned tuna.

1.7 Biotoxins[1]

Bivalves feed by filtrating large volumes of seawater. Through this process of filtration, they can accumulate pathogens and toxic substances, such as natural biotoxins and heavy metals. Biotoxins (phycotoxins) are planktonic algae products which they produce as a defence against predators. The concentration of biotoxins in bivalve tissue is directly related to the abundance of toxic algae in the water. Therefore, the risk of biotoxin accumulation is higher during algal bloom events. Depending on the type of poisoning, biotoxins are separated into several groups:

AZP - Azaspiracid Shellfish poisoning	NSP - Neurotoxic Shellfish poisoning
ASP - Amnestic Shellfish poisoning	PSP - Paralytic Shellfish poisoning
DSP - Diarrheic Shellfish poisoning	VSP - Venerupin Shellfish poisoning

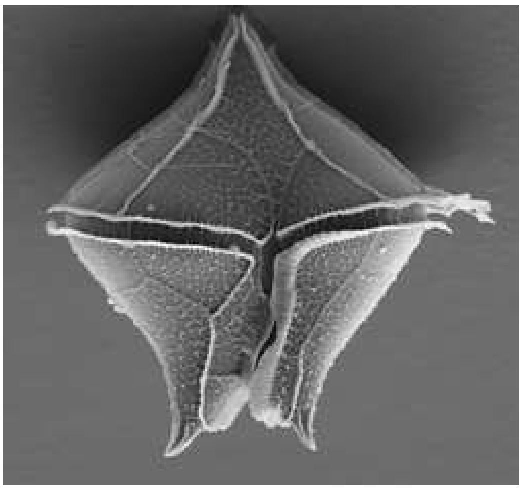
A further variety of biotoxin poisoning is the Ciguatera syndrome. In contrast with all other syndromes, which are caused by consuming bivalves tainted with biotoxins, Ciguatera is caused by consumption of tropical reef fishes.

Azaspiracid Shellfish Poisoning

Azaspiracid Shellfish Poisoning (ASP) is caused by the dinoflagellate species *Protoperidinium crassipes* (Fig. 6), which produces a type of toxin called azaspiracids. It has been suggested that the effects of azaspiracids could be related to cytoskeletal changes or even gene expression alterations. The highest accumulation of azaspiracids is found in the bivalves' digestive glands. When contaminated bivalves are ingested, the toxin spreads all over the body except the brain.

ASP leads to severe neurological symptoms, including confusion, memory loss, disorientation, seizure, and coma. Recovery may take years. Fatalities have been recorded (Poli 2003). The maximum allowable concentration of this toxin should not exceed 160 µg/kg bivalve meat (EU Regulation No. 853/2004).

Figure 6. The dinoflagellate *Protoperidinium crassipes*, causal agent of Azaspirazid shellsfish poisoning.



Source: www.gbif.org/occurrence/1322592937, ©Maria Faust

[1] This subsection is almost entirely based on Gvozdenović *et al.* 2015, unless other authors are explicitly quoted.

Amnestic Shellfish Poisoning

This poisoning is caused by two diatom species, *Nitzschia* and *Pseudo-nitzschia*, which produce domoic acid. The highest accumulation of this toxin is found in the bivalves' kidneys, gonads, and digestive tract. Domoic acid has a neuro-excitatory effect (it interferes in the neurotransmission process), and damages neurons in the hypothalamus which is responsible for memory processes. Symptoms of poisoning in humans are confusion, memory loss, nausea, headache, and vomiting. They occur within 24-48 hours after consumption of contaminated bivalves. The maximum allowable concentration of this toxin is set at 20 mg/kg bivalve meat (EU Regulation No. 853/2004).

Diarrheic Shellfish poisoning

This poisoning is caused by several dinoflagellate species belonging to two genera, *Dinophysis* and *Prorocentrum*. These species can produce three groups of toxins: okadaic acid and its derivatives, pectenotoxins, and yessotoxins. All three groups tend to accumulate in the fat tissues of the bivalves. Symptoms of poisoning in humans are gastrointestinal disturbances and appear one hour after the ingestion of contaminated bivalves. Some research suggests that okadaic acid can act as a carcinogenic substance. The maximum allowable concentration of okadaic acid and pectenotoxins, together, should not exceed 160 µg/kg shellfish meat (EU Regulation No. 853/2004).

Neurotoxic Shellfish poisoning

This poisoning is caused by the dinoflagellate *Karenia brevis*. This species produces toxins that belong to brevetoxins group. In humans, symptoms of poisoning appear 3-4 hours post-ingestion. They can be gastrointestinal and neurological: nausea, vomiting, diarrhea, loss of taste, numbness of the lips and face, dilated pupils, and alternating sensations of cold and heat. The maximum allowable concentrations of these toxins should not exceed 80µg/100g shellfish meat.

Paralytic Shellfish Poisoning

This poisoning is caused by some dinoflagellate species from the genus *Alexandrium: A. minutum, A. tamarensis* and *A. catanela*, and also by some cyanobacteria genus: *Anabaena, Aphanizomenon, Nostoc, Nodularia, Oscillatoria*, and unicellular colonial *Microcystis* and *Lyngbya* (Ferreira *et al.* 2001). All these organisms produce a type of very potent alkaloid neurotoxins, saxitoxins, which accumulate in the bivalves' digestive system. After ingestion of the tainted bivalves, saxitoxins are quickly absorbed and become widespread in the human body. The first symptoms of poisoning, such as muscle numbness and paralysis, appear thirty minutes after ingestion of the bivalves. They can lead to death due to suffocation. There is currently no antidote or detoxification pathway (Faber 2012). Worldwide there are about 2,000 cases reported per year with a 15% human mortality rate (Kellmann *et al.* 2008). The maximum allowable concentrations of these toxins should not exceed 800µg/kg bivalve meat (EU Regulation No. 853/2004).

Venerupin Shellfish Poisoning

This syndrome is caused by the dinoflagellate *Prorocentrum minimum*, which produces the toxin venerupin. Events of explosive population growth (Harmful Algal Blooms, HAB) of this dinoflagellate often happen after heavy rains, which cause floods and/or increased river flow and thus release increased amounts of phosphate, nitrate and ammonia into coastal seawater. Symptoms of poisoning are nausea, vomiting, stomach pain, headache, and loss of appetite. Liver and kidney damage may also occur, but based on the available knowledge VSP, does not seem to be lethal.

Ciguatera fish poisoning (CFP)

Ciguatera fish poisoning (CFP) is acquired through consumption of tropical reef fishes contaminated with ciguatoxins (CTXs), a type of neurotoxin produced by benthic dinoflagellate *Gambierdiscus* spp. Both spatially and temporally unpredictable, a tainted fish is impossible to differentiate from an untainted one by appearance, taste, texture, or odour (Kumar-Roiné *et al.* 2010). It is not due to the mishandling of fish and is not prevented by any particular storage, preparation, or cooking methods (Mohiuddin 2019).

CFP is the most frequently reported seafood-toxin illness in the world. It produces a myriad of gastrointestinal, neurologic, and/or cardiovascular symptoms which last days to weeks or even months. Although there are reports of symptom amelioration with some interventions (e.g. IV mannitol), the appropriate treatment for CFP remains unclear (Friedman *et al.* 2008). CFP it is not considered as endemic to the West African coast and has never been reported in Senegal. However, it should be noted that the geographical distribution of ciguatera changes constantly with new locations recorded every year. Although the Caribbean area is classically considered as the only Atlantic risk zone, recent publications suggest the reality may be more complicated: fish contaminated with ciguatoxins have been found in Cameroon, and several cases of ciguatera have been observed after ingestion of local fish species (*Seriola rivoliana*) in the Canary Islands (Glaizal *et al.* 2011).

1.8 Organic chemical pollutants

This category collects several groups of substances which share a common trait despite their chemical disparity: they all are the products of industrial pollution (i.e. none of them are naturally present in the environment), and they can contaminate seafood through several pathways. The following groups of substances are assessed:

-Persistent Organic Pollutants (POPs) and polychlorinated biphenyls (PCBs)

-Organochlorinated pesticides (OCPs)

-Polybrominated diphenyl ethers (PBDEs)

Persistent organic pollutants (POPs) and polychlorinated biphenyls (PCBs)

POPs are a class of organic compounds that are produced industrially for use as insecticides and herbicides, as additives in wood and electrical products, and as plasticizers in a variety of products. Additionally, POPs may be produced as incidental by-products of incineration. They are known for their toxicity, ubiquity, long-range transportability, persistence in the environment, and bioaccumulation in the food chain. Long-term exposure to POPs, even at low doses, has been linked to cancer, reproductive disorders, immune system dysfunction, and nerve damage (Waite and Yousef 2010, Net *et al.* 2015).

According to Bodin *et al.* (2011), some POPs have been relatively well studied, whilst others have only recently gained scientific interest. Examples of the former group are organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs), with brominated flame retardants such as polybrominated diphenyl ethers (PBDEs) being examples of the latter. All these POP groups have in common two characteristics: 1) they are very stable in the environment and 2) they present a high lipophilicity, through which they can accumulate in the organisms and biomagnify through the food chain (Bodin *et al.* 2011). These authors state: "*Long-term exposure to these chemicals leads to adverse effects in wildlife and humans, including disturbance of thyroid hormone endocrinology, adverse effects on reproduction, teratogenicity, developmental toxicity, hepatotoxicity, immunotoxicity, and tumour promotion. Dietary intake, especially the consumption of marine organisms, is considered to be the main path of human exposure to these compounds.*"

As stated by Bodin *et al.* (2011), mollusks are excellent organisms to monitor the quality of water ecosystems due to their widespread occurrence in aquatic habitats, sessile biology, ease of sampling, and high bioaccumulation capacity. Thus, the authors conclude, "*The analysis of POPs in sediments and exploited mollusks allows to monitor the quality of the marine environment and to estimate the food safety risk for local people.*" Following this rationale, Aguirre-Rubi *et al.* 2017 used the mangrove cupped oyster, *Crassostrea rhizophorae*, as a biomonitor species for chemical contamination assessment in mangrove forests in Nicaragua and Colombia. The authors compared the samples for their content in different types and levels of contamination, including POPs, PCBs, heavy metals, polycyclic aromatic hydrocarbons (PAHs), and others. POPs and PCBs "*have been found at increasing levels in developing countries as a result of poor waste management practices and improper burning*" (Aguirre-Rubi *et al.* 2017). These authors found the following: Organochlorine pesticides (HCHs and DDTs) were above the environmental levels in samples of water, sediment, and mangrove cupped oysters from the Nicaraguan mangroves. Also, they found higher levels of PCBs than had been found by previous studies.

Bodin *et al.* (2011) analysed chemical pollutants in samples of five species of edible mollusks from southern Senegal. They found significantly high concentrations of PCBs accumulated in the tissues of these species. They also found a strong seasonality in the pattern of contamination, with higher levels of pollutants during the rainy season, when the wash-out of residues from inland agricultural areas pour into the estuarine areas. Nevertheless, the authors concluded that the levels of PCBs observed did not pose a health risk to the Senegalese population, because the maximum values of PCBs and DDTs found in exploited mollusks from the sampled regions were below the maximum acceptable limits for fish and seafood of 2 and 5 ppm, respectively (Bodin *et al.* 2011).

Net *et al.* (2015) studied the concentration of PCBs and other pollutants in seven marine species sampled at several locations in greater Dakar's area: one macroalgae species (*Ulva lactuca*), the mussel *Perna perna,* the shrimp *Penaeus kerathurus*, and four fish species (grey mullet *Mugil cephalus*, blackchin tilapia *Sarotherodon melanotheron*, flatfish *Solea senegalensis,* and round sardinella *Sardinella aurita*). They found the overall highest PCBs levels in the bivalve *P. perna* and the lowest in the shrimp *P. kerathurus.* The four fish species exhibited intermediate values, with sardinella showing the lowest concentration and blackchin tilapia the highest, within the fish group.

Organochlorine pesticides (OCPs)

Thompson *et al.* (2017) conducted a review aimed to assess the incidence of OCP contamination in various foods in Africa. In the authors' words: "*Organochlorine pesticides (OCPs) have been used worldwide, particularly in Africa, for several decades. Although* *many are banned, several African countries still use OCPs especially for the prevention and control of malaria. OCPs are characterized by their bio-accumulation in the environment, especially in the food chain, where they find their way into the human body.* (…) *many studies have reported positive associations between the use of OCPs and neurological and reproductive disorders, and cancer risk. There is a clear gap in published reports on OCPs in Africa and their potential health hazards*." Despite the prohibition of most OCPs under the Stockholm Convention, some (for instance DDT) are still used for disease vector control in many African countries. The problem posed by OCPs to public health is that they can enter the human body by multiple pathways: by breathing polluted air, dermal penetration, or ingestion of contaminated foods and drinking water (Thompson *et al.* 2017).

In their review Thompson *et al.* (2017) also examined data on OCPs contamination in samples of fish and shrimp from local markets in The Gambia and Senegal. The samples showed significant levels of contamination by OCPs, especially DDT. Mollusk sampling also showed significant levels of OCPs including DDT. The authors concluded that the data are evidence of a significant exposure of African population to OCPs. The data reviewed by Thompson *et al.* (2017) also revealed that multiple OCP compounds were simultaneously present in a given sample, which raises the added concern of potential synergistic effects by the multiplicity of OCPs present in the food. This is especially worrying since "*at least 50,000 tonnes of obsolete pesticides and contaminated soils have accumulated in African countries, which pose serious threats to the health of populations, especially the poorest of the poor*" (Bodin *et al.* 2011).

In their study of mollusk contamination by POPs and other chemicals in southern Senegal, Bodin *et al.* (2011) also found that the observed pattern of DDT and its metabolites pointed out to recent applications of DDT for public health emergencies in Senegal. Mollusk samples from the Petite Côte shown DDT levels three times higher than those from the Sine-Saloum estuary (Bodin *et al.* (2011). The authors concluded that it is likely that DDT and other insecticides will continue to be used in Africa, to combat malaria and other vector-transmitted diseases. Thus, *"developing countries will probably still be exposed to this chemicals for decades, posing a serious threat to human health as well as local and global environment*."

Brominated flame retardants (BFRs), Polybrominated diphenyl ethers (PBDEs)

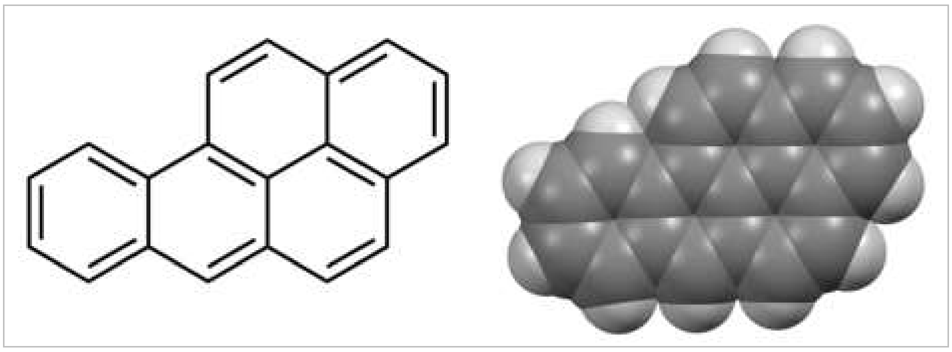
PBDEs are bioaccumulative halogenated compounds used as flame retardants in automobile, textile, and electronics industries and are considered to be emerging environmental contaminants. (Aguirre-Rubi *et al.* 2017). They are persistent and toxic and can bioaccumulate and biomagnify. PBDEs have been linked in thyroid hormone disorders, deficiency in neural responses, and carcinogenicity (Lee and Kim 2015). Because of their toxic effects and their persistence, the environmental distribution of BFRs has been a subject of concern over the past decades (Brits *et al.* 2016). The most commonly used BFRs are polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), tetrabromobisphenol-A (TBBPA), and polybrominated biphenyls (PBBs) (Brits *et al.* 2016).

Brits *et al.* (2016) found that BFR levels in breast milk samples from some African countries were higher than reported for Asia and Europe and remarked that "*due to limited data or non-detection of alternative-BFRs, it is unclear whether banned formulations were replaced in Africa*." These findings of a higher prevalence of BFRs in Africa are all the more worrying given that the global demand for PBDEs reached 200,000 tonnes in 2003 (Lee and Kim 2015). As stated by Lee and Kim (2015), "*the sheer volume of PBDEs that are emitted into the environment has created problems for marine ecosystems and public health. Marine environments are global sinks for many hydrophobic POPs* (…). *This pollution is increasing throughout the food chain*."

1.9 Post-processing seafood health safety hazards: Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs, Fig. 7) are carcinogenic and genotoxic substances that pose potential food safety and health hazard concerns (European Food Safety Authority 2008). PAHs are formed during the incomplete combustion of organic matter, and they are widely distributed in the environment via the air. Burning of garbage and plants, as well as crude oil production and transportation can result in elevated levels of polycyclic aromatic hydrocarbons (PAHs) at regional scale (Aguirre-Rubi *et al.* 2017). Humans are consequently mainly exposed by inhalation, skin contact, and ingestion. Besides being environmental contaminants, PAHs are also formed in food processing, such as drying, grilling, roasting, and smoking. For non-smokers, the diet appears to be the main source of PAH exposure (Hokkanen *et al.* 2018).

Figure 7. Benzo[a]pyrene molecule: skeletal formula (left) and space-filling model (right).



Source: Wikipedia.

The carcinogenic capacity varies between the different PAHs, despite having similar structural properties. Some, as benzo[a]pyrene (BaP), are effective carcinogens belonging to Group 1 carcinogens, according to the International Agency for Research on Cancer (Hokkanen *et al.* 2018). Additionally, PAHs have teratogenic, haematological, and immunotoxic effects, and their concentrations in food should therefore be as low as reasonably achievable (ALARA principle) (Hokkanen *et al.* 2018). Due to their toxic, carcinogenic, and mutagenic effects, sixteen PAHs have been classified as priority substances by the United States Environmental Protection Agency (Net *et al.* 2015).

PAHs are highly lipophilic compounds and are ubiquitous in coastal, estuarine and river waters, as well as sediments (Net *et al.* 2015). Aquatic organisms are prone to bioaccumulate them. However, besides bioaccumulation, there is a second pathway by which PAHs can become a seafood health hazard: throughout the processing of artisanally cured fish.

PAHs as a health hazard in artisanal smoked fish

Food smoking is one of the oldest preservation methods and is still widely used. Traditional smoking generally uses wood as fuel. Wood smoke contains a combination of antioxidant and antimicrobial chemicals (e.g., phenols, carboxylic acids, aldehydes), but also some harmful compounds, such as PAHs. Burning wood results in the production of four carcinogenic PAHs: benzo(a)pyrene, chrysene, benz(a)anthracene and benzo(b) fluoranthene, together referred to as PAH4 in the context of fish smoking (EFSA 2008). PAHs and other chemical compounds present in smoke particles migrate into the food product being smoked (Hokkanen *et al.* 2018).

According to the FAO/WHO Codex Alimentarius Commission, formation of PAHs in smoked fish is dependent on various factors, among which: the type of wood used, smoking time, the temperature reached, and the design, cleanliness, and maintenance of the equipment -with especial relevance of the combustion chamber (Beran 2018). PAHs form whenever food enters in direct contact with combustion gases, which happens when smoking fish or any other food over an open flame (Beran 2018).

In tropical countries, smoking fish helps reducing post-harvest losses and prolongs the shelf life of fish (Owusu 2019). In developed countries, the formation of PAHs during the smoking of food has been greatly reduced with the application of proper designs, adequate materials, and computerized technology. This is not the case in developing countries, where fish smoking is still performed under rudimentary conditions which cause the accumulation of dangerous PAHs levels in the final product (Beran 2018).

Hokkanen *et al.* (2018) studied PAHs formation in a range of fish and meat smoked products in Finland. These authors found that the main parameters affecting PAH levels on the smoked products were: smoking technique (direct/indirect), smoking time, smoke generation temperature, and the distance (<5m/>5m) between the food and the smoke source. Specifically, their findings were:

-Direct smoking produced higher PAH levels (BaP and PAH4) than indirect smoking. This means that the direct contact of the product with combustion gases is an important source of PAH contamination.

-The shorter smoking time generated higher PAH concentrations in fish samples, particularly observed for the PAH4 sum (This is especially relevant when fish is braised, rather than smoked (Fig. 8)).

-The most significant parameter influencing PAH concentrations was the smoke generation temperature. When it increased within the range 400-1000°C, there was a linear increase in the formation of PAHs. Smaller amounts of PAHs were formed when the temperature was lowered to 400-600°C.

-Longer distance generated lower concentrations of PAHs.

-Small fish species contained higher PAH levels than those of larger fish species.

It must be noted though, that both the smoking technique and the design of the smoking facilities assessed in this study in Finland are completely different from the techniques and several kinds of fish stoves used to smoke fish in Senegal. Hence, these findings are of somewhat limited applicability for the reduction of PAHs in smoked fish in Senegal.

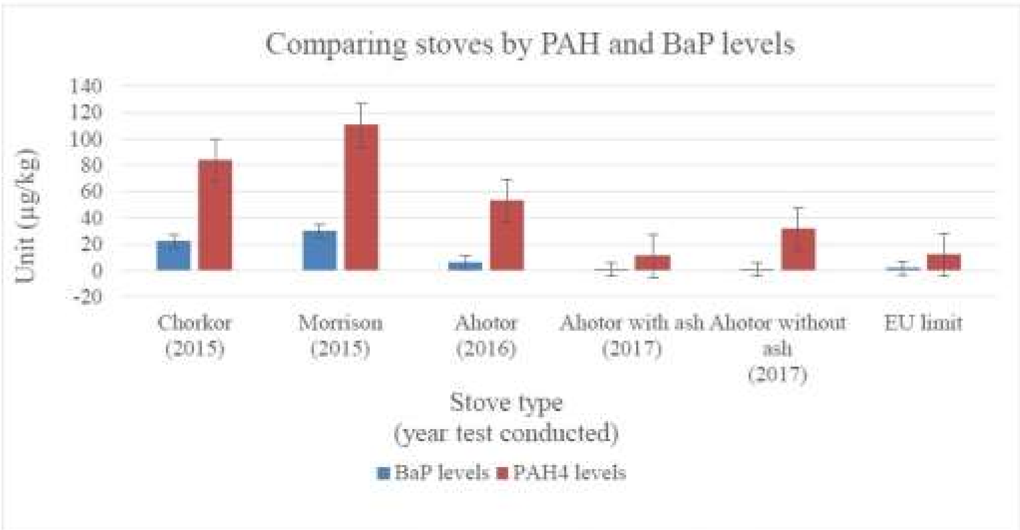
Still, Hokkanen *et al.* (2018) highlight the following recommendations from The Codex Alimentarius code of practice, which are of direct relevance to traditional fish smoking: "*attention should be paid to choosing wood with a low lignin content, filtering or cooling the smoke, replacing direct with indirect smoking when possible, optimising the smoking time, temperature, and airflow, avoiding fat dripping onto the heat source, regularly cleaning and maintaining the equipment, increasing the distance of the product from the smoking source, and washing the product with water after smoking.*"

Figure 8. Basic kilns used to braise fish in an artisanal fish processing site, Mballing, Senegal.

Source: J. Vilata.

Both Beran (2018) and Owusu (2019) compared the use of traditional stoves versus the adoption of a new improved model, the ahotor stove, in Ghana. The ahotor ("comfort") stove was developed in 2016 through a collaborative effort including public institutions such as the Ghana Standards Authority (GSA), Ghana's Council for Scientific and Industrial Research (CSIR), and the Fisheries Commission Post-Harvest Unit, with financial support from the United States Agency for International Development (USAID) Sustainable Fisheries Management Project, under the overall management of the University of Rhode Island (URI) with implementing partner SNV Netherlands Development Organisation (Beran 2018). The ahotor stove was specifically designed to reduce the formation of PAHs indicators (benzo[a]pyrene and PAH4 compounds) during the smoking process. Tests were conducted to check production of BaP and P4H4 in fish smoked in the ahotor compared to levels in fish smoked in the traditional chorkor or Morrison models (Fig. 9).

Figure 9. PAHs levels by stove types.



Source: Beran (2018).

These initial tests encompassed a very limited sample. PAH levels in the ahotor-smoked fish were lower than in the other two stove models, but only one sample was within the European Union maximum residue limit of 2.0 µg/kg for BaP (Beran 2018). More tests were later carried out by the Ghana Standards Authority (GSA) laboratory. These tests showed that PAH level in ahotor-smoked fish was 11µg/kg, while that of chorkor-smoked fish was 84µg/kg (Owusu 2019). Although they represented a vast improvement, total levels in the ahotor stove still surpassed the EU maximum threshold.

Owusu (2019) also reported other shortcomings from the ahotor oven:

-The fish processors pointed out that the ahotor oven shrinks the fish. This was a problem, because fish is priced in the market by size instead of weight.

-Prices offered for ahotor-smoked fish do not compensate for the investment in the oven (about USD$270, Beran 2018). Previously to the development of the Ahotor model, FAO had also devised yet another stove model called the FTT (Thiaroye Processing Technique). FAO's Thiaroye model successfully reduced PAH formation and also required less fuel. However, its cost is even higher than for the ahotor stove, which made it unaffordable to most stakeholders (Owusu 2019).

Owusu (2019) presented the following conclusions:

• The uptake of the ahotor oven could increase if fish processors could attract a premium price commensurate with their additional investment to cover the ahotor's costs.

• Ahotor advocates might create a tripartite relationship between (1) fish processors, (2) retailers or exporters, and (3) financial institutions, in which offtakers of smoked fish would guarantee credit to processors in exchange for fish. This would only work if fish processors are formally recognized for keeping adequate hygienic and handling practices.

Additionally, Beran (2018) investigated another aspect of the use of ahotor ovens compared to other models: the amount of fuel each model required to process a given amount of fish. With all other conditions equal, ahotor ovens represented a net saving in fuel. Hence, they would be economically profitable in the medium to long-term, despite their higher cost. Still, Beran acknowledged that the difficulty remained in convincing the fish processors that the high investment required to purchase an ahotor oven would be compensated in due time by the decrease in fuel use (Beran 2018).

ANNEX 2. INITIATIVES BY INTERNATIONAL DONORS AND AGENCIES

Context

The risk of depletion of the demersal and pelagic stocks brought pressure by international donor agencies and NGOs towards the implementation of a more efficient fisheries governance framework in Senegal. This pressure led to reforms at the legislative level during the 1990s and early 2000s - not only of the institutions responsible for fisheries management, but also of the regulations that govern them (Belhabib *et al.* 2017). Major revisions were made to the content and implementation of the Fisheries Director Plan and the Marine Fisheries Code (1998, later modified in 2015) (I. Niamadio, pers. comm). The 1998 Code defined the structure and role of the *Conseils locaux de pêche artisanal* ("Local Councils of Artisanal Fishers"; French abbreviation CLPAs), community level organizations whose main objective was to federate all the local stakeholders involved in the sustainable management of fisheries and to contribute to the implementation of fisheries regulations. The Senegalese government also called on the cooperation of Western donors to strengthen the Senegalese fisheries monitoring system in order to prevent illegal (IUU) fishing and overfishing (World Bank 2008, MPEM 2011).

By the 2000s, it was apparent that this revision of the Marine Fisheries Code and the regulations therein had not been successful. The artisanal fleet did not comply with the stipulations of the Code, and the problems already ailing the fishing sector continued to worsen (JICA 2017). It is unclear whether the authorities undertook sufficient efforts to reach out effectively to the coastal fishing communities in order to enable them to implement the changes required by the new legal framework.

JICA's initial projects

It was in this context that the first externally funded co-management project for artisanal fisheries in Senegal was initiated, with the support of the Japanese International Cooperation Agency (JICA). This project ran from 2003 to 2006 and promoted a bottom-up management approach in three pilot sites: Nianing, Pointe Sarène, and Mballing, all three within the Petite Côte region south from Dakar (JICA 2006). Several initiatives were put in place: a seasonal closure for the octopus and cymbium fisheries, the immersion of artificial reefs, and other accompanying activities such as awareness-raising and capacity building (JICA 2006).

World Bank's GIRMaC and GDRH projects

After this first experience led by JICA, from 2005 to 2012 the World Bank funded two new projects aimed to promote fisheries co-management in Senegal: the GIRMaC (*Integrated marine and coastal resources management*) and its extension, the GDRH (*Sustainable management of fish resources*) project, whose combined budget reached a total disbursed amount of about US$ 14 million (World Bank 2012).

GIRMaC's main goal was to promote the sustainable management of Senegal's coastal demersal fisheries through two complementary agendas: (i) reducing the overfishing of coastal fish stocks through the promotion of area-based co-management, under supervision of the Ministry of Maritime Economy; and (ii) the protection of critical habitats and ecosystems upon which these fisheries depend through the management of biosphere reserves under the Ministry of Environment (World Bank 2012).

The project was originally designed to apply an ecosystem approach to the management of the fisheries sector in Senegal. However, this approach proved unworkable, and the two agendas were implemented separately through a combination of activities at the local and national levels. The project extended into four co-managed pilot sites: Ngaparou in the Petite Côte, Ouakam in Dakar, and Foundiougne and Betenty in the Sine-Saloum region. The co-management system was then legally recognized through agreements between the local communities and the central government (World Bank 2012). These agreements allowed local CLPs, created by the project, to regulate designated fisheries (CLPs are a different institution than CLPAs; see text Box).

CLPs and CLPAs

CLPs (*Comité Local de Pêche*) and CLPAs (*Conseil Local de Pêche Artisanal*) are the two local organizations in charge of implementing co-management measures in Senegal. They seem confusingly similar but have different origins and structures: the creation of CLPs at pilot sites was supported by the World Bank's GIRMaC project in 2005, and their mission is to prepare management plans for the fisheries which are legally recognized by the Ministry of Fisheries (Virdin 2008, World Bank 2015). Alternatively, CLPAs were established by the government, but also with the instrumental participation of COMFISH PENCOO GEJ project (see below). The aim was for the CLPAs to become part of the framework structure for fisheries consultation at the community level; specifically, to coordinate management between different communities and CLPs, as well as to serve as a communication channel between the Ministry and the communities. Thus, the CLPs are, by their inception, private institutions, whilst CLPAs are public (Virdin 2008, World Bank 2015).

Under the World Bank's auspices a national registry for the artisanal boats or *pirogues* (the first step to control and reduce fishing effort) was also established, and an updated Sector Policy Letter (*Lettre de politique sectorielle des pêches et de l'aquaculture*) was approved to provide a more conducive environment for implementing artisanal fisheries management measures in 2008 (IndiSeas.org 2016, World Bank 2015). The targeted fisheries in all four pilot sites demonstrated some signs of recovery. Based on these pilot experiences, the government adopted co-management as an official tool for implementing fisheries regulations and has been replicating the model in other sites (World Bank 2015).

The GDRH project was designed as a complement to the fisheries management activities of the GIRMaC project (World Bank 2012). The GDRH aimed to consolidate and expand the fisheries co-management pilot experiences by replicating the model to new sites, providing additional implementation support to consolidate co-management efforts in the four initial pilot sites, and extending the impact and geographic coverage of the initiative by preparing management plans across multiple co-management sites (World Bank 2012). However, project management problems, procurement delays, and inadequate implementation timeframes hampered the implementation of both projects and in the Project Performance Assessment Report (PPAR) their outcomes were evaluated as unsatisfactory and highly unsatisfactory, respectively (World Bank 2012). Therefore, several of the uncompleted activities were transferred to the West Africa Regional Fisheries Program WARFP – PRAO, also funded by the World Bank and the GEF. WARFP-PRAO's main aim is to sustainably govern and manage fisheries in nine countries along the West African coast (World Bank 2015).

JICA's COGEPAS

JICA also continued its activities in the sector and in 2009 it funded a new five-year project, ***COGEPAS*** (*Co-Management of Artisanal Fisheries in Senegal*) with a total budget of 2 billion CFAs (about 3 million EUR). Its overall goal was to strengthen organizational capacities in the artisanal fisheries of Senegal. The objective was the extension of the co-management system to four new fishing communities: Lompoul, Cayar, Joal, and Djiffer (JICA 2020a, b). The project trained artisanal fisheries stakeholders about the importance of the sustainable fisheries management and reinforced the capacities of both the Local Artisanal Fishing Councils (CLPAs) and the Local Fisheries Committees (CLPs) (JICA 2020b).

The main stages of the project's implementation were raising awareness among stakeholders on the importance of sustainable management of fisheries resources, strengthening their capacities in this area; establishing CLPAs and CLPs, to ensure the co-management of resources at the local level; and helping CLPAs and CLPs with the development of fisheries management plans, including co-monitoring systems and implementing income-generating activities (JICA 2020b).

EU's ADUPES

The EU-funded ***ADuPeS*** ("Aménagement durable des Pêcheries du Sénégal"; *Sustainable development of Senegal's fisheries*) project ran between 2013 and 2017. Its main objective was to put in place a sustainable management system for a number of fisheries selected as priority and to improve the scientific assessment and advice on the main demersal fisheries in Senegal (ADUPES 2014, CEPPECHE 2020). Several workshops were held aiming to update the stock assessments of a number of stocks, namely octopus (*Octopus vulgaris*), deep-water shrimp (*Parapenaeus longirostris* and *Aristeus varidens*), coastal shrimp

(*Farfantepenaeus notialis*), "Thiof" or white grouper (*Epinephelus aeneus*), and a few other finfish species (*Pagellus bellottii, Sparus caeruleostictus, Galeoides decadactylus, Pseudupeneus prayensis*) (Lallemand 2017).

The expected specific results were to improve the monitoring of the status of demersal fisheries resources and also improve the regulatory system of these fisheries. The main tangible result of this project was the development of the National Management Plan for the Octopus Fishery (PAPP), approved in 2016, which strengthened several measures already in place, such as the annual seasonal closure for the octopus fisheries, and implemented a minimum landing size. It also introduced new measures to control fishing effort and aimed at the introduction of a Total Allowable Catch, TAC (and also an Individual Transferable Quota (ITQ) system in the medium term). Accompanying activities, such as the reinforcement of the capacities of the CLPAs and the implementation of participative committees for the octopus fisheries monitoring and surveillance, were also considered in the plan (CEPPECHE 2020). It is not known at the time of writing if, besides octopus, management plans for any of the remaining stocks were also put in place.

USAID's COMFISH and COMFISH Plus

COMFISH PENCOO GEJ (Collaborative Management for a Sustainable Fisheries Future in Senegal) was a five-year (2011-16) project funded by USAID to support the collaborative and sustainable management of fisheries in Senegal. It was implemented by the Coastal Resources Centre (CRC) at the University of Rhode Island's Graduate School of Oceanography (URI) in partnership with national and local actors in Senegal (URI 2018). "*The project's long-term goal, in 20 to 30 years, is to ensure that Senegal's fisheries are no longer overexploited and provide (1) a durable source of high quality protein supply to the nation; (2) in ways that contribute to improve the quality of life in artisanal fishing communities; and (3) maintain the capacity of coastal and marine ecosystems to produce goods and services that the Senegalese people want*" (URI 2014).

COMFISH Plus was a two-year follow-on project. In the words of the implementing institution, URI: "*The two year, $4.5 million USAID/COMFISH Plus project (FY 2017-2018) supported fisheries sector stakeholders to scale up and institutionalize new and transformative approaches for ecosystem-based fisheries co-management successfully demonstrated under the previous five-year USAID/COMFISH project (FY 2011-2016). The project assisted the Government of Senegal in its efforts to achieve reform in the fisheries sector as stated in the Sector Policy Letter for the Development of Fisheries and Aquaculture (2016-2023). USAID/COMFISH Plus was implemented by the University of Rhode Island in partnership with the Ministry of Fisheries and Maritime Economy (MPEM) and other government agencies, fisheries associations, university centers, research institutions, and non-governmental organizations working on marine capture fisheries in Senegal*" (URI 2018).

According to URI's Coastal Research Centre (CRC) website, "*URI/COMFISH worked with local fisheries actors and relevant fisheries departments to promote the development of participatory fishery management plans for sardinella and bonga (a shad species). This is a crucial objective because sardinella and bonga account for over 80 percent of fish landings by artisanal fishers in Senegal, and is one of the main sources of animal protein in Senegal – over 70 percent (CRC 2020). These management plans are a boost to long-term food security in the country and serve the goals of safeguarding livelihoods for communities working in all aspects of sardinella fisheries (including small-scale fish processing), and optimizing revenues produced by fisheries resources while helping keep fisheries stocks in good health*" (CRC 2020).

As regards COMFISH Plus, "*Seven new Local Artisanal Fisheries Councils (CLPAs) were installed in the Sine Saloum with Local Agreements (CLs) approved by the Government of Senegal for local management of fisheries resources. A participatory ethmalosa Fisheries Management Plan (FMP) covering Sine Saloum was also finalized, approved by the Government, and implementation initiated. Project supported research resulted in a consensus among resource users and decision-makers to increase minimum mesh size for this fishery. This science-informed management decision will also be applied to the Ziguinchor Region plan which is ready for approval and will likely be adopted in the national plan. As a result of expansion to the Sine Saloum, 8,886 additional fishers were added to 20,952 in previously targeted zones for a total of 29,838 who applied improved technologies or management practices with USG assistance. Another 3,025 households were added to 16,533 benefitting directly from project interventions in previous zones for a total of 19,558 households"* (URI 2018).

FAO's Coastal Fisheries Initiative (CFI)

The CFI is funded by the Global Environment Facility (GEF). According to its webpage, its stated goal is to rally "*UN agencies and international conservation organizations behind the common goal of promoting the sustainable use and management of coastal fisheries, championing innovative approaches to improve governance and strengthening the seafood value chain*". The webpage further states that the initiative focuses on:

"*-Policy: Incorporating environmental, social and economic sustainability into policies, as well as legal and regulatory frameworks.*

-People: Improving the capacity and capability of fishing nations, regional management bodies and local communities in sustainable fisheries management.

-Partnerships: Promoting public-private partnerships for responsible investment in the seafood value chain.

CFI provides hands-on support to coastal fisheries in six countries across three geographies: Indonesia, Latin America (Ecuador and Peru) and West Africa (Cape Verde, Côte d'Ivoire and Senegal)". (CFI 2020)

Specifically for Senegal, the CFI website provides the following information: "*Over 5 years, the Coastal Fisheries Initiative (CFI) team will work with stakeholders in Senegal to make coastal fisheries more sustainable while protecting the environment and delivering economic and social benefits for the Senegalese. FAO and partners will carry out a number of activities, including:*

-Improving fisheries governance and management

-Restoring mangrove forests for better fisheries

-Capacity building and best practices in coastal fisheries."

However, at the time of writing this report, no evidence was found that any activity had been yet carried out in Senegal under the CFI's framework.

Other finished initiatives

The above-mentioned projects are those more frequently quoted in the literature, including grey sources such as news sites, journal reports, mid-term and final evaluation reports, etc. But there have been more projects related to fisheries management in Senegal and/or West Africa. The website of the Directorate for Marine Fisheries (DPM, *Direction de la Pêche Maritime*) lists the following finished projects:

1. **ODINAFRICA** : «Réseau d'Echange de Données et d'Informations Océanographiques pour l'Afrique» (The Ocean Data and Information Network for Africa)
2. **PRAO/SENEGAL** : « Projet Régional des Pêches en Afrique de l'Ouest » (*Regional Partnership for Conservation of the coastal and marine zone in West Africa*)
3. **GoWAMER** : « *Gouvernance, politique de gestion des ressources marines et réduction de la pauvreté dans l'éco-région WAMER* »
4. **ACP FISH II**
5. **CCLME** : « Projet Protection du Grand Eco-marin du Courant des Canaries » (*Canary Current Large Marine Ecosystem Protection Project*)
6. **PROJET PETITS PELAGIQUES** : « Vers des politiques régionales pour une pêche durable des petits pélagiques en Afrique du Nord-Est » (*Towards regional policies for sustainable fishing of small pelagics in North East Africa*)
7. **MESA**: « Projet Surveillance de l'Environnement et la Sécurité en Afrique » (*Monitoring for Environment and Security in Africa*)
8. **PROCOVAL**: « Promotion de la Cogestion des pêcheries par le développement de la Chaîne de Valeur » (*Promotion of fisheries co-management through Value Chain development*)
9. **AFTER** (African Food Tradition rEvisited by Research)
10. **ADuPeS** : Aménagement durable des Pêcheries du Sénégal

ODINAFRICA

The Ocean Data and Information Network for Africa (ODINAFRICA) is a Pan-African project aiming to coordinate the oceanographical and marine science research of about 40 institutions belonging to 25 African countries. It was supported and funded by UNESCO. According to its website: "[ODINAFRICA] *has been one of the most successful projects of the International Oceanographic Data and Information Exchange programme (IODE) of the Intergovernmental Oceanographic Commission of UNESCO (IOC). The Ocean Data and Information Network for Africa (ODINAFRICA) brings together more than 40 marine related institutions from twenty-five countries in Africa (below) to address the challenges faced in accessing data and information for coastal management*" (ODINAFRICA 2020).

PRAO-SENEGAL (WARFP-PRAO)

PRAO (French acronym for «*Partenariat Régional pour la Conservation de la zone côtière et Marine en Afrique de l'Ouest*»; *Regional Partnership for Conservation of the coastal and marine zone in West Africa*) is a World Bank-funded, regional program encompassing nine coastal countries in West Africa. The DPM website provides the following information about PRAO: "*The Government* *of Senegal has received funding (6,750,000,000 CFA francs) from the International Development Agency (World Bank) to ensure its participation in the Regional Fisheries Project in West Africa (PRAO), which is a Sub-Regional Program, implemented in 9 coastal countries which are Senegal, Mauritania, Cape Verde, Guinea, Guinea-Bissau, The Gambia, Sierra Leone, Liberia and Ghana. PRAO-Senegal is an investment by the Government to support the implementation of the Letter of Sectoral Policy for Fisheries and Aquaculture. The expected results of PRAO-Senegal are expected to contribute to achieving the first specific objective of the Sector Policy Letter, namely the sustainable management and restoration of fishery resources and their habitats. In other words, the mission of PRAO-Senegal is to strengthen Senegal's capacities in the areas of adequate fisheries governance, the fight against illegal fishing (IUU fishing) and increasing the added value of fishery products*." It was not possible to find which specific initiatives had been carried in Senegal's fishing sector under this program's funding.

GoWAMER

GoWAMER is a project developed by UNDP and co-financed by the EU. According to its website: «*The program "Governance, marine resource management policies and poverty reduction in the Ecoregion WAMER - West Africa Marine Ecoregion (Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea and Cape Verde)", started in 2012, is co-financed by the European Union for more than 6 billion FCFA, and by the United Nations Development Program, up to 350 million FCFA, for a total budget of almost 7 billion FCFA* [approx. 11.8 Million USD]». The website states further that "*After 5 years of activities, the project has recorded considerable results and has led to many advances in the governance and policies of marine resources* (…), *for instance the adoption of a sub-regional management plan for Bonga shad* [*Ethmalosa fimbriata*, a small pelagic species], *always in partnership with the CSRP (…), and the development of aquaculture projects in Senegal*" (UNDP 2020).

At the time of writing this report (2020) it is unclear whether the Bonga shad fishery is managed under the mentioned sub-regional plan. No evidence that such management plan is on its way to implementation was found at the website of CECAF (the Fishery Committee for the Eastern Central Atlantic), the RFMO in charge of coordinating the management of fish resources in West Africa (CECAF 2020).

ACP FISH II

According to their website: "*The ACP FISH II Programme is a 4.5-year programme financed by the European Development Fund on behalf of ACP (African, Caribbean and Pacific Group of states) countries. The aim of the programme is to improve fisheries management in ACP countries so as to ensure that fisheries resources under the jurisdiction of these countries are exploited in a sustainable manner*" (ACP FISH II 2020). It has not been possible to find more specific information about activities linked to ACP FISH II in Senegal.

CCLME - The Canary Current Large Marine Ecosystem project

Information from the project's website (CCLME 2020) states that "*The Canary Current Large Marine Ecosystem (CCLME) project is unique in its strategic combination of fisheries and ecosystem governance frameworks and will, through governance reforms, investments and management programs, enable the participating countries to address priority transboundary concerns on declining fisheries, associated biodiversity and water quality*." It continues, "*The current phase of the CCLME project will be operational for five years (2010-2015) in the seven participating countries Cape Verde, Guinea, Guinea Bissau, Mauritania, Morocco, Senegal and The Gambia*." However, it seems that the project is now terminated (judging from the lack of updated news since 2016). More detailed information is available at the project's website.

Project Petits Pelagiques

According to the website (SPCSRP 2020): "*The overall objective of the Project is: Promote policies and management plans that allow sustainable use of small pelagic fish stocks in the upwelling region of north-west Africa. The specific objectives are:*

-Facilitate the process of harmonization and coordination of management measures at the level of the four States by setting up an advisory committee at the regional level.

-Improve the contribution of professionals to the development of fisheries policies by strengthening their capacities" (SPCSRP 2020).

MESA - The Monitoring for Environment and Security in Africa

The CSC (Climate Services Centre) website offers the following description: "*The Monitoring of the Environment for Security in Africa (MESA) was a follow-up initiative to the African Monitoring of the Environment for Sustainable Development (AMESD) programme. It contributed to the Joint Africa-EU Strategy (JAES) 6th Partnership on Climate Change and Environment and on the AMESD programme achievements. The initiative was focused on using Earth Observation (EO) data and information products for environment and sustainable development, specifically designed for African*" (CSC 2020). It included seven thematic actions, one of which encompasses the ECOWAS region (where Senegal is included) and was termed "Marine and coastal management."

PROCOVAL (Promotion of fisheries co-management through Value Chain development)

PROCOVAL was a JICA-funded project focused in the region of Mbour, in Senegal's Petite Côte. Its stated specific objectives were:

-Improved conservation of products on board;

-Development of fishing docks to sanitary and technical standards;

-Support for market diversification;

-Promotion of co-management of the species targeted by the project.

These stated objectives have been taken from SAKSS website (SAKSS 2020). JICA's final report on PROCOVAL (JICA 2017) confirms those objectives. At the time of writing, there were a few media reporting the announcement of two new landing sites to be built in Ngaparou and Pointe Sarène with PROCOVAL's funding. Due to the interruption of the COVID-19 pandemic it was not possible to confirm whether the said infrastructures were finally built.

AFTER (African Food Tradition rEvisited by Research)[2]

Funded by the EU and launched in 2010 for 4 years, AFTER helped improve several traditional African products (from a nutritional and health safety point of view) to benefit consumers and processors in Africa and Europe. One of such products was smoked catfish (*Arius heudelotii*, "Kong"), produced in Senegal. The project was coordinated by CIRAD (International Centre for Agricultural Research). It mobilized partners from seven African countries: Benin, Cameroon, Ghana, Egypt, Madagascar, Senegal, and South Africa, and four European countries: France, Italy, Portugal, and the United Kingdom.

The project developed a technical guide for smoked fish producers, with the purpose of helping processors to optimize their manufacturing processes. Based on the research results obtained, the guide showed the processing steps necessary for the manufacture of smoked catfish under improved food safety conditions:

- Ensuring the microbiological quality of the product throughout the process.
- Limiting Polycyclic Aromatic Hydrocarbons (PAHs) content in accordance with EU's requirements.
- Optimization of storage conditions of the finished product.

[2] Information provided by B. Sene (pers. comm.) and AFTER (2020).

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Smoked or braised and salted fish, left to dry exposed at the sun and wind, Cayar traditional processing site. Source: J. Vilata.