



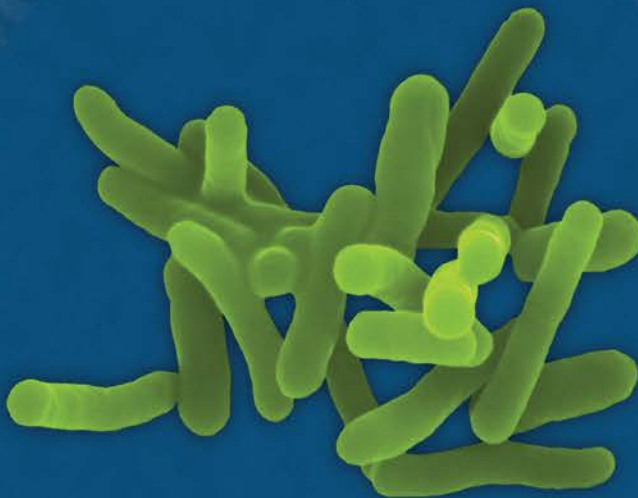
Food and Agriculture  
Organization of the  
United Nations



World Health  
Organization

# Safety and quality of water used in the production and processing of fish and fishery products

Meeting report



41

MICROBIOLOGICAL RISK  
ASSESSMENT SERIES



# Safety and quality of water used in the production and processing of fish and fishery products

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Meeting report

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# Preface

In November 2016, the Codex Committee on Food Hygiene (CCFH) noted the importance of water quality in food production and processing and requested that the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) provide guidance on the use of “clean water” as mentioned in Codex texts. Specifically, CCFH requested guidance on the safety and quality of seawater, and water reused for irrigation and food processing. In addition, the Committee sought guidance on the appropriateness of using clean water for these purposes (FAO and WHO, 2019). To facilitate this work, FAO and WHO established groups of Experts and convened a series of meetings.

The first meeting, held in Bilthoven, the Netherlands from 21 to 23 June 2017, discussed the scope of the work. The second meeting, held in Rome, Italy from 14 to 18 May 2018, considered the recommendations of the first meeting concerning fresh produce, fishery, and water reuse (FAO and WHO, 2019). A third expert meeting, held in Geneva, Switzerland from 23 to 27 September 2019, further explored the safety and quality of water used in the production of fresh fruits and vegetables. This meeting discussed the feasibility of applying microbiological criteria for water used in fresh produce to support decision making when applying the concept of “fit-for-purpose” water. Practical interventions that could be applied pre- and post-harvest to mitigate food safety risks when water does not meet the requirements of fit-for-purpose were also discussed.

In 2020, the 43rd Session of the Codex Alimentarius Commission (CAC) approved the Development of Guidelines for the Safe Use and Reuse of Water in Food Production (Guidelines for Water) proposed in the 51st Session of the CCFH. This work was to elaborate guidelines for the safe sourcing, use and reuse of water in direct and indirect contact with food throughout the food chain (from primary production to processing) by applying a risk-based approach and the concept of fit-for-purpose water. The proposed new Codex Guidelines for Water would follow the general principles and guidance of the overarching Codex General Principles of Food Hygiene, Code of Hygienic Practice for Fresh Fruits and Vegetables, Code of Practice for Fish and Fishery Products, and Code of Hygienic Practice for Milk and Milk Products.

To support this work, the CCFH requested that the Joint FAO/WHO Expert Meeting on Microbiological Risk Assessment (JEMRA) provide scientific advice on sector-specific applications and case studies for determining microbiological criteria for water sourcing, use and reuse in:

- fresh produce;
- fish and fishery products from primary production to retail; and
- the dairy sector from milk harvest to manufacturing.

This report presents the conclusions and recommendations of the 4th Expert meeting held online from 14 June to 2 July 2021 and the three additional sessions on 29 July, 30 August, and 14 October 2021.

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The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) would like to express their appreciation to all those who contributed to the preparation of this report through the provision of their time and expertise, data and other relevant information before, during and after the meeting. Special appreciation is extended to all the members of the expert committee for their dedication to this project and to Dr Rob de Jonge for his expert chairing of the committee and to Dr Carlos Campos for his excellent support as a rapporteur. All contributors are listed on the following page.

The preparatory work and the expert meeting convened for the development of this report was coordinated by the Secretariat of the Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA).

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# Declaration of interests

All participants completed a Declaration of Interests form in advance of the meeting. The reported interests were not considered by FAO and WHO to present any conflict in light of the objectives of the meeting.

All the declarations, together with any updates, were made known and available to all the participants at the beginning of the meeting. All the experts participated in their individual capacities and not as representatives of their countries, governments or organizations.

# Abbreviations and acronyms

ATP	adenosine triphosphate
BOD <sub>5</sub>	five-day biochemical oxygen demand
CCFH	Codex Committee on Food Hygiene
CCPs	critical control points
CFU	colony forming unit
COD	chemical oxygen demand
DAPs	defect action points
ddPCR	digital droplet PCR
DNA	deoxyribonucleic acid
ELISA	enzyme-linked immunosorbent assays
FAO	Food and Agriculture Organization of the United Nations
FIB	faecal indicator bacteria
HACCP	hazard analysis and critical control points
HPC	heterotrophic plate count
HUS	haemolytic uremic syndrome
ISO	International Organization for Standardization
JEMRA	Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment
mAbs	monoclonal antibodies
MPN	most probable number
MT	million tonnes
mS	millisiemens
NASBA	nucleic acid sequenced-base amplification
NGS	next-generation sequencing
NoV	norovirus
PAA	peracetic acid
PCR	polymerase chain reaction
QMRA	quantitative microbial risk assessment
qPCR	quantitative polymerase chain reaction
RNA	ribonucleic acid
RO	reverse osmosis
RT-PCR	reverse-transcription PCR
TN	total nitrogen
TP	total phosphorus



TSS	total suspended solids
UASB	upflow anaerobic sludge blanket
UNICEF	United Nations Children's Fund
WGS	whole genome sequencing
WHO	World Health Organization
WSP	water safety plan

# Executive summary

## **BACKGROUND AND OBJECTIVES**

In 2020, the 43rd Session of the Codex Alimentarius Commission approved the “Development of Guidelines for the Safe Use and Reuse of Water in Food Production” proposed at the 51st Session of the Codex Committee on Food Hygiene (FAO and WHO, 2020a). To support this work, JEMRA was asked to provide scientific advice on sector-specific applications and case studies for determining appropriate and fit-for-purpose microbiological criteria for water sourcing, use and reuse in:

- fresh produce;
- fish and fishery products from primary production to retail; and
- the dairy sector from milk harvest to manufacturing.

The purpose of this meeting was to develop clear and practical guidance on the criteria and parameters that can be used to determine if water is fit-for-purpose for sourcing, use and reuse by applying risk-based approaches in the fisheries and aquaculture sector. The scope includes the harvesting and production of fish and fishery products across the food chain, from primary production to processing, including fishing vessels, freshwater production sites and processing facilities.

## **SITUATION ANALYSIS CONCERNING WATER USE AND REUSE IN THE PRODUCTION AND PROCESSING OF FISH AND FISHERY PRODUCTS**

Water is a key element in the production and processing of fishery products. Water can be sourced from the sea, estuaries, deltas and lagoons, or, in the case of land-based fish farming systems, from springs, wells, rivers, lakes, surface runoff, groundwater or municipal sources. These waters are subject to many detrimental effects from climate change, pollution associated with population growth and development, and increasing demands for food production and other uses. In the fish and shellfish production and processing industry, water is used:

- for rearing or harvest;
- as an ingredient;
- to transport/convey products;
- to wash, cool down and cook food;
- to clean and sanitize facilities, utensils, containers and equipment; and
- to make ice and glazed products.

There is a need to implement more sustainable practices for the management and efficient use/reuse of water resources in the fish production process, as well as a need to preserve and protect aquatic ecosystems.

Any source of water can be used in primary production of fish and other aquatic organisms, provided that the risks are previously assessed, water quality is monitored, and the water complies with quality criteria defined by a risk assessment.

The experts agreed that there are multiple opportunities for reusing water in the fish and fishery sector, especially in processing activities, many of which have not yet been materialized by the industry. While there are commercially available water treatment technologies to achieve the desired safety and quality attributes for specific applications, economic and environmental impact assessments are needed to facilitate decision-making by fish processors. The application for which water is intended to be reused determines whether that water is fit-for-purpose and/or a specific treatment is required before it can be used.

Fish and fishery products are generally regarded as safe, healthy, and nutritious foods. However, these products have been associated with infections and intoxications mediated by viruses (principally norovirus and Hepatitis A), bacteria (principally *Vibrio* spp. and *Salmonella* spp.), protozoans (principally *Giardia* sp. and *Cryptosporidium* sp.), and helminths (principally *Anisakis* spp.). In addition, intoxication by histamine associated with scombroid fish has frequently been reported. The causes of such seafood safety concerns are diverse, ranging from indigenously present microorganisms and parasites to contamination of primary production environments or poor hygiene practices during processing and consumption.

The global burden of illnesses associated with fish and fishery products is uncertain although it is thought to be substantial. It is evident from epidemiological data that water (including direct contact, indirect contact, and unintended contact) is a very important vehicle for attribution purposes, often acting as a vector to transmit pathogens among food items, thus increasing the number of people exposed to the pathogens. Depending on the pathogen, they can remain infectious in sources of water for a considerable period of time and affect the suitability of a site to produce or harvest fishery products. Populations, communities, fish producers and processors served by inadequate levels of water treatment are potentially more vulnerable to the microbiological hazards relevant to seafood products.

To mitigate these health risks, the use of water in the production and processing of fishery products should be subject to a risk-based approach covering the whole water system from the source or catchment area to storage, distribution and up to the point of use (from “source to tap”). In this context, sanitary surveys/profiling

and a hazard analysis and critical control point (HACCP)-based approach such as water safety plans (WSPs) are important to determine water fitness and the likelihood of contamination in the production and processing systems. To prevent contamination, good hygiene practices should be applied to all steps of the chain, from harvesting, processing, storage and distribution. The requirements for hygienic practices constitute the prerequisite programmes that are essential for any food operation prior to the implementation of HACCP systems.

It was noted that, in many parts of the world, existing regulations limit the use of fit-for-purpose water and may not reflect current technological capabilities of water treatment. Additionally, many regulations do not sufficiently consider the widespread use of brackish water and seawater in the fisheries and aquaculture sector. Development of new regulations and/or improvement of existing ones on quality and safety criteria for water sources, as well as minimum requirements for use in fish production and processing would assist the definition of fit-for-purpose water from different water sources and reuse applications.

## **ANALYSIS OF CASE STUDIES FOR DIFFERENT RISK-BASED WATER USE AND REUSE PROCESSING SCENARIOS AND SPECIES**

The experts were asked to appraise international case studies representing a range of risk-based water use and reuse scenarios and fish and shellfish species. From the selected case studies, the experts noted the following:

- In aquaculture, selecting a source of continuous high-quality water is critical to any successful farm operation as the source determines the quality of production water. Fish require large quantities of unpolluted water to grow rapidly and maintain their wellbeing.
- While integrated aquaculture-treated wastewater systems are becoming more common in geographies with limited access to public and municipal sources or private wells, presently there is insufficient evidence to consider the use of treated municipal wastewater as a suitable source of safe water for fish farming.
- To preserve the sanitary quality of fish and fishery products on board vessels and in processing factories, precautionary measures must be applied to control any cross-contamination and temperature abuse occurring from capture to market.
- The canning industry uses large volumes of water in multiple processing steps (e.g. cleaning, washing, cooling, thawing, ice production and removal). Each of these steps should comply with internationally recommended standards to control physical, chemical and biological hazards that could affect the safety and quality of the products.

## WATER QUALITY MONITORING AND THE USE OF NON-CULTURE BASED MICROBIOLOGICAL METHODS

Water monitoring is a core element of food safety management systems and is required to ensure water quality and safety and to define fit-for-purpose water in the seafood sector (FAO and WHO, 2020b). Worldwide, most seafood industries monitor the quality of the water used in production and processing of fish and understand the concept of water fitness, but monitoring practices are not always incorporated into a safety management system. Ideally, such safety management systems should be risk-based and consider historical data and expertise of the safety manager. While much good practice guidance on monitoring has been elaborated for primary production environments, there is no agreed definition of what constitutes an appropriate monitoring programme for direct and indirect contact waters in the fish processing environments.

Indicator species (e.g. *E. coli*) have been used in monitoring programmes to indicate the presence of pathogens for assessing the microbiological fitness of water used in fish production and processing. The use of indicator microorganisms (process indicators, faecal indicators, index organisms) has been successful in assessing the fitness of water for its intended use(s) and in reducing human exposure to microbiological hazards. However, irrespective of the fish production and processing step, today we recognize that on a sample-by-sample basis, there is rarely a direct correlation between coliform bacteria and indigenous marine pathogenic bacteria such as vibrios, enteric protozoans or viruses.

Physical or chemical parameters provide more timely results on which to base ongoing monitoring than microbiological indicator species provide and can indicate the need to take corrective action. Given that the microflora relevant for the reuse of water is operation-specific, it is generally not appropriate to rely solely on testing of microbiological parameters when these are not relevant in the context of a particular fish processing operation. It is more appropriate to conduct an operation-specific assessment to determine which indicator(s) could be used to control the reconditioning treatment for water reuse or the need to take corrective action. Since water disinfection, in particular chlorination, is commonly used to ensure water safety in fish processing plants, frequent monitoring of this stage, or on-line measurement of the disinfectant residual, is recommended.

The experts also noted that despite significant developments in non-culture-based microbiological methods (polymerase chain reaction, whole genome sequencing, microbiome analysis) for detection and quantification of pathogens in water, there is currently insufficient information on method performance, harmonization and standardization to enable their use in regulatory monitoring.

## RECOMMENDATIONS CONCERNING THE SAFETY AND QUALITY OF WATER USED IN FISH PRODUCTION AND PROCESSING

Water use and reuse needs to be tailored to the particular conditions of the specific fish production or processing operation it is applied to, considering the operation's potential reusable water sources, the various applications of the reused water, available recovery and treatment technologies, and the capabilities of the operator. Frequently, relevant information on source water quality can be obtained from water suppliers. For each possible water reuse scenario considered for implementation, it is recommended that operators consider the following in assessing and managing microorganisms in water use and reuse:

- Ensure the safety of water used in the production and processing of fishery products using a risk-based approach covering the whole water system from the source to the point of use. Additionally, characterization of surface or groundwater quality in abstraction points should be extended upstream, to include the whole water catchment area.
- Coastal sources, used for abstraction of seawater in land-based establishments, cannot be guaranteed to be free from pathogens from the marine biota or from faecal contamination, and cannot be classified as fit-for-purpose sources. Seawater from offshore sources are generally considered safe. However, depending on the geographical region and temperature, seawater can hold indigenous potentially pathogenic bacteria, such as *Vibrio* spp., that may require control.
- Elaborate and put in place risk assessment and management procedures and implement efficient monitoring plans according to recognized guidelines or standards. The risk management is validated by both compliance with official control limits and standards in water or finished products and additional self-controls of production and processing steps.
- In the risk assessment, consider the specific waterborne hazards (e.g. marine microbiological contaminants) that may impact the safety and quality of the fishery product(s). Where necessary, develop and apply a risk-based approach such as a water safety plan (WSP).
- Where disinfection forms part of the water treatment, validate the efficacy of the disinfection step. The same applies to any other water treatment that may be applied to the water used in the industry.
- Hazards and hazardous events at the level of the catchment area were found to determine water fitness for different sources of surface and groundwater. Operators should assess all possible contamination risks from the immediate area of the catchment and seasonal and climatic factors affecting source water

quality through regular testing and development of farm-specific profiling and precautionary measures. Take every precaution to protect the source water from any contamination. In some regions, this can be particularly relevant during the rainy season.

- Implement operational monitoring of the water used in the production and processing of fishery products to provide insight into process performance and associated water quality issues, enabling rapid remedial action in the event of nonconformity.
- Control the microbiological stability of finished products to confirm that food safety criteria are respected before marketing.
- Implement good hygiene practices throughout primary production and processing. Provide training on good hygiene practices to all staff and eliminate the potential for littering and faecal contamination (e.g. in areas without sewerage systems or where open defecation is observed).
- Regulatory agencies and other relevant organizations should provide examples and training on how to use food safety plans and risk assessments to define water quality targets for fit-for-purpose water.
- Regulators, processors and consumers have a negative perception about the use of fit-for-purpose water. Strategies to overcome misconceptions should be considered.
- Some countries lack water management policies to protect and effectively use water sources. As safe water recycling and recuperation are currently improbable due to technical and financial barriers, ensuring the protection and sustainability of these sources should be of utmost importance. In remote areas, provision of water wells and toilets for the local population will further reduce the risk of human exposure to pathogens and help regulate access and use of water sources.
- Ensure that there is an adequate supply of drinking (potable) water and facilities for its storage and distribution to ensure the safety and quality of food.

## **CRITICAL RESEARCH GAPS AND POLICY DEVELOPMENTS**

- Limited information was found on artisanal production and processing practices. This is true for quantities of fish, applied technologies and quantities of water used. Scarce information was also found on the volumes of water used in industrial fish processing. This limits the ability to assess the effects and opportunities of water reuse.
- Detailed characterization (microbiological and chemical) of individual outlet water from different unit operations is limited in peer-reviewed literature.

Yet, such information is critical to design effective water conservation strategies, assess the need for treatment and its extent, and conduct risk assessments for hazard control and robust WSP.

- There is a lack of information on how to design operational water monitoring plans. These should be site specific and must consider the relevant hazards and hazardous events and the outcomes of a risk assessment of the water system.
- There is a need for clear and simple standard operating procedures for water monitoring in vessels, for primary production and for processing facilities of fish and fishery products.
- Improved and/or new regulations on quality and safety criteria for water sources are needed, including minimum requirements for use in production and processing of fish products. International regulatory bodies should aim to harmonize guidelines on the use of brackish and seawater during transport and processing, and revise guidelines for the safe use of water in the fish and fishery sector. This was also identified in the previous meeting (FAO and WHO, 2019).
- There is a need to obtain more data on seawater quality and to harmonize the types and quality of water used in the different steps of fish production and processing, particularly on board vessels.
- Research should be carried out to define suitable criteria for characterizing water quality and the safety of waters used in the production and processing of fishery products.
- There is also a need to improve analytical methodologies and establish quality criteria for verifying the quality of seawater when used for production and processing of fishery products.
- Further research is needed to determine the pathogen reduction efficiencies in water treatments, the relationships between water quality parameters tested in fish production environments, and the pathogen infectivity and health effects on fish producers, processors and consumers.
- There is a lack of information on the impacts of public (municipal) wastewater reuse in the primary production of fishery products, namely in aquaculture.
- There is a lack of information on hazards and hazardous events in the catchment area of different water sources (namely in surface and groundwater).





# Introduction

Fisheries and aquaculture are crucial to global food security and nutrition and offer development pathways to contribute to a more prosperous, peaceful and equitable world. Today, the importance of utilizing fisheries and aquaculture resources responsibly is widely recognized and prioritized worldwide. The *Code of Conduct for Responsible Fisheries*, unanimously adopted by Food and Agriculture Organization of the United Nations (FAO) Members in 1995, is a foundational document that sets out principles and standards for the use of fisheries and aquaculture resources to ensure sustainable use of aquatic living resources in harmony with the environment (FAO, 1995).

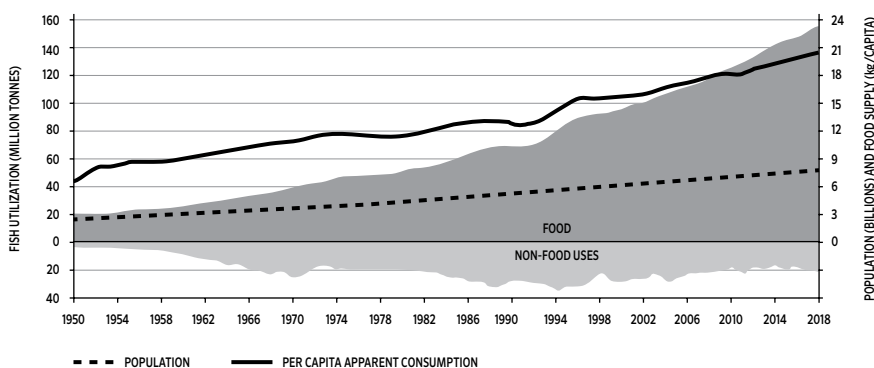
Water is a key element in the production and processing of fish and fishery products. It is used in fish harvesting and production operations. Water can be sourced from the sea, estuaries, deltas and lagoons, or, in the case of most land-based farming systems, from springs, wells, rivers, lakes, surface runoff, groundwater, or public municipal sources. All these water resources are subject to many detrimental effects, from population growth and development to increasing demands for food security, as well as pollution and climate change.

While natural seawater environments provide ample opportunity to harvest and produce large volumes of fish, coastal and freshwater environments are subject to greater variations in physical, chemical and microbiological properties which limit the type and scale of operation and the species that can be harvested or produced. The need to implement more sustainable practices for the management and efficient use/reuse of water resources in the fish production process, as well as the need to preserve and protect aquatic ecosystems, have increased public awareness and concern over the past decades.

## 1.1 CONSUMPTION AND PRODUCTION

Global consumption of fish has increased consistently over the past 60 years. Per capita apparent utilization of fish for food purposes increased from 9 kg in 1961 to 20 kg in 2017 (as live weight equivalent). In 2018, the estimated per capita consumption of fish was approximately 21 kg (Figure 1).

**FIGURE 1** World utilization and apparent consumption of fish, 1950–2018



Note: Excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants.

Source: FAO. 2020. *The State of World Fisheries and Aquaculture 2020*. Sustainability in action. Rome. <https://doi.org/10.4060/ca9229en>

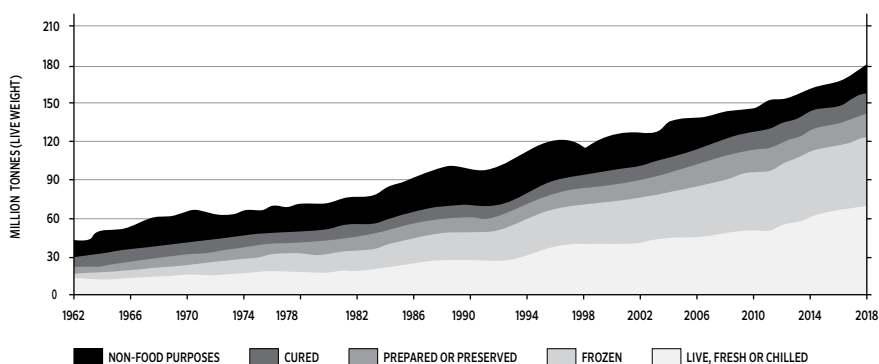
This growth in fish consumption has been driven by an increase in production and many other factors, including technological developments in processing, cold chain, shipping and distribution, and rising incomes. These in turn correlate strongly with increased demand for fish and fishery products, reductions in loss and waste, and greater awareness of the health benefits of these products among consumers (FAO, 2020).

## 1.2 FISH UTILIZATION AND PROCESSING

In 2018, live, fresh or chilled fish together represented the largest share of fish utilized for direct human consumption (44 percent) and were often the most preferred and highly priced forms of fish. These forms were followed by frozen fish (35 percent), prepared and preserved fish (11 percent) and cured fish (10 percent). Freezing is the main method for preserving fish for food, accounting for 62 percent of all processed fish for human consumption (Figure 2). However, these percentages mask major differences. Fish utilization and processing methods differ significantly across continents, regions, countries and even within countries.

The share of fish utilized for reduction into fishmeal and fish oil is highest in Latin America, followed by Asia and Europe. In Africa, the proportion of cured fish is higher than the world average. About two-thirds of the fish production used for human consumption is used in frozen and prepared and preserved forms in Europe and North America. In Asia, a large volume of fish produced is sold live or fresh to consumers.

**FIGURE 2** Utilization of products from fisheries and aquaculture, 1962–2018



Source: FAO. 2020. *The State of World Fisheries and Aquaculture 2020*. Sustainability in action. Rome. <https://doi.org/10.4060/ca9229en>

### 1.3 SAFETY OF FISH AND FISHERY PRODUCTS

In 2015, the World Health Organization (WHO) published statistics on the global incidence of foodborne diseases (WHO, 2015a). Based on these statistics, Hoffmann *et al.* (2017) reported on the attribution of infectious diseases to specific foods, such as beef, vegetables, fish and shellfish. They considered consumption of fish and shellfish to be important causes of infection with non-typhoidal salmonellosis. Of all cases attributed to *Salmonella* spp. (all food types), 1–2 percent was associated with fish or shellfish (Hoffmann *et al.*, 2017). The Dutch National Institute for Public Health and the Environment (RIVM) also reports annual estimates of foodborne disease (most recent report: Lagerweij *et al.*, 2020). The reports show the number of incidences, burden of disease and cost of infections caused by 14 food-related pathogens and summarize results of studies that attribute the infections to food categories. The reported data for 2019 suggest that 8 percent of all foodborne infections is linked to the consumption of fish and fishery products, with human norovirus (NoV) as one of the most frequently identified causative agents.

## 1.4 USE AND REUSE OF WATER IN FISH AND FISHERIES

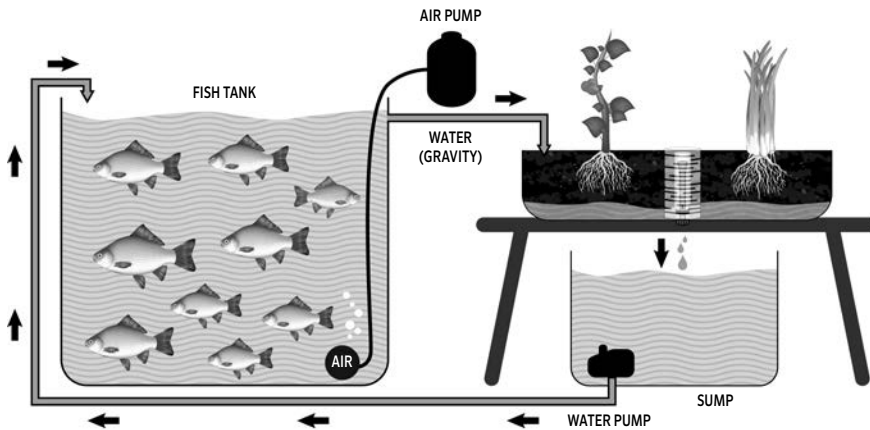
Water provides the nutrients and elements that fish, shellfish and other species require to grow and reproduce. Wild fish and shellfish live in aquatic environments subject to frequent changes in water flows and quality, particularly near the coast. In aquaculture systems, the source of water varies according to the species, geographical location and water availability. Seawater is used in marine aquaculture while inland aquaculture uses mainly surface and groundwater sources. Treated domestic wastewater or water originating from agricultural activities like hydroponics (a method for growing agricultural crops without the use of soil) can be reused, as long as the microbiological and chemical quality of the wastewater is thoroughly controlled. Wastewater from aquaculture itself can also be reused for agricultural purposes. Examples can be found in Corner *et al.* (2020) and FAO (2014). There are also multiple ways of reusing water in integrated multi-trophic aquaculture systems. These are similar to polyculture where multiple aquatic species from different trophic levels are farmed in an integrated fashion (e.g. finfish and seaweed) to improve efficiency, reduce waste, and provide ecosystem services, such as bio-remediation. Integrated multi-trophic aquaculture systems are regarded as a way of making aquaculture more sustainable and profitable on land or at sea.

An interesting reuse development in aquaculture is the aquaponic system. Aquaponics integrate recirculating aquaculture and hydroponics into a single production system. In an aquaponic unit, water from the fish tank cycles through filters and plant growth beds and is then pumped back into the fish tank (**Figure 3**). The aquaculture effluent is diverted through plant beds and is not released into the environment, while at the same time the nutrients for the plants are supplied from a sustainable, cost-effective and non-chemical source.

This integration addresses some of the limitations of running aquaculture and hydroponic systems independently. Plant and fish production in aquaponic systems are comparable with those in hydroponics and recirculating aquaculture systems. Aquaponics can be more productive and economically feasible in certain geographical areas, especially where land and water are limited (FAO, 2014).

Water is used for various purposes during handling and processing of fish and shellfish. Examples of water use in the fish industry can be found in the *Code of Practice of Fish and Fishery Products* (FAO and WHO, 2020b). Water is used for storage, depuration, washing, cooling, ice making, glazing and de-glazing, freezing and thawing, as an ingredient (e.g. pickles, brines, batters) and for other purposes, such as pasteurization and pacifying. Little information is available on the volumes of water used in each of these processes.

**FIGURE 3** Schematic of a simple aquaponic unit



Source: FAO. 2014. *Small-scale aquaponic food production. Integrated fish and plant farming*. FAO Fisheries and Aquaculture Technical Paper No. 589. Rome, FAO. <https://www.fao.org/3/i4021e/i4021e.pdf>

Water used as ingredient or water that comes into direct contact with food or food contact surfaces should be of potable quality (FAO and WHO, 2020c). With a few exceptions, the use of non-potable water is allowed during handling and processing, as long as its use does not compromise the safety of the product(s). Examples of the use of non-potable water in the handling of fish can be found in the Code of Practice (FAO and WHO, 2020b).

Ensuring appropriate levels of water safety in every step of the production and processing chain is of paramount importance to securing levels of safety in end-products consistent with human consumption. Considering the many uses of water in the production and processing of fish and shellfish, the growing environmental pressures on water resources and their effects on the safety and quality of the products, FAO and WHO have discussed the feasibility of applying a “fit-for-purpose” concept for water used in the various seafood production sectors. Water, as well as ice and steam made from water, should be fit for its intended purpose based on a risk-based approach and should not cause contamination of food (FAO and WHO, 2019, 2020c). In applying the concept of fit-for-purpose, it can be concluded that not all water that comes into contact with food products needs to be of potable quality. This allows various possibilities for reusing water in the production of fish and fishery products. The Code of Practice (FAO and WHO, 2020b) provides examples of water reuse for these purposes. Water used in brines, batters and for de-glazing and thawing is reused, and water from dried, salted fish

or fishmeal can be reclaimed. Reclaiming water is also possible in the production of surimi, as the final product is partly de-watered. Although the reported examples show that reuse of water in fish processing is possible, it is not yet common practice in this sector.

## 1.5 SCOPE OF THIS REPORT

The Codex Committee on Food Hygiene (CCFH) requested assistance from the Joint FAO/WHO Expert Meeting on Microbiological Risk Assessment (JEMRA) to provide scientific advice on sector-specific applications and case studies for determining appropriate and fit-for-purpose microbiological criteria for water sourcing, use and reuse in fish and fishery products from primary production to retail. The specific objectives of the meeting were to:

- identify the availability and suitability of the water used and at what point in the food chain water is introduced;
- describe measures used for assessing “fitness” of water for its intended purpose and the benefits and pitfalls of the different measures;
- establish threshold values, risk-benefit tables and/or decision trees to assist in decision making when water meets or exceeds certain criteria and/or parameters;
- consider practical interventions used to treat water for direct use and reuse in low- and middle-income countries to achieve an acceptable level of risk based on the intended purpose;
- develop case studies for different risk-based water use and reuse processing scenarios and species; and
- provide scientific evidence and recommendations on criteria for the safety and quality of various types of water used for different production, processing, transportation, retail, sale and consumption applications.



## Water sources

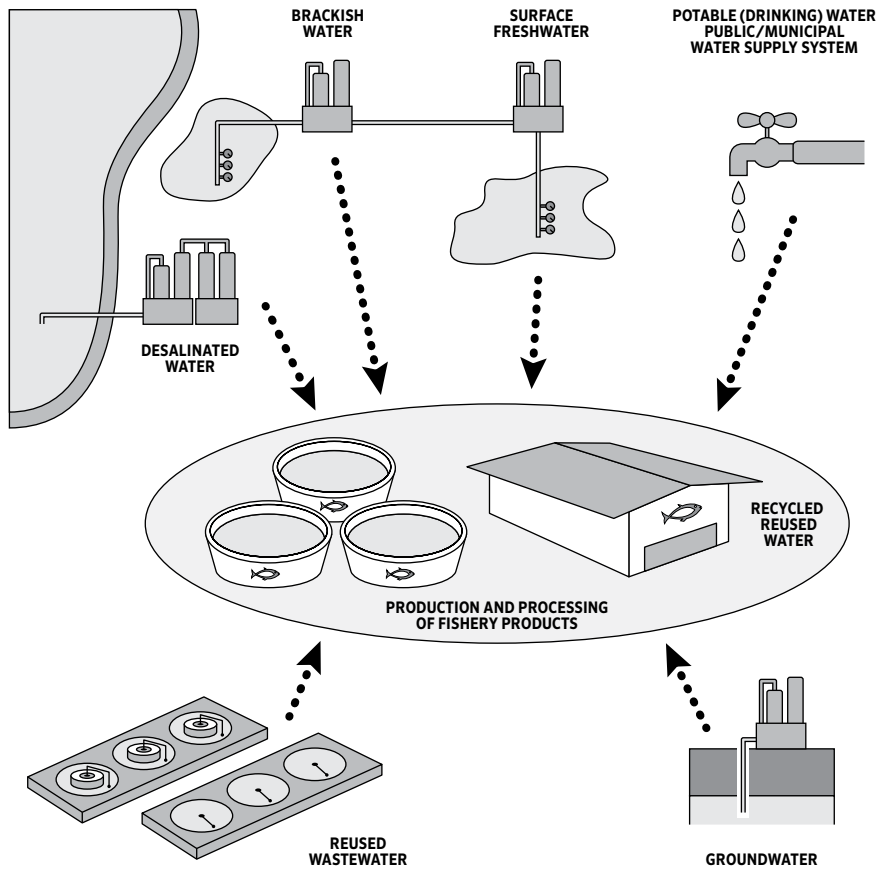
The use of brackish- and seawater, in addition to freshwater, is widespread for the purpose of rearing, harvesting, transporting and processing fish and fishery products. Other food-producing commodities do not normally use brackish- or seawater; thus, any microbiological issue specific to brackish- and seawater is relevant to fish and fisheries products and their processing. Water used in the production and processing of fish and fishery products can be obtained from many sources, namely (**Figure 4**):

- drinking (potable) water from a public/municipal water supply system; or
- other types of water, usually from private or independent supplies (operator's own supply or other), including:
  - > freshwater from surface and groundwater sources;
  - > harvested rainwater;
  - > seawater and brackish water;
  - > desalinated water;
  - > recycled/reused processing water within an establishment recovered from a processing step within the operation; and
  - > reused wastewater from public or municipal wastewater systems – for fish primary production (note: very limited information available).

Production and processing operations require an adequate supply of water in both quantity and quality. Therefore, safety aspects are a primary concern because of the broad use and application of water in these operations. Hazard analysis and critical control point (HACCP) plans must comprise the sources of water that come into contact with food or food contact surfaces, or water used to make ice, to ensure that the water does not adversely affect the quality of the product.

The plans should account for eventual cross-connections between the safe supply of water of potable quality and any unsafe or questionable supply of water of non-potable quality or sewer disposal system.

**FIGURE 4** Sources of water used in the production and processing of fishery products



Source: ritacortez\_illustration

In public water supplies, the responsibility for ensuring appropriate safety and quality of the water lies with the supplier while in private or independent supplies this responsibility falls upon the operators. Many seafood companies use water from public supplies and undertake their own additional water testing to address specific risks and controls as determined by their HACCP plans.



Depending on the type of water used, the characterization of the source water quality can present different degrees of complexity, but it is an essential step to ensure safe production and processing of fishery products. If water is taken from a private source (with or without treatment), it should be verified prior to its use to determine if the water meets the required quality, based on an analysis of hazards and other risk factors, for use in the production and processing of fishery products. A good example of Specifications for Suitable Water Supplied by Operators, including a Water Supply Assessment Checklist, was recently published by the New Zealand's Ministry for Primary Industries (MPI, 2019, 2020).

Characterization of source water quality normally requires extensive laboratory testing for various physico-chemical and microbiological parameters. For a comprehensive physico-chemical characterization, water sampling should be carried out in different seasons and/or weather conditions to reflect the influence of environmental factors on source water quality. Samples should be taken so that they are representative of water quality throughout the year. Irrespective of the water source, the supply should be monitored with adequate frequency to ensure that the water is safe for use in seafoods and seafood contact surfaces.

In primary production, any source of water can be used provided that the risks have been previously assessed, that the water complies with predefined quality criteria based on the outcome of a risk assessment and that water quality is regularly monitored. It is worth noting that information on the safe reuse of treated wastewater for production of fish and shellfish is very limited, and therefore the reuse of water for these purposes should be carefully considered.

In fish processing, water can be obtained from most sources mentioned above (except from reused public wastewater) as long as the water undergoes the treatment(s) required to obtain the quality needed for its use, i.e. *fit-for-purpose* (see **Chapter 4**).

According to the European Food Safety Authority (EFSA, 2012a), seawater from offshore sources is generally considered pristine. However, depending on the geographical area, local conditions of temperature and salinity can promote the proliferation of indigenous pathogenic bacteria such as vibrios, which may require specific control measures. In contrast, seawater and brackish water in nearshore areas cannot be considered pristine and safe due to the wide range of natural and anthropogenic contaminants that may be present. In coastal areas, seawater conditions can change depending on seasonal factors and human activities, and therefore monitoring of these waters should be undertaken to define the condition of these waters. If clean seawater is used on fishing vessels, it must only be taken from offshore areas that are some distance away from pollution sources to ensure

that the water is of suitable quality. There should be no cross-contamination between the point at which seawater is taken from offshore sources and wastewater streams and engine coolant outlets on a fishing vessel (MPI, 2019).

In the factory environment, the use of seawater is specific to the type of fish and shellfish processed, and therefore there is a need to establish quality criteria for verifying the quality of each type of water used in each production and processing step along the chain. A suitable supply of drinking (potable) water with appropriate facilities for storage and distribution and an adequate temperature control should be available to ensure the safety and quality of the products. If potable water is not available, or its use is not possible in the production and processing environment, a thorough identification of the risks linked to the water source is required. Furthermore, minimum quality requirements and criteria should be clearly established based on risk assessment and risk management procedures and Codex guidance. Risk metrics should consider hazards and hazardous events throughout the whole water system from the source to the point of use. Additionally, the characterization of surface or groundwater quality should be extended upstream of the abstraction point to include the whole catchment area and its potential risks.

In any production or processing facility, care must be taken to avoid contamination of the potable water system with non-potable water from other sources. Contamination may occur due to cross connections, backflows or back siphonage in the water plumbing systems and can result from improper installations, altered plumbing and additions to the existing plumbing (Seafood HACCP Alliance, 2000). The risk of cross-contamination should be considered in the HACCP plans specific for each industrial facility. Before any processing or transformation stage at a seafood facility, water coming into direct or indirect contact with material or product must be sourced and, where necessary, tested and treated so that it complies with appropriate standards.

Irrespective of the source, water used in the production and processing of fish and fishery products must be frequently monitored to ensure that it is safe for use on food products, food contact surfaces and to make ice (see **Chapter 5**). As part of this monitoring, water should be tested by an approved laboratory with accreditation for the required tests or, at minimum, by a laboratory with appropriate quality control procedures as determined by international standards (e.g. ISO 17025).

## 2.1 KNOWLEDGE GAPS/LIMITATIONS

- Insufficient information is available on the microbiological quality and related risk factors of water used in the production and processing of fish and fishery products. Baseline data are needed to adequately characterize the possible risks.
- Information on hazards and hazardous events in the catchment area of different water sources (namely in surface and groundwater) is lacking.
- Limited data are available on seawater quality used in fish processing (including water on board fishing vessels).
- There is a need to improve regulatory quality criteria for water sources, including minimum requirements for use in production and processing of fishery products.
- There is a need to harmonize the types and quality of water used in the different steps of fish production and processing, including on fishing vessels.
- Assessments of water quality when evaluating its use in seafood safety should not be based on monitoring of faecal indicator bacteria alone because these bacteria are not considered appropriate surrogates for the diversity of pathogenic microorganisms that may be present, particularly in brackish and seawaters. Thus, research should be carried out to define suitable surrogates and criteria for characterizing the quality and safety of waters used in the production and processing of fishery products.
- There is a general lack of information on the impacts of public (municipal) treated wastewater reuse in the primary production of fishery products, namely in aquaculture.
- The available guidance on water sources other than potable water is scarce. This limits decision-making by seafood producers and processors.

## 2.2 RECOMMENDATIONS

- The quality and safety of water sources used in the production and processing of fish and fishery products are crucial for ensuring the safety of these products. Seafood operators should obtain as much information as possible on source water quality to inform their risk assessments.
- In case potable (drinking) water is not available, or its use is not feasible in fish production and processing facilities, a thorough assessment of the risks associated with the water source should be undertaken.
- If a private source of water is used and irrespective of the treatment applied, the source should be verified before its use to determine if the water meets the required quality. This verification should follow principles of risk analysis for water use in food production and processing.

- Characterization of surface or groundwater quality in abstraction points should consider the whole catchment area.
- Where required in industrial facilities for processing of fish and fishery products, a supply of drinking (potable) water comprising proper facilities for storage and distribution to ensure the safety and quality of food should be made available.



## Microbiological hazards transmitted through water

The most common and widespread human health risks associated with water used in the production and processing of fish and fishery products are biohazards caused by a wide diversity of pathogens, including bacteria, viruses and parasites (e.g. protozoa and helminths). Bacteria that mediate the production of biogenic amines in certain fish species and antibiotic resistant bacteria and their resistance genes are also carried by water. **Table 1** lists the most relevant biohazards and provides basic information on their significance, resistance to chlorine (considered here as water disinfectant), animal zoonotic source, and the relative risk the biohazard represents.

The occurrence and distribution of these pathogens in water is a function of many factors, including their possible indigenous prevalence; contamination from land by sewage and agriculture; characteristics of the catchment area as temperature, salinity and influence by human populations and their lifestyles (e.g. living conditions, immunity status); water and wastewater uses and treatment; and medical interventions.

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<b>BACTERIA</b>				
<i>Aeromonas hydrophila</i>	Bacterium common in fresh-, brackish and marine environments. Known to cause gastrointestinal and extra-intestinal infections in humans.	Moderate	No	!!
<i>Bacillus cereus</i>	Spores commonly found in soils, freshwaters and coastal waters. May grow and produce emetic toxins (cereulide) in products, particularly after heat treatment and temperature abuse. Can cause two types of gastrointestinal illness: the emetic (vomiting) syndrome and the diarrhoeal syndrome.	High (spores)	No	!!
<i>Campylobacter jejuni/C. coli</i>	Common in the intestines of birds and shed by infected humans. Contamination may occur during fish farming, harvesting and processing. Low tolerance to freezing and drying. Common cause of gastrointestinal infections with fever, diarrhoea, vomiting and possible reactive arthritis post infection.	Low	Yes	!!!
<i>Clostridium botulinum</i>	Widespread in the environment. Possible anaerobic growth in vacuumed or non-sterile canned products. Some types grow at temperatures as low as 3 °C. Produces very potent neurotoxins (botulin) with moderate heat tolerance.	High (spores)	No	!!!
<i>Escherichia coli, pathogenic</i>	Group includes enterohaemorrhagic, enteroinvasive, enterotoxigenic and enteropathogenic strains. Occurs in the faeces of humans and farm animals. Depending on the strain, may cause infections of varying severity, including diarrhoea, fever and haemolytic uremic syndrome.	Low	Yes	!!!
<i>Listeria monocytogenes</i>	Common in the environment and in the intestines of warm-blooded animals. May cause severe systemic infections among susceptible persons (young, pregnant, immunocompromised and weak elderly). Able to grow at low temperatures, under anaerobic conditions and with high salt concentrations. Commonly found in seafood processing environments and occasionally in lightly preserved ready-to-eat seafood.	Moderate	Yes	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<i>Pseudo-monas aeruginosa</i>	Common in soil, water, on plants and in the intestines of humans and animals. Causes nosocomial and severe systemic infections in humans. Occurs in fish and fisheries products.	Moderate	No	!
Non-tuberculosis mycobacteria	Found in fresh-, brackish- and seawater. Occasionally infects humans after bathing. Group includes <i>Mycobacterium marinum</i> and <i>M. fortuitum</i> . May be carried by fish and fisheries products.	High	No	!
<i>Salmonella enterica</i> , all serovars	Globally one of the most common foodborne bacterial pathogens. Over 2 500 serovars described within this species. Shed by faeces of infected humans, domestic and wild animals including mammals and birds. Infection gives varying manifestation strength from asymptomatic carriage to fever, bloody diarrhoea and a possibly fatal outcome. Possibility for contamination at all stages during production of fish and fishery products.	Low	Yes	!!!
<i>Salmonella</i> , typhoid	<i>S. typhi</i> and <i>S. paratyphi</i> , found within the species <i>S. enterica</i> , present in the faeces of infected humans, and thereby possibly in contaminated water. Gives severe systemic infection with fever and diarrhoea, sometimes with blood, and possibly mortality. Possibility for contamination at all stages during production of fish and fishery products.	Low	No	!!!
<i>Shigella</i> spp.	Found in the faeces of infected humans. Causes shigellosis, also termed bacillary dysentery. Symptoms include systemic infection with fever and diarrhoea, sometimes with blood. Infection may be lethal.	Low	No	!!!
<i>Vibrio cholerae</i>	Indigenous to fresh-, brackish- and seawater. Toxigenic types (O1, O139) cause violent watery diarrhoea and severe dehydration. May be lethal if untreated. Non-toxigenic types (non-O1, non-139) cause milder diarrhoea. Prevalence of toxigenic varieties is positively correlated with high water temperatures.	Low	No	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<i>Vibrio parahaemolyticus</i>	Indigenous to brackish- and seawater. Toxigenic types (tdh, trd positive) cause fever and diarrhoea (sometimes bloody) and dehydration. Prevalence of toxigenic varieties is positively correlated with high water temperatures.	Low	No	!!!
<i>Vibrio vulnificus</i>	Indigenous to brackish- and seawater. Causes severe and rapidly progressing skin and connective tissue infections. High mortality in predisposed immunocompromised persons after bathing or handling contaminated seafood. Prevalence is positively correlated with high water temperatures.	Low	No	!!!
<i>Vibrio, other species</i>	Indigenous to brackish- and seawater. Several other vibrios may cause milder infections of the gastrointestinal tract, skin and ear after contact with seawater or contaminated seafood. Species in this group include <i>V. alginolyticus</i> , <i>V. fluvialis</i> , <i>V. mimicus</i> , <i>V. metschnikovii</i> , <i>V. furnissii</i> , <i>V. hollisae</i> and <i>V. damsela</i> .	Low	No	!
<i>Yersinia enterocolitica</i>	Found in the faeces of infected animals, particularly pigs and humans. Spreads by contaminated water and food, occasionally by direct transmission between animals and humans, or between humans. Occasionally contaminates fish and fisheries products.	Low	Yes	!!
<b>VIRUSES</b>				
Enteroviruses	More than 100 types of enterovirus have been described. This group includes poliovirus, which causes acute infection and paralysis, particularly in children under five years old. Poliomyelitis is a serious health challenge worldwide, but active vaccination has reduced the problem. Enteroviruses are shed by infected persons and transmitted by direct contact or contaminated drinking water/ food. Several outbreaks described from consuming fisheries products.	Moderate	No	!!!



**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<b>Hepatitis A virus (HAV)</b>	Endemic to some tropical and subtropical regions in Asia, Africa and South America. Few symptoms, but lifelong immunity if infected as a child. More pronounced symptoms occur in adults exposed first time to the virus. Causes jaundice due to temporary liver insufficiency. Several outbreaks linked to contaminated drinking water or after consuming contaminated raw fish and shellfish. The virus remains infectious after freezing but is inactivated by common food heating procedures.	Moderate	No	!!!
<b>Hepatitis E virus (HEV)</b>	Similar to HAV, but less frequent. May cause severe disease among pregnant women. Some outbreaks linked to contaminated drinking water or contaminated raw fish/shellfish.	Moderate	Possibly	!!!
<b>Norovirus and sapovirus</b>	Norovirus is the most common cause of waterborne and foodborne illness. Sapovirus resembles norovirus, but it is less common. Long lasting immunity not experienced after infection. Infection occurs after eating contaminated raw bivalve shellfish. Low infectious dose. Causes gastroenteritis with fever, nausea, vomiting and diarrhoea. Shed in high numbers in the faeces of infected persons. Usually self-limiting but may cause dehydration. The virus remains infectious after freezing but is inactivated by common food heating procedures.	Moderate	No	!!!
<b>Rotavirus</b>	One of the most common agents of waterborne and foodborne illness worldwide. Low infectious dose. Causes gastroenteritis with fever, nausea, vomiting and diarrhoea. Shed in high numbers in the faeces of infected persons. May cause dehydration. The virus remains infectious after freezing but is inactivated by common food heating procedures.	Moderate	No	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<b>PROTOZOANS</b>				
<i>Acanthamoeba</i> spp.	Microscopic, free-living amoeba that can cause rare but severe infections of the eye, skin and central nervous system. Found worldwide in soils and aquatic environments. Most people are exposed to Acanthamoeba during their lifetime, but very few become sick. Spread by contaminated water/food.	High	No	!
<i>Cryptosporidium parvum</i>	Causes the diarrheal disease cryptosporidiosis. The parasite is protected by an outer shell that allows survival outside the human host and increases tolerance to chlorine disinfection. Commonly spread by contaminated water (drinking and recreational) and contaminated food.	High	Yes	!!
<i>Cyclospora cayetanensis</i>	Causes intestinal illness in humans. Common in tropical and subtropical regions. Infectious stage spread by faeces of infected persons. Common symptoms include initial influenza-like symptoms followed by watery diarrhoea, sometimes profuse. Spread by contaminated water/food.	High	No	!!
<i>Entamoeba histolytica</i>	May cause amoebic dysentery after ingestion. Shed in the faeces of infected persons. More common among people who live in tropical areas with poor sanitary conditions. Spread by contaminated water/food.	High	No	!!!
<i>Giardia lamblia</i>	Found in soils, food or water contaminated with faeces from infected people or animals. Causes the diarrheal disease giardiasis. Giardia spreads easily from person to person or through contaminated water/food/surfaces/objects. The most common transmission pathway is swallowing contaminated water from lakes, rivers or pools.	High	Yes	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<i>Toxoplasma gondii</i>	Intracellular parasite with a complex life cycle involving cats as the main host and birds, man and other mammals as intermediate hosts. Toxoplasma produce spores in the faeces of infected cats which remain infectious over 1-2 years. May cause toxoplasmosis in immunocompromised people or pregnant woman where the foetus is severely affected. This parasite is inactivated by heating to 90 °C for 30 seconds. Spread by contaminated water which could contaminate fish and fishery products.	High	Yes	!!!
<b>HELMINTHS</b>				
<i>Anisakis</i> spp.	Group of nematode parasites commonly found globally in the marine environment. Less common in farmed fish solely fed with commercial heat treated compound feed. Complicated life cycle involving marine mammals, pelagic crustaceans and fish. Found in the viscera and muscle of fish and cephalopods. May cause gastrointestinal manifestations if ingested live, and allergy even when dead. Dies by freezing, drying, heavy salting and heating as during common food preparation heating.	N.R.	Yes	!!!
<i>Dracunulus medinensis</i>	The guinea worm is a freshwater nematode with a life cycle comprising copepods (small crustaceans), fish, frog or other aquatic animals and humans or other warm-blooded animals such as dogs. Humans are infected when ingesting infected copepods by drinking contaminated water or eating contaminated food. The parasite penetrates the host stomach or intestinal wall and matures in humans to a size of 70-120 cm before migrating for release through the skin, usually on the leg. Most common in Africa.	Moderate	Yes	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<i>Schistosoma</i> spp.	The infection termed <i>Schistosomiasis</i> (Bilharziasis) is caused by species of blood trematodes (flukes) of the genus <i>Schistosoma</i> . One of the most common parasitic diseases, with approximately 200 million cases and 20 000 fatalities annually. Most common in tropical and sub-tropical regions, particularly in Africa, but also in South America. Complex life cycle in freshwater comprising free living stages, snail, humans and other mammals. Infection occurs mainly by penetration of the skin during bathing and also by drinking water or eating contaminated food with the infectious form (cercarie).	Moderate	Yes	!!!
<i>Diphyllobothrium latum</i>	This helminth is commonly termed the broad tapeworm or the fish tapeworm. The parasite is found in freshwater, particularly in northern temperate regions and has a life cycle comprising free living forms, copepods (small crustaceans), fish, mammals and birds. The parasite adheres to the intestinal wall and matures to a maximum length of 10 m. While most infections in humans are asymptomatic, complications may include obstruction of the gall bladder and vitamin B12 deficiency. Infections may occur after eating contaminated raw or undercooked fish. Freezing and common food preparation heating kill the parasite.	N.R.	Yes	!!
<b>OTHERS</b>				
<b>Antibiotic resistance</b>	Bacteria with resistance to antibiotics can be transmitted to consumers through fish and shellfish or through water used during transport and processing. In addition, mobile antibiotic resistance genes from antibiotic-resistant bacteria can pose a risk if transmitted by horizontal gene transfer to human pathogens.	Variable	Yes	!!!

**TABLE 1** Summary information on the most significant waterborne biohazards of relevance to fish and fishery products (cont.)

BIOHAZARD	RELEVANCE TO FISH AND FISHERY PRODUCTS	RESISTANCE TO CHLORINE	ANIMAL SOURCE	RISK RANKING
<b>Biogenic amines</b>	Biogenic amines are produced post-mortem by bacterial degradation of amino acids present in the product. The most challenging biogenic amine is histamine, produced by several bacterial species by decarboxylation of the amino acid histidine found in comparably high concentrations in some fish species (e.g. tuna and mackerel).	N.R.		!!!

N.R. = Not relevant.

*Notes:* The hazards listed are assumed to represent all regions globally and include those hazards relevant to all types of water, including fresh-, brackish- and seawater. The selection of hazards when evaluating risk should be based on local circumstances, particularly where the water is used. The risk ranking in the table refers to the risk for consumers of seafood and is based on the perceived frequency and consequence of disease: (!) low risk to consumers; (!! ) common cause of foodborne disease, but of variable importance for seafood; and (!!!) cause of seafood-mediated disease and of potentially high risk to consumers.

*Source:* Authors' own elaboration, based on Doyle, Diez-Gonzalez and Hill, 2019; Håkonsholm *et al.*, 2020; Huss, Ababouch and Gram, 2004; Lunestad, Rosnes and Levsen, 2011; Ortega and Sterling, 2018; Sheng and Wang, 2021; West, 1989; WHO, 2004.

The Guidelines for Drinking-Water Quality (WHO, 2022) list the main characteristics of waterborne pathogens:

- They can cause acute and chronic health effects.
- They can grow in the environment (some pathogens).
- They are able to aggregate/adsorb to suspended solids in water.
- Their concentrations vary in time, depending on temperature and exposure to the source.
- The likelihood of acquiring an infectious dose cannot be predicted from the average concentration of pathogens in water.
- Disease occurrence depends upon the infectious dose, invasiveness and virulence of the pathogen and immune status of the infected person.
- If infection is established in the community, pathogens multiply in human hosts.
- Certain waterborne pathogens can multiply in food and warm water environments, increasing the likelihood of infection.
- Unlike many chemical contaminants, waterborne pathogens do not exhibit a cumulative effect.

For pathogens transmitted through the faecal–oral route, drinking water is a common vehicle. Contamination of food, hands, utensils and clothing is also important, particularly when sanitation and hygiene practices are poor (WHO, 2022). Some pathogens grow in piped water distribution systems (e.g. *Legionella*), while others occur in source waters (e.g. bacteria, viruses, protozoan, guinea worm *Dracunculus medinensis*) and may cause large disease outbreaks (WHO, 2022).

In surface freshwaters, potential sources of enteric pathogens include point sources (e.g. public and municipal wastewater treatment plants, sewage overflows) and diffuse sources (such as run-off from urban and agricultural land, wildlife). In the environment outside the human host, pathogens are subject to a range of stress factors (e.g. predation, thermal and sunlight inactivation) which reduce concentrations because most pathogens cannot replicate in the environment.

Groundwater is less vulnerable to contamination than surface water because soils offer a protective barrier. A good understanding of pathogen occurrence in surface waters and groundwaters helps to inform selection of appropriate treatment methods and health-based targets.

### 3.1 MICROBIOLOGICAL INDICATORS AND PATHOGENS

Microbiological monitoring of water quality to reduce the risk of water- and foodborne disease has, for many years, relied upon simple and relatively quick tests for the presence of indicator organisms. The most common approach involves culturing the microorganisms in an appropriate growth medium. The following groups of organisms have been used to assess the microbiological quality of water used in the production and processing of fish and fishery products:

- heterotrophic plate count (standard plate count, mesophilic plate count, aerobic plate count)
- presumptive coliforms/total coliforms
- thermotolerant coliforms/faecal coliforms
- *Escherichia coli*
- Enterococci (faecal streptococci)

No single microbiological indicator is suitable in all circumstances. Microbiological indicators have disadvantages that must be understood when using test results to assess the microbiological quality of water. This means that, in most circumstances, testing for multiple groups of indicators is more appropriate. However, there is a vast amount of evidence on the use of microbiological indicators for this purpose, and a good level of confidence can be placed in indicator test results, assuming that testing laboratories are accredited (ISO 17025) or, at least, follow internationally accepted standards and good laboratory practices.

There is a common generalization that greater numbers of microbiological indicators in water and food are associated with higher risk of disease. However, it should be noted that pathogens must be present together with microbiological indicators for disease to occur. The low correlations observed between microbiological indicators and pathogens, in different types of water used for food production and processing and the occasional failure of indicators to predict pathogen occurrence, highlight the need for risk assessments and hazard analysis and critical control point (HACCP) to control these hazards and reduce the risk of human exposure to pathogens. An example commonly referred to in risk assessments is the use of indicator bacteria to predict the presence and abundance of norovirus (NoV). This virus is shed in high concentrations in the faeces of infected persons; it survives longer in the environment than indicator bacteria, and it has a low infectious dose.

Although many pathogenic microorganisms have been proposed as indicators of faecal contamination or indicators of water treatment efficiency, testing for pathogens alone has been discouraged because they do not afford the degree of health protection given by the traditional non-pathogenic indicators.

Detection and quantification of pathogens in water and food is still relatively complex, time consuming and expensive. In most cases, it can take several days to determine whether a water sample is contaminated with pathogens and whether the pathogen is infectious. In addition, testing methods for protozoans and pathogenic viruses have low recovery efficiencies.

Currently, it is not possible to routinely monitor for all pathogens of interest and new pathogens continue to be recognized. Nevertheless, information on the prevalence and abundance of pathogens is very useful in identifying sources of contamination, validating water treatment technologies, and investigating disease outbreaks. Because pathogens are not shed by infected persons at constant rates, routine pathogen monitoring based on spot sampling provides limited information on their occurrence in source and treated water. However, positive samples for pathogens in water monitoring programmes should prompt further investigation and consideration of further risk mitigation response.

There is a vast array of molecular techniques such as polymerase chain reaction (PCR) for the rapid, sensitive and specific detection of index and indicator microorganisms and pathogens (Martinez *et al.*, 2005; Ohshima and Takahashi, 2018; Parlapani, 2021). The development and standardization of PCR methods for non-culturable viruses, such as NoV, has been a significant progress in the field of microbiological water quality and safety. The main drawback of PCR methods is that they only target the nucleic acid sequences, not the intact virus capsid.

Therefore, additional techniques often in combination with PCR, must be used to determine if the target virus in a water or food sample is infectious. Several research groups have developed PCR techniques for the rapid detection of *E. coli*, which make detection possible within several hours. In recent years, the application of next generation sequencing technologies has allowed a more in-depth understanding of the microbiome (all microbiological populations present in a sample) facilitating our understanding of the sources of pathogenic and spoilage microorganisms.

To ensure higher levels of seafood safety and consumer protection, it is necessary to rely on approaches that prevent the hazards from entering the supply chain at the source or that reduce its likelihood to acceptable levels, reflecting proper application of codes of practices, control, and corrective measures (Ryder, Karunasagar and Ababouch, 2014). There is good evidence that the implementation of HACCP systems has contributed to improving the quality and safety of fishery products over the last few decades. Nevertheless, there is a growing awareness of the importance of integrated, multidisciplinary approaches to safety and quality that consider the entire food chain (Ryder, Karunasagar and Ababouch, 2014). Principles of risk analysis, comprising risk assessment, risk management, and risk communication are key to characterizing health risks to consumers, assisting the development of standards, thresholds and risk mitigation measures. The identification of vibriosis as a significant safety issue in relation to the consumption of bivalve molluscs is a good example of the application of risk analysis principles. For instance, in the United States of America, the control of oyster-associated vibriosis is based on risk assessments that consider the relationships between *V. parahaemolyticus* or *V. vulnificus*, water temperature (the main risk factor) and, in some cases, salinity (FAO and WHO, 2005, 2011). The risk assessment models are integrated with satellite imagery and other water quality observations to estimate *Vibrio* spp. concentrations in oysters and to determine the corresponding risk level to consumers. These approaches have been successfully applied in other countries (e.g. New Zealand [Dorothy-Jean and Associates Ltd., 2018] and Canada [Canadian Food Inspection Agency, 2020]).

### **3.2 INTERNATIONAL MICROBIOLOGICAL STANDARDS FOR DRINKING WATER QUALITY**

A global survey of national regulations and standards for drinking water quality undertaken by WHO (2018a) identified numerical standards for 24 microbiological parameters. The survey showed that there is much variation in numerical parameters between surveyed countries/territories, with nine of the parameters designated by only one country and a further nine parameters designated by fewer



than ten countries/territories. The highest number of countries/territories specified numerical values for *E. coli* (or faecal coliforms/thermotolerant coliforms), followed by total coliforms, enterococci (faecal streptococci), *Clostridium perfringens*, total heterotrophic bacteria at 22 °C and total heterotrophic bacteria at 37 °C (**Table 2**). A smaller number of countries specified numerical values for enteric viruses and *Pseudomonas aeruginosa*, *Cryptosporidium*, *Giardia*, *Salmonella*, somatic coliphages, *Staphylococcus aureus*, pathogenic protozoa, *Shigella*, *Vibrio cholerae*, helminths and *Legionella*. In addition to setting values for some parameters, regulations in many countries/territories contain a statement such as the following: [drinking-water] shall be free from any micro-organisms and parasites which, in numbers or concentrations, constitute a potential danger to human health.

**TABLE 2** Numerical values for selected microbiological parameters applied in several countries and territories surveyed by the World Health Organization

MICROBIOLOGICAL INDICATOR	MINIMUM	MAXIMUM	NUMBER OF COUNTRIES (OUT OF 104) <sup>a</sup>
Total coliforms <sup>b</sup>	0	150	98
Enterococci <sup>b,c</sup>	0	0	47
<i>E. coli</i> <sup>d</sup>	0	1	103
Total heterotrophic bacteria 22 °C <sup>e</sup>	5	10 000	19
Total heterotrophic bacteria 37 °C <sup>e</sup>	0	500	14
<i>Clostridium perfringens</i> <sup>b,f</sup>	0	0	44

<sup>a</sup> Countries or territories setting a regulatory guideline value.

<sup>b</sup> Values are counts/100 ml.

<sup>c</sup> Or faecal streptococci.

<sup>d</sup> Or faecal coliforms or thermotolerant coliforms.

<sup>e</sup> CFU/100 ml.

<sup>f</sup> Or sulphite-reducing, spore-forming anaerobes.

Source: WHO. 2018a. *A global overview of national regulations and standards for drinking-water quality*. Geneva, Switzerland. <https://apps.who.int/iris/handle/10665/272345>





# 4

## Reuse of water in fish production and processing

There are many opportunities for increasing water use efficiency and promoting water reuse. Water reuse can be made more efficient by targeting the water quality requirements to specific processes. In many countries, potable water use is a requirement for all applications in food premises. Matching water quality requirements with the type of water use requires an analysis of the critical control points (CCPs) and an evaluation of the potential for contamination of the food products (Kirby, Bartram and Carr, 2003). For example, using water of “lower quality” might be appropriate for washing the factory floor but could pose a health risk if it is used for washing equipment surfaces that get in contact with the food product. Therefore, in addition to developing a framework for water reuse in food production/processing, where possible water reuse in the factory should be integrated into existing HACCP programmes. Advanced water treatment technologies make it possible to treat water to a very high degree, significantly reducing potential health risks associated with water recycling (Kirby, Bartram and Carr, 2003). For instance, sequential treatment systems, combining sedimentation/flotation, coagulation/flocculation, aerobic biological degradation, filtration, reverse osmosis (RO), and ultraviolet (UV) disinfection, have been recommended for the canning industry in Portugal (Cristóvão *et al.*, 2015).

Treating water by filtration, RO or UV disinfection is expensive. The quality of the water and the degree of treatment required should correspond to the water use. Consequently, a framework must be developed based on the concept of fit-for-purpose water for reuse in food production and processing. The implementation of cleaner production measures throughout the production chain to address water conservation and water contamination issues often has

other synergistic effects, such as reduction of the water use and production of less processed wastewater. This provides economic savings and reduces the environmental impacts associated with groundwater abstraction and wastewater emissions (Thrane, Nielsen and Christensen, 2009).

## **4.1 STRATEGIES TO INCREASE WATER-USE EFFICIENCY**

Potential savings in operational costs are often the main drivers that motivate managers to implement water conservation programmes. Cultural and operational changes are among the first to be implemented because they require little capital investment and can result in water use reductions of up to 30 percent (Kirby, Bartram and Carr, 2003). Other types of changes require higher investment, but they can achieve operational water reductions of up to 50 percent (Lindgaard-Jorgensen, Kristensen and Andersen, 2018) and even 80 percent (Meneses and Flores, 2016), depending on the technology implemented. Strategies to increase water use efficiency in seafood processing facilities include:

- reduction of use through water consumption analysis (water mapping);
- improved planning;
- improved equipment maintenance; and
- water recycling/water reuse after appropriate treatment.

### **Water use mapping, planning and equipment maintenance**

The first step towards optimizing water use in a seafood processing facility is to quantify water consumption in each stage of the operation. Water use mapping is a water consumption analysis, water balance or audit that helps identify water-intensive operations, identifies opportunities to reduce water consumption, and helps achieve operational efficiency.

To map water use, the boundaries of the water system must be established to define the unit operations to be included in the mapping and to identify critical points for data collection. Flow diagrams can provide input about water circulation in a particular process and recycling activities in place. Once the system boundaries have been established, information must be collected about the consumption of the relevant inputs. Utility bills can be used although they do not distinguish water consumption in individual processing operations from other uses (lavatories, gardening, fire systems and so on). To further evaluate volumes and locations of water consumption, in-line meters can be installed in pipelines. In-line meters can also help to determine the difference in water consumption patterns (processing versus cleaning operations). If meters are not available, flow rates can be calculated

using a known volume and a timer. A detailed description of water mapping methodology for a food-processing plant is provided by Li *et al.* (2018).

Connecting water and energy usage is an excellent strategy to demonstrate potential operational cost savings, especially for processing facilities where the monetary cost of water is not representative of its real value. Energy in the form of electricity and/or natural gas is frequently used to heat or cool water for different uses in a food-processing facility.

Low-cost fixes such as equipment maintenance, use of appropriate nozzles (devices that control stream flow, speed, direction and pressure) can achieve water savings of up to 50 percent (Seafish Industry Authority, 1996). To achieve optimum performance, the equipment must be checked routinely because equipment that uses water is susceptible to fouling, causing it to work out of specification. Changing to spray balls (similar function than nozzles but different design) with 180 degree coverage from handheld spray guns for cleaning operations can allow a reduction in water usage of 66 percent per year while also reducing chemical use in cleaning, which also impacts the quality of the wastewater (Spraying Systems Co., 2015).

Cleaning activities have been identified as water-intensive operations. In contrast to manual cleaning methods, automated cleaning-in-place systems save significant amounts of water, energy and labour because these systems allow recycling of cleaning solutions and rinsing water. Vacuums and sweepers are good alternatives to water washing for cleaning solids.

Appropriate production scheduling can also reduce water use for cleaning purposes. Production lines (tanks, pipelines and equipment) can be installed to process multiple products, avoiding cleaning in between runs. Furthermore, continuous operations reduce the cleaning frequency in comparison to batch processing, as well as reducing the need for additional equipment (Oklahoma Cooperative Extension Service, 2016).

Finally, the successful implementation of individual or combined strategies to increase water use efficiency depends highly upon the level of engagement of the staff in a factory. When employees are well trained on standard operation procedures and understand the importance of water conservation as part of the company's culture, they become proactive in solving water-related issues and in using water more efficiently (Oklahoma Cooperative Extension Service, 2016).

## 4.2 REUSE POTENTIAL AND WATER-FIT-FOR PURPOSE

Potable water is defined as water that is safe to drink or to use in food preparation. While potable water quality is required for places intended for food contact, lower quality may be acceptable for low-risk activities and processes in a food production facility. The mapping of water consumption and assessment of water quality characteristics of different streams discussed above demonstrate the potential of specific water streams to be recycled or reused after appropriate treatment to meet quality requirements for the intended use(s). This combination of water quality needs with proper operations is known as the fit-for-purpose concept.

The Codex Alimentarius Commission recognizes two types of water quality as appropriate for use in food-processing establishments: potable water and clean water. Clean water is “water which does not compromise the safety of the food in the contexts of its use” (FAO and WHO, 2017). Under this definition, clean water for reuse can be obtained from food product condensates recirculated in the same system, or effluents from different operations could be reconditioned (treated) for water reuse as needed to meet certain microbiological quality requirements. Today, organizations are shifting from the use of the term “clean water” to “fit-for-purpose” water.

The use of fit-for-purpose water satisfies the water demands of the processing operation by helping it to become more resilient and by reducing its environmental impacts and the costs of wastewater discharge, especially in water-scarce areas. Even though water reuse for food contact applications is not widely applied in the food industry, an increasing number of companies from different sectors (e.g. dairy, meat, fresh produce, seafood) are adopting this practice. Food processors ensure the safety and quality of their final products by using appropriate technologies and understanding the water quality needs for the intended use, by applying principles of hazard analysis and critical control points (HACCP) in water reuse, and by implementing appropriate risk-based process control programmes (FAO and WHO, 2019).

Safe water reuse in the food industry requires careful consideration of all the factors that affect the quality of the water used throughout the operation. To develop fit-for-purpose for any stage of a particular food sector, it is very important to understand the likelihood of contamination spreading through the various water streams. FAO/WHO recently published a report on the safety and quality of water used in food production and processing which reviews the food safety aspects related to water that is fit-for-purpose (FAO and WHO, 2019). Only by understanding the potential hazards and the potential contamination scenarios is it possible to design robust reconditioning treatments and to establish appropriate criteria and

parameters for control and monitoring during the implementation phase. The use of fit-for-purpose water in the food industry should be tailored for each sector. While literature is limited in this area, there are some guidelines developed for the dairy sector in the United States of America (US FDA, 2017) and Denmark (Lindgaard-Jorgensen *et al.*, 2018). These are great examples of how collaborations among the scientific community, the industry and regulatory entities can create significant contributions to implement water reuse in the food industry while protecting the health of consumers.

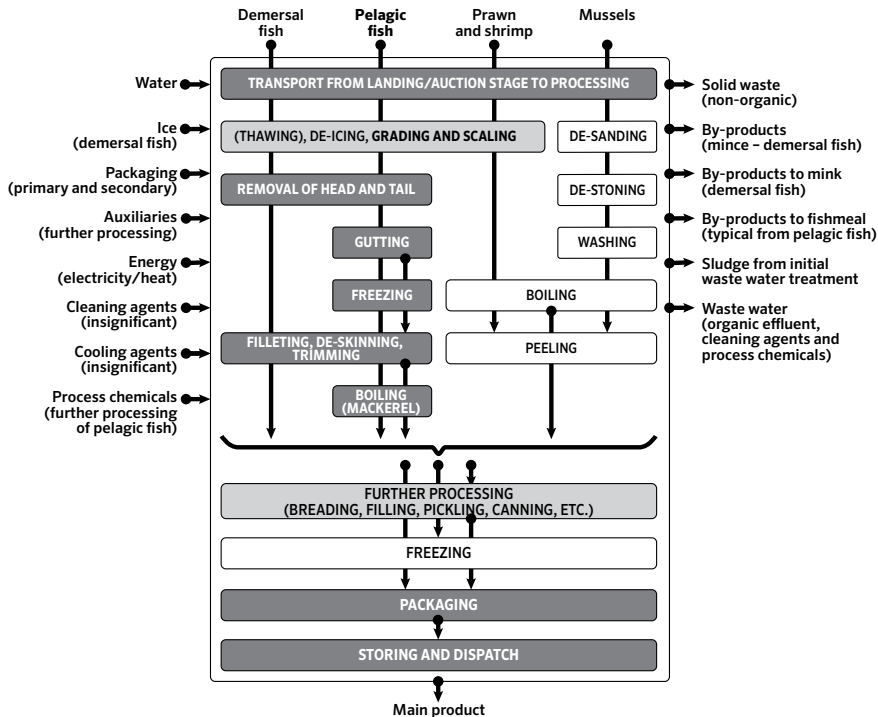
### 4.3 EXAMPLES OF REUSE IN FISH PROCESSING

In factories, water is used in various processing steps, including storage of harvested fish and shellfish (e.g. chilling and frozen storage) and various preparation processes (e.g. washing, gutting, filleting, skinning, trimming), glazing and mincing. The latter includes water used to clean equipment and any surfaces that are likely to come into contact with fish products. **Figure 5** illustrates the main processing steps for fish and shellfish used by the industry in Denmark. Note the introduction of water and its use through the process. Pelagic fish are usually gutted in the factory while demersal fish are gutted at sea. This results in higher volumes of wastewater produced from pelagic fish processing. Shellfish are usually boiled and therefore add to the volume of water use by the industry.

Understanding the water quality characteristics of individual water effluents across a fish and shellfish process is critical to defining the treatment and uses of fit-for-purpose water. Unfortunately, there is limited information on this in the literature. Information is available on water consumption and wastewater characteristics (mainly chemical) generated by the process as a whole for a number of seafood products. These data are summarized in **Table 3** and **Table 4**. It is important to note that these data are not representative of the entire sector or a particular product. Each table is a collection of data reported in the literature and is presented here to provide a basic understanding of water usage and the quality of different water streams. Fish processors should test the quality of water streams in their processing facilities to fully understand the quality of the water.

In general, the level of fish and shellfish processing correlates directly with water usage. For instance, adding a peeling step to shrimp processing can increase water consumption by almost threefold compared to unpeeled shrimps. As discussed previously, the significant variations observed in water consumption for a given product between countries can be related to different factors. In **Table 3**, shrimp processing in Sweden and Viet Nam consumes 17 and 84 L water/Kg raw, respectively.

**FIGURE 5** Flow chart of fish and shellfish processing steps used by the industry in Denmark. Demersal fish include codfish and flatfish; pelagic fish include herring and mackerel



Source: Thrane, M., Nielsen, E.H. & Christensen, P. 2009. Cleaner production in Danish fish processing - experiences, status and possible future strategies. *Journal of Cleaner Production*, 17: 380-390. (Reproduced with permission from Elsevier)

The facility in Viet Nam processes shrimps along with vegetables; the latter consumes 27 percent of the water; thus, the overall consumption is higher in that plant. The water consumption for fish processing ranges from 1.8 to 74.9 L water/kg raw. The lowest water usage reported is for Jack mackerel processing in Chile and the highest for anchovy in Türkiye.

Water management in the processing plant plays an important role in optimizing water usage. A plant in Türkiye processing anchovy reduces almost half of its water consumption (from 64 to 35 L/kg product) through water treatment and recycling. Separation of streams facilitates treatment design and performance. Lightly polluted wastewater streams such as those from cooling and thawing should be separated and recycled from those generated in evisceration and cleaning.



**TABLE 3** Water use in the seafood industry reported in the literature

CONTINENT	COUNTRY	PRODUCT	WATER USE (L WATER/KG RAW )	REFERENCE
Europe	Türkiye	Anchovy	21-75	Alkaya and Demirer (2016)
	Denmark	Peeled shrimp	50	Casani, Leth and Knøchel (2006)
	Sweden	Shrimp	17	Holland (2018)
		Marinated herring	7-8	
South America	Brazil	Tambaqui, matrinxã and spotted surubim	15	Ferraciolli <i>et al.</i> (2018)
	Chile	Jack mackerel	2-3	Bezama <i>et al.</i> (2012)
Asia	Thailand	Aquatic products	10-40	Sridang <i>et al.</i> (2006)
		Tuna	10-20	Nair (1990)
	Viet Nam	Shrimp	15-84	Anh <i>et al.</i> (2011); Dan Visvanathan and Kumar (2003)
Africa	Tunisia	Cuttlefish	50	Walha <i>et al.</i> (2008)

Source: Authors' own elaboration.

Wastewater from seafood processing is generated mainly from thawing, washing, evisceration, cleaning, and cooking. **Table 4** compiles wastewater quality characteristics from several seafood products including canned fish, sardines, fish, canned anchovies and shrimp. The wastewater quality parameters show wide variation and high concentration of organic compounds (chemical oxygen demand, 5-day biochemical oxygen demand and nutrients) which can harm the environment if released without treatment. Generally, wastewater produced from evisceration and cooking steps contains high concentrations of fats and oils, blood and suspended solids while wastewater produced from thawing, cooling and cleaning is less polluted (cleaning stream: COD: 110 mg/L; BOD<sub>5</sub>: 43.8 mg/L, TSS: 60 mg/L) and can be recycled or reused after treatment (Ferraciolli *et al.*, 2018). The high conductivity values reported in **Table 4** for canned fish and canned anchovies results from the use of brine in both products which contains high concentrations of salt. Anchovies presented higher conductivity (7-35 times higher) compared to canned fish (sardines and mackerel) because the wastewater stream was collected right after the application of brine, while in the case of canned fish, the effluent was a sample of the entire process; the mixing of streams diluted the salt content.

**TABLE 4** Water quality characteristics of wastewater generated by the seafood industry

PRODUCT	CANNED FISH <sup>a</sup>	SARDINES	FISH <sup>b</sup>	CANNED ANCHOVIES	SHRIMP
Reference	Cristóvão <i>et al.</i> (2015)	Duarte <i>et al.</i> (2015)	Ferracioli <i>et al.</i> (2018)	Corsino <i>et al.</i> (2016)	Anh <i>et al.</i> (2011)
pH	6.13–7.14	6.5–6.9	5.5–9.2	NA	NA
COD (mg/L)	1147–8 313	6 000–15 767	110–1 722	16 984	1 200–2 300
BOD <sub>5</sub> (mg/L)	463–4 569	2 122	43.85–890	7 060	720–1 100
TN (mg/L)	21–471	NA	10.8–102	1 152	45–77
TP (mg/L)	13–47	56.8	0.058–16.4	NA	18–71
TSS (mg/L)	324–3 150	NA	60–940	4 621	122–872
Conductivity (mS/cm)	4.73–24.8	NA	NA	160	NA

COD: chemical oxygen demand; BOD<sub>5</sub>: 5-day biochemical oxygen demand; TN: total nitrogen; TP: total phosphorus; TSS: total suspended solids; NA: value not available.

<sup>a</sup> Canned fish includes sardines and mackerel.

<sup>b</sup> The fish category includes tambaqui, matrinxã and spotted surubim.

Source: Authors' own elaboration.

## 4.4 TREATMENT TECHNOLOGIES

Fish and shellfish processing plants vary considerably in terms of raw material used, source of water, and unit processes. Consequently, the quality of the effluents produced also varies. Wastewater from fish processing operations contains organic contaminants in soluble, colloidal and particulate form. The main components of these types of wastewaters are lipids and proteins (González, 1996). Depending on the operation, the degree of contamination may be small (e.g. washing operations), mild (e.g. fish filleting), or heavy (e.g. blood water drained from fish storage tanks). Fish evisceration operations and cooking produce effluents with high content of chemical oxygen demand (COD), nutrients and fat, oil and grease (Tay, Show and Hung, 2006). Food-processing wastewater is considered the best type of wastewater from a treatment perspective due to the low level of toxic compounds present in comparison with wastewaters from the chemical and metal industries (Barbera and Gurnari, 2018). Food-processing wastewater contains mainly biodegradable organic material, cleaning and sanitizing products, microorganisms and nutrients.

As mentioned earlier, the pollutant strength of food-processing wastewater is higher (10–100 times higher biochemical oxygen demand [BOD] and COD) than that of domestic wastewater (Ölmez, 2013). The composition of food-processing wastewater is also variable due to the different production levels, cleaning frequencies, equipment and plant designs used. Therefore, the treatment of food-processing effluents often comprises biological, physical and chemical methods to separate nutrients and recover water (Meneses, Martinez and Hu, 2019). Wastewater treatment can be classified into primary, which targets separation of suspended solids; secondary, which further reduces organic loads and solids remaining from the primary process; and tertiary, which includes more advanced treatments to achieve low microbiological concentrations and low BOD values in the effluent (Barbera and Gurnari, 2018). The complexity of the treatment increases with the level of pollutant removal requirements. If a food company has the goal to generate water fit-for-purpose, the treatment should be selected considering the nature of the water stream and the target water quality.

**Table 5** provides a description of technologies frequently applied in the treatment of effluents from food-processing establishments. This is not an exhaustive list; there are many other treatment technologies available. Barbera and Gurnari (2018) provide a detailed discussion of the different wastewater treatment options available to the food industry. Treatment technologies for drinking water are also thoroughly discussed in the literature and can be applied for water reuse in the food industry.

**TABLE 5** Summary of wastewater treatment technologies used in food processing

METHOD	APPLICATION	PERCENT POLLUTANT REMOVAL	ADVANTAGES	LIMITATIONS
<b>CHEMICAL</b>				
<b>Chlorine</b>	Disinfection; oxidation (for example of metals)	NA	Low cost; widely available; residual chlorine remains in water and prevents recontamination during storage; simple testing of free residual	Organic matter reduces efficiency; potential hazardous by-product; handling chlorine has significant safety risks (highly toxic)
<b>Ozone</b>	Disinfection; impurities removal; oxidation (for example of metals)	COD: 60 Andreozzi <i>et al.</i> (2008)	Short contact time (no harmful residues - there are potential hazardous by-products, such as bromates)	High energy demand (if produced on-site); potential hazardous by-product; no residual remains in water
<b>Peracetic acid</b>	Disinfection	NA	Not inhibited by high organic load. Effective in low concentration	Corrosive (equipment); increase BOD and COD in the effluent; handling acid has significant safety risks (highly toxic); major safety hazard (possible spontaneous combustion)
<b>PHYSICAL</b>				
<b>Membranes</b>	Removal of impurities (chemical pollutants) and micro-organisms	COD: 95 BODs: 98 Yordanov (2010)	High efficiency in pollutant and microorganism removal; absence of toxic by-products; safe to use and monitor	Maintenance needed to reduce membrane fouling. Operational costs may be significant
<b>UV light</b>	Disinfection	NA	Absence of residual toxicity	UV-dose difficult to determine; require low turbidity in wastewater

**TABLE 5** Summary of wastewater treatment technologies used in food processing (cont.)

METHOD	APPLICATION	PERCENT POLLUTANT REMOVAL	ADVANTAGES	LIMITATIONS
<b>BIOLOGICAL</b>				
<b>Aerobic bacterial</b>	Degrade organic nutrients	COD: 98 BODs:99 Sroka, Kamiński and Bohdziewicz (2004)	Efficient removal of COD and BOD; easy to build up and operate; low investment	Require energy for aeration; inefficient in phosphorus and nitrogen removal; generate carbon dioxide
<b>Anaerobic bacteria</b>		BODs: 95 Dendooven and Escamilla-Silva (2005)	Less affected by organic loading; generate biogas as by-product	Require large space; inefficient in phosphorus and nitrogen removal; require long treatment period
<b>Microalgae</b>			Efficient in phosphorus and nitrogen removal; synthesize lipids, proteins and starch	High cost of biomass, production and harvesting; less efficient in COD removal
<b>Yeast</b>		COD: 41 Lanciotti <i>et al.</i> (2005)	Tolerate high COD; generate enzyme-like lipase and amylase	Require longer biodegradation period; less resistant to exterior contamination
<b>Vermi-filtration</b>		COD: 96 TN: 22 TP: 43 Singh, Bhunia and Dash (2019)	Low cost; no energy requirement; does not generate sludge	Low removal of TN and TP

COD: chemical oxygen demand; BODs: 5-day biochemical oxygen demand; TN: total nitrogen; TP: total phosphorus; TSS: total suspended solids; NA: value not available.

Sources: Casani, S., Rouhany, M. & Knöchel, S. 2005. A discussion paper on challenges and limitations to water reuse and hygiene in the food industry. *Water Research*, 39(6): 1134-1146; Collivignarelli, M.C., Abbà, A., Benigna, I., Sorlini, S. & Torretta, V. 2018. Overview of the main disinfection processes for wastewater and drinking water treatment plants. *Sustainability*, 10(1): 86;

Meneses, Y.E., Martinez, B. & Hu, X. 2019. Chapter 10 - Water reconditioning in the food industry. In: C. M. Galanakis & E. Agrafioti, eds. *Sustainable Water and Wastewater Processing*, pp. 329-365. Amsterdam, the Netherlands, Elsevier

## Chemical treatments

Chemical treatment methods like chlorine, ozone and peracetic acid (PAA) have long been used in wastewater treatment, including in the food industry. These disinfectants are especially used in the fruits and vegetables and in the poultry industries to improve the quality of the water recirculated in the washing and chiller systems. Chlorine has a low cost, is easily available and is highly effective in eliminating microorganisms while maintained as a residual chlorine. The reaction of chlorine with organic matter which can produce hazardous oxidation by-products and the risks of handling this toxic product are factors that cause concerns when using or reusing water reconditioned with chlorine in the food industry (Micciche *et al.*, 2018). Although PAA is approved for use in poultry processing water at a concentration up to 2 000 ppm, its effectiveness against *Salmonella* spp. and *Campylobacter* spp. has been demonstrated at concentrations of 20–200 ppm. One of the features that make PAA so popular in the poultry industry is that it is not significantly inhibited by high organic material as is in chlorine, although there are some safety issues in handling PAA.

Ozone is used in water disinfection of swimming pools, wastewater treatment plants and in the production of bottled water. Compared to chlorine, the presence of organic matter does not significantly affect the disinfectant potential of ozone. Besides, ozone decays into non-toxic deposits (Micciche *et al.*, 2018) although toxic by-products (e.g. bromate) can be produced. Ozone is effective in reducing pathogenic bacteria, including *E. coli*, *Listeria monocytogenes*, *Pseudomonas* spp., *Bacillus* spp., *Salmonella* spp. and yeasts. Regardless of the efficiency of ozone in reducing pathogens, worker safety, and the need for an on-site generation to maintain its concentration, are of concern. Furthermore, the application of ozone in seawater environments has been debated due to the possible formation of undesirable bromines (Gonçalves and Gagnon, 2018).

## Physical treatments

Membrane processes, including microfiltration, nanofiltration, ultrafiltration and RO are efficient in purifying water and have been widely used in water and wastewater treatment. Membrane filtration is effective in the removal of suspended solids, microorganisms and soluble pollutants. Water subjected to membrane filtration is generally of high quality and can be recovered for reuse. Membrane filtration can be integrated with biological processes such as bacterial degradation into a membrane bioreactor and activated carbon to improve treatment efficiency. Until recently, the high cost of membranes hindered broader application, but there has been greater acceptance of this treatment process due to price reductions. Membrane fouling is still a factor to consider when selecting this treatment process for water treatment applications.

Currently, disinfection with UV light is the most common method in municipal wastewater treatment plants. In comparison to chlorine and ozone, disinfection using UV light does not generate hazardous residuals and does not require high input of energy; thus, it is safer and economical to use. The efficiency of UV light in reducing bacterial contaminants is mainly affected by the turbidity of wastewater which limits the light transmission to bacteria. Therefore, suspended solids in wastewater need to be removed before disinfection with UV light.

## Biological treatments

Biological methods employing microorganisms such as bacteria, microalgae, yeast and fungi have been applied to treat high-strength food-processing wastewater. Among them, biodegradation using sludge bacteria is well developed and widely used. Under aerobic conditions, sludge bacteria can efficiently oxidize organic carbon into carbon dioxide. However, this process requires mechanical aeration to provide oxygen which is energy intensive and accounts for about 50 percent of energy consumption in the activated sludge treatment (Novoveská *et al.*, 2016). Anaerobic biodegradation does not have this problem, and organic pollutants can be degraded by anaerobic bacteria into biogas like methane and biohydrogen that can be used to fuel the plant. Compared to the aerobic process, anaerobic bacterial biodegradation needs to be conducted in a closed bioreactor and is more complicated to operate, which means higher investment may be required.

Natural treatments, including stabilization ponds, sand filters, constructed wetlands and vermifiltration offer low-cost options to improve the quality of effluents. These alternatives have been applied to the treatment of domestic wastewater and effluents from feedlots and other animal operations. Cruddas *et al.* (2018) found a 78 percent reduction in COD concentrations in stabilization ponds. Sand filters have been reported to remove 92 percent of COD, 72 percent of total phosphorous (TP) and 59 percent of total nitrogen (TN) (Leverenz, Tchobanoglous and Darby, 2009). Wetlands offer good organics and nutrients removal, along with many contaminants of emerging concern (Vymazal, 2009). Vermifiltration is a type of treatment that integrates soil filters and earthworms to remove organic nutrients from wastewater. It is ecologically safe, sustainable, requires minimal to negligible investment and does not produce harmful by-products (Singh *et al.*, 2019)

**Table 6** summarizes information on treatment performance for a range of aerobic and anaerobic systems currently used by or available to the fish processing industry. Given that wastewater from fish processing plants contains biodegradable organic matter, the potential for a net production of energy in the form of biogas is high (Chowdhury, Viraraghavan and Srinivasan, 2010). Therefore, anaerobic treatment is the preferred option.

**TABLE 6** Performance of aerobic and anaerobic systems for processing wastewater from fish processing operations

TREATMENT PROCESS	FISH PROCESSING INDUSTRY	CHARACTERISTICS OF RAW WASTEWATER (mg/L)	ORGANIC LOADING	ORGANIC REMOVAL	REMARKS	REFERENCE
<b>AEROBIC</b>						
Activated sludge	Fish processing industry		0.5 kg BOD <sub>5</sub> /m <sup>3</sup> day	90–95 percent BOD <sub>5</sub>	Detention time: 1–2 days; F/M 0.1–0.3; sludge age: 18–20 days; HRT: 48 days; effluent TSS: 290 mg/L	Carawan, Chambers and Zall (1979)
RBC	Fish cannery	pH: 6–7; COD: 6 000–9 000; BOD: 5 100; TSS: 2 000; TKN: 750	0.018–0.037 kg COD/m <sup>2</sup> day	85–98 percent COD	HRT: 48 days; effluent TSS: 290 mg/L	Najafpour, Zinatizadeh and Lee (2006)
Trickling filter	Squid processing	BOD: 2–3 000	0.08–0.4 kg BOD <sub>5</sub> /m <sup>3</sup> day	80–87 percent BOD <sub>5</sub>		Park <i>et al.</i> (2001)
Aerated lagoon	Fish processing			90–95 percent BOD <sub>5</sub>	Retention time: 2–10 days; ponds: 2.4–4.6 m deep	Carawan, Chambers and Zall (1979)
<b>ANAEROBIC</b>						
Anaerobic fluidized bed reactor; anaerobic fixed filter	Fish cannery (herring brine)	COD: 90 000; BOD: 78 000; Oil/fat: 4 000; TN: 3 000; SS: 10 000; pH: 3.8	6.7 kg COD/m <sup>3</sup> day; 4.7 kg COD/m <sup>3</sup> day	88 percent COD; 85 percent COD		Balslev-Olesen, Lynggaard-Jensen and Nickelsen (1990)
Anaerobic filter	Seafood processing		0.3–0.99 kg COD/m <sup>3</sup> day	78–84 percent COD	HRT: 36 days	Prasertsan, Jung and Buckle (1994)
	Seafood processing (tuna condensate)	Volatile acids: 3 340	1.67 kg COD/m <sup>3</sup> day	60 percent COD	OLR: 2 kg COD/m <sup>3</sup> day; initiated system failure	
Anaerobic digester	Tuna cooking	COD: 34 500; TS: 4000; Cl <sup>-</sup> : 14 g/L	4.5 kg COD/m <sup>3</sup> day	80 percent COD		Mendez <i>et al.</i> (1992)
	Mussel cooking	COD: 18 500; TS: 1 400; Cl <sup>-</sup> : 13 g/L	4.2 kg COD/m <sup>3</sup> day	75–85 percent COD	HRT: 5 days	



**TABLE 6** Performance of aerobic and anaerobic systems for processing wastewater from fish processing operations (cont.)

TREATMENT PROCESS	FISH PROCESSING INDUSTRY	CHARACTERISTICS OF RAW WASTEWATER (mg/L)	ORGANIC LOADING	ORGANIC REMOVAL	REMARKS	REFERENCE
Anaerobic fixed film	Tuna processing industry		2 kg COD/m <sup>3</sup> day	75 percent COD		Veiga, Mendez and Lema (1991)
UASB	Mixed sardine and tuna canning	COD: 2 718±532; lipids: 232±29; TKN: 410±89; pH: 7.2-7.6	1-8 kg COD/m <sup>3</sup> day	80-95 percent COD	HRT: 7.2±2.8 hours, 61±17 percent/COD conversion to methane	Palenzuela-Rollon <i>et al.</i> (2002)
<b>INTEGRATED BIOPROCESS</b>						
Physical pre-treatment+-anaerobic digester+-activated sludge bioreactor	Tuna processing	pH: 6.96; TSS: 1575; COD: 5 553; BOD: 3 300; TKN: 440; fat: 1 450	1.2 kg COD/m <sup>3</sup> day	85-95 percent COD		Achour <i>et al.</i> (2000)

Notes: a. RBC: rotating biological contractor b. UASB: upflow anaerobic sludge blanket reactor c. BOD5: 5-day biochemical oxygen demand d. COD: chemical oxygen demand e. HRT: hydraulic retention time f. F/M: food to microorganism ratio g. OLR: organic loading rate h. TSS: total suspended solids i. TKN: total Kjeldahl nitrogen

Source: Chowdhury, P., Viraraghavan, T. & Srinivasan, A. 2010. Biological treatment processes for fish processing wastewater - a review. *Bioresource Technology*, 101: 439-449. (Reproduced with permission from Elsevier)

Attached growth processes such as anaerobic fluidized bed reactors achieve >80 percent removal of COD and can be operated at high salt concentrations. Anaerobic filters also achieve good COD removal. High-rate anaerobic treatment systems such as upflow anaerobic sludge blanket (UASB) reactors achieve >90 percent COD removal and are also good options for fish processing wastewater. System pH, organic loading rates, total ammonia and wastewater salinity are the main factors affecting treatment efficiency of UASB reactors.

Extended aeration type activated sludge processes are used in some fish processing plants because of the high oxygen requirement compared to other food-processing wastewaters. A multistage rotating biological contractor is considered a better treatment process than an activated sludge system in terms of stability, mixed liquor volatile suspended solids content and energy requirements. Trickling filters are not commonly used in fish processing plants.

## 4.5 CONCLUSIONS AND RECOMMENDATIONS

Current regulation limits the use of fit-for-purpose water and may not reflect current technological capabilities of water treatment. There are opportunities for fit-for-purpose and water reuse in the fish industry sector, especially in processing activities. Risk assessment and risk management approaches such as water safety plans (WSPs) should be used to identify microbiological and chemical hazards and establish reduction targets for these. While there are technologies to achieve any desired water quality for a specific application, economic and environmental impact assessments are needed to facilitate decision-making.

Detailed characterization (microbiological and chemical) of individual water streams from different unit operations is non-existent in the literature. Such information is critical to design effective water conservation strategies, assess the need for treatment and its extent and conduct robust risk assessments for hazard control.

Public-private partnerships are essential to advance the implementation of fit-for-purpose and water reuse in the fish industry. Regulators should be engaged in debates about the effectiveness of new water treatment technologies in providing safe water reuse for potable and non-potable applications. Likewise, fish and fishery product companies should be open to sharing information about water usage, wastewater quality and technology adoption. Only through joint efforts will it be possible to implement effective conservation practices and transform the fish industry into a sustainable sector.



# 5

## Monitoring and control of contamination

### 5.1 WATER MONITORING IN FISH PRODUCTION/ PROCESSING ENVIRONMENT

Monitoring of water is a core element of any food safety management system and is required for ensuring water quality and safety and defining fit-for-purpose water in the seafood sector. Water monitoring is recommended to verify the presence of microbiological hazards or their indicators that may be present in the primary production environment. Monitoring is also conducted in fish processing facilities to verify the effectiveness of measures to control hazards in fish and fishery products. This is carried out by observing or measuring certain microbiological, physical and/or chemical parameters. Typically, monitoring programmes comprise a range of tests, including adenosine triphosphate (ATP), indicator organisms, pathogens, and spoilage organisms, conducted on samples collected at varying frequencies throughout the production and processing chains. Monitoring of physical parameters such as time, temperature, humidity, water activity, pH, pressure, flow rate and manufacturing operations such as freezing, dehydration, heat processing and refrigeration are also undertaken to ensure that mechanical breakdowns, time delays, temperature fluctuations and other factors do not contribute to the decomposition or contamination of the fishery products. While the basic elements of a monitoring programme (e.g. sampling sites, sampling frequency, testing method(s), acceptable criteria, corrective actions) are undertaken by most seafood industries worldwide, there is lack of practical guidance on what constitutes an appropriate monitoring programme for direct and indirect contact waters in the fish production and processing sector.

## 5.2 WATER MONITORING IN THE CONTEXT OF HAZARD ANALYSIS AND CRITICAL CONTROL POINTS

All requirements for microbiological monitoring and verification must be derived from the HACCP principles. A properly applied HACCP system is an effective means of ensuring food safety. In many countries, there is a legal requirement for all food business operators to have some form of hazard analysis based on HACCP as a means of ensuring food safety. An HACCP-based approach to develop a monitoring programme for a fish processing environment could start with the identification of the potential hazards. The operator would then decide which specific hazards could be transmitted through the processing environment while recognizing that there are many ways in which contaminants may be introduced and transmitted in that environment.

According to WHO Drinking Water Guidelines (WHO, 2022), monitoring programmes should be developed for operational and verification monitoring and documented as part of HACCP. These programmes can be designed adopting a risk management approach, such as a WSP, detailing the strategies and procedures to follow for monitoring the various aspects of the water system. Thus, monitoring programmes should focus not only on numerical compliance with parameter limits but should also be integrated in a broader management approach. The monitoring plans should be fully documented and include the following information:

- parameters to be monitored;
- sampling location and frequency;
- sampling methods and equipment;
- schedules for sampling;
- corrective actions, including responsibilities;
- qualifications and certification requirements for testing laboratories;
- methods for quality assurance and validation of sampling results;
- requirements for checking and interpreting results;
- responsibilities and necessary qualifications of staff;
- requirements for documentation and management of records, including how monitoring results will be recorded and stored; and
- requirements for reporting and communication of results.

HACCP plans for fish and fishery products require the establishment of a system to monitor critical control points (CCPs) or defect action points (DAPs) and identify corrective action(s) when monitoring shows that a CCP/DAP is not under control (Figure 6; FAO and WHO, 2020b). A CCP is a step at which control can be applied and is essential for the safety of the product as defined by a regulatory requirement or operator-defined limit. Some points to consider when determining

if control at the particular step is essential include the degree of hazard control that is achieved at the step, the likelihood of failure, and the consequence of control failure considering the intended use and consumer (i.e. risk to health). Commonly, essential steps are those that are specifically designed to eliminate or reduce the hazard to an acceptable level.

In general, the recommended approach to verifying the microbiological safety of water is based on testing of indicator organisms. The organism of choice is usually *E. coli*, although other indicators, such as thermotolerant coliforms, can be used. Despite having some shortcomings, particularly as an indicator of viruses and protozoa due to higher sensitivity to inactivation and environmental pressures, *E. coli* remains an important indicator of the presence of faecal contamination and associated pathogens. As a complement to *E. coli* testing, certain operational parameters can serve as indicators of pathogen removal or inactivation and are often included in monitoring plans, namely turbidity, disinfectant (chlorine or other) residual and pH (which is important in determining disinfection efficacy). These parameters should be measured at sites where samples are collected for *E. coli* (WHO, 2018b).

If monitoring indicates a deviation from the critical limit for a CCP, action must be taken that will bring it back under control. Actions taken should also include proper isolation of the affected product, repair of defective equipment, and an investigation as to why the deviation occurred. Monitoring should be either continuous or carried out at a sufficient frequency to ensure control of the CCP (Leatherhead Food International, 2009). In addition to determining loss of control/deviation from a CCP, monitoring helps to verify the operation of the production and processing steps and provides written evidence for use in verification and audit of production/processing practices (NACMCF, 1997). Ideally, monitoring should not be based solely on microbiological testing, as this is frequently retrospective, but should also include the measurement of physico-chemical parameters. Therefore, physical and chemical on-line measurements are usually preferred or used as a complement of MB analysis to time-consuming microbiological testing.

### **A water monitoring plan should consider the following aspects:**

**Monitoring objectives:** The plan could simply measure a characteristic of the fish production environment or processing step or the product to determine compliance of a given parameter with a critical limit. The plan could also focus on observing whether a control measure at a CCP is being implemented. Examples include the measurement of fish temperature, sensory quality, histamine concentration, and verification of hygienic practices (Ryder, Karunasagar and Ababouch, 2014).

**How critical limits and control measures are monitored:** A deviation from a critical limit should be detected as quickly as possible to allow prompt corrective action to ensure the safety and quality of the product. Microbiological testing is rarely effective for monitoring CCPs. Instead, physical and chemical measurements (e.g. pH, time, temperature and sensory quality) are preferred as they can be done rapidly and can often be related to the microbiological control of the process. However, the correlation between rapid measurements and microbiological control should be regularly validated. The equipment used in monitoring programmes should be periodically calibrated or standardized to ensure its accuracy. Operators should be trained in the proper use of the monitoring equipment and should be provided with a clear description of how the monitoring should be carried out (Ryder, Karunasagar and Ababouch, 2014).

**Monitoring frequency:** Continuous monitoring is preferred to spot monitoring. Continuous monitoring provides accurate in-line control of water quality in fish processing facilities using computer-aided automatic water treatment systems. Modern water treatment and monitoring equipment includes sensors, detectors or controllers for many types of physical or chemical parameters which provide high-frequency data on water quality. Examples of continuous monitoring include the automatic measurement of free chlorine levels in water, time turbidity and temperature of sterilization and freezing temperature. Continuous monitoring reduces the likelihood of water safety failure associated with system malfunction or human error. Where non-continuous monitoring is used, the frequency of monitoring should be determined from historical knowledge of the process and product. If a problem is detected, the frequency of monitoring may need to be increased until the cause of the problem is corrected (Ryder, Karunasagar and Ababouch 2014).

**Monitoring location:** Monitoring normally takes place at each CCP where a given control measure is applied to control a given hazard.

In the fishery industry, the most common control factors with critical limits for processing water are:

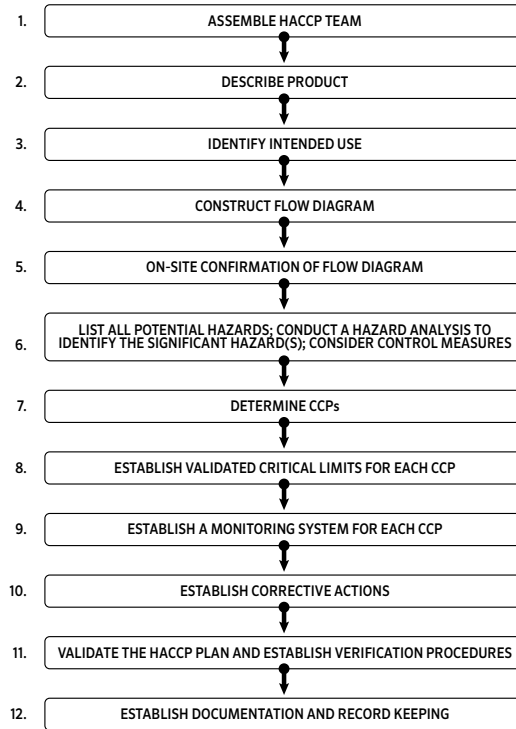
- Total bacterial counts: These are the most practical and sensitive indicators of the removal and inactivation of microorganisms in individual processes.
- Total coliform bacteria: These are used as indicators of microbiological contamination of water because they are easily detected and found in the digestive tract of warm-blooded animals. While not all of them are disease producers, they are often found in association with other microbes that can cause disease. Coliform bacteria are more tolerant to adverse environments than many disease-causing organisms; therefore, their absence from water indicates bacteriological safety for human contamination.

- Faecal coliform (mostly *E. coli*): Faecal coliforms constitute a portion of the coliform bacteria group. They originate in the intestinal tract of warm-blooded animals and pass into the environment in faeces.
- Coagulase test: A positive response indicates that *Staphylococcus aureus*, *Listeria monocytogenes*, *Legionella* spp. and other related pathogens should be considered.
- Temperature: In many fish processing operations, the optimal temperature is determined by more than one single factor. Besides the reduction of the risk of microbiological hazards, the maintenance of other quality attributes should also be considered.
- Antimicrobial chemicals: The effectiveness of antimicrobial agents depends on their chemical and physical states, treatment conditions (water temperature, acidity, and contact time), and the resistance of pathogens. Ozone has been used to sanitize wash and flume water in packing operations. Ultraviolet radiation may also be used to disinfect processing water.
- pH: Adjusting the pH of processing water down to a certain level may be an effective safeguard against many pathogens. Furthermore, pH levels influence the disinfection effectiveness of chlorine in water.
- Contact time or flow rate: The effectiveness of a cleaning or cooling operation is affected by contact time.
- Pressure: When a pressure wash is used, critical control limits on the pressure should be set and monitored.
- Free disinfectant (e.g. chlorine) concentration in water.

Concentrations of indicator bacteria in fish production environments vary considerably, depending on the type of water, pollution sources, season and climatic factors. Because of this variation and the fact that indicator bacteria are not randomly distributed in water, specific procedures and a greater sampling effort (i.e. higher number of samples, higher sampling frequency) are needed to adequately characterize contamination levels in water compared to those in fishery products. This variation should be considered when applying the concept of fit-for-purpose water using risk-based approaches.

Control strategies (e.g. sanitation, good manufacturing practices) are prescribed to control each hazard. Subsequently, the operator should identify monitoring activities to verify that the preventive control measures address the target hazard(s). This verification may include measurements and records other than the classical environmental monitoring tests.

**FIGURE 6** Hazard analysis and critical control points-based approach to environmental monitoring in a fish processing facility



Source: FAO & WHO. 2011. Codex Alimentarius. General principles of food hygiene, CXC 1-1969. Rome, FAO. [https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXC%252FB1-1969%252FCXC\\_001e.pdf](https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?Ink=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXC%252FB1-1969%252FCXC_001e.pdf)

A complete monitoring plan must account for the sources and treatment of water that comes in contact with fish or fish contact surfaces or water that is used to make ice. It must also consider cross connections between the safe water supply (potable water) and any unsafe or questionable water supply (non-potable) or sewer disposal systems. In seafood processing plants, cross connections have been found in many places, such as hard plumbing between potable and non-potable water lines; unprotected hose bibs (i.e. those with no backflow prevention devices); hoses lying in pooled water or submerged in wash tanks; or metering pumps used for cleaning chemicals without a backflow prevention device (Seafood HACCP Alliance, 2000).



In a water monitoring programme, the minimum frequency of sampling and analysis shall be proportional to the volumes of water used in production and processing. Generally, monthly monitoring is adequate for problematic cross-connections in hard (permanent) plumbing between the potable water lines and non-potable water or sewer lines. More frequent (e.g. daily) monitoring is required to prevent potential water contamination from cross-connections created by back siphonage or improper use of hoses. Many countries have specific regulations or good practice guidance with specifications on how to conduct water monitoring in fish processing facilities. If hot water is used for cleaning, temperature should be monitored. Regular changing or cleaning of screens and filter assemblies is important to maintain sanitary conditions for the reconditioning of washing water. The benefits of chilling to remove field heat and the temperature requirements for optimal keeping quality vary for different types of fish products. Maintaining temperatures that promote optimal product quality may reduce the risk of microbiological hazards. Chilling equipment, such as hydrocoolers and containers holding produce during chilling operations, should be clean and sanitary.

In microbiological analyses which assesses the risks of water safety and temporal trend analysis of microbiological quality, the choice of either pathogen presence and/or enumeration of microbiological indicators, the sampling plans for the microbiological targets, and the acceptable limits, should be proportionate to the water safety risk and the risk management goals. (FAO and WHO, 2021). Consequently, frequencies of sampling should balance the benefits and costs of obtaining additional monitoring data (WHO, 2022). Other considerations when verifying microbiological water quality are as follows:

- Selection of indicator organism: *E. coli* may not always be the best indicator as new studies show that, despite the low concentration of *E. coli*, source waters may contain pathogenic enteric viruses, and bacteriophages may be more reliable indicators.
- Selection of tests for the types of indicator organisms: These could be based on culture methods or non-culture gene-based (e.g. PCR) techniques.
- Designing a sampling plan and its sampling frequency: These should be feasible and fit the budget of the water suppliers and fish production managers.

Sampling plans for microbiological targets used to determine water quality, including pathogen detection or concentration of microbiological indicators, should be based on risk assessment and risk management approaches and procedures.

Water quality criteria for use in fish supply chains should be established within the framework of national food and water regulations and guidelines and take into consideration local resources, infrastructure and capability (FAO and WHO, 2021).

## 5.3 SAMPLING

Water quality monitoring is commonly defined as the sampling and analysis of water constituents for various purposes, according to pre-defined schedules. Sampling, *in situ* and laboratory analysis are the most resource- and labour-intensive phases in monitoring programmes. It is important to design sampling and analysis campaigns wisely and to ensure the collection of reliable and accurate data, while considering the costs. Guidance on water quality sampling is given in the International Organization for Standardization (ISO) standards. The most relevant standards are listed below:

- ISO 5667-1:2020. Water quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques
- ISO 5667-3:2018. Water quality – Sampling – Part 3: Guidance on the preservation and handling of water samples
- ISO 5667-5:2006. Water quality – Sampling – Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems
- ISO 5667-6:2014. Water quality – Sampling – Part 6: Guidance on sampling of rivers and streams
- ISO 5667-11:2009. Water quality – Sampling – Part 11: Guidance on sampling of groundwaters
- ISO 5667-14:2014. Water quality – Sampling – Part 14: Guidance on quality assurance of environmental water sampling and handling
- ISO 5667-20:2008. Water quality – Sampling – Part 20: Guidance on the use of sampling data for decision making – Compliance with thresholds and classification systems
- ISO 5667-23:2011. Water quality – Sampling – Part 23: Guidance on passive sampling in surface waters
- ISO 19458:2006. Water quality – Sampling for microbiological analysis

### 5.3.1 Sampling Design

Water quality heterogeneity, both spatial and temporal, from source to point of use, is one of the most significant aspects when designing sampling programmes. Consequently, spatio-temporal variability determines the number of sampling sites and the frequency of sampling (ANZECC and ARMCANZ, 2000). Standard ISO 5667-1 provides guidance on the design of sampling programmes and sampling techniques. An example checklist for designing sampling programmes is given by ANZECC and ARMCANZ (2000).

### 5.3.2 Selection of Sampling Sites

The selection of representative sampling locations depends on the water quality constituent(s) examined and the water catchment and distribution system from its source to the point of use. These are site specific for any given primary production and processing facility, and sampling plans should be tailored for each water system and facility. As mentioned in Chapter 2, if the water is not sourced from a public supply, it is important to characterize the quality of source water through frequent monitoring to ensure that the water is safe for use in foods and food contact surfaces.

When developing a sampling plan, the first step is to understand the water system within each facility in detail. The water quality issue addressed (e.g. specific pathogen contamination), identified in the first phase of the monitoring plan along with the water system design, largely determines the number and locations of the sampling sites. In any case, sampling should always be undertaken at critical points in the water systems, such as the intake and outflow of the system, points with low water flow or high retention times, and specific points in the water treatment process. There are some additional practical considerations when selecting sampling sites:

- Before carrying out any sampling, all sites and procedures should be assessed on site to verify the feasibility of sampling at each location.
- Safe access to sampling points should be guaranteed because sites that are inaccessible or difficult to reach may pose health and safety risks to staff carrying out the sampling.
- Sampling points need to be clearly identified so that they can be sampled regularly.

### 5.3.3 Sampling Frequency

Frequency of water sampling for testing of individual constituents depends on their spatial and temporal variability. Usually, sampling for testing of microbiological constituents is more frequent than that for chemical constituents. This is because brief episodes of microbiological contamination can quickly lead to water quality degradation and food contamination. Surveillance of the microbiological quality of water distribution systems must be undertaken to ensure that contamination events are detected as quickly as possible. Sampling should therefore account for potential variations of water quality in distribution systems. Sampling plans normally consider the locations and times of increased likelihood of contamination and therefore the frequency of sampling will depend on the magnitude and probability of the identified potential risks (WHO, 2022; FAO and WHO, 2019).

Regarding source waters, sampling and analysis should be more frequent in surface waters because their quality varies more widely as a result of seasonal factors and environmental conditions (e.g. heavy rain, flooding). The quality of groundwater tends to be more stable and therefore this type of source water is sampled less frequently. Furthermore, sampling frequency depends upon:

- risk of contamination in various parts of the system;
- complexity of the water system (e.g. pipe length, existence of reservoirs);
- water quality history; and
- intended use of the water within the processing facility.

When establishing a new monitoring programme, it may be appropriate to sample and test water more frequently to establish a baseline assessment of water quality and inform subsequent monitoring. Besides regular sampling, operators should prepare clear procedures and provide appropriate equipment for sampling and storage of water in the event of an incident, as these can be valuable for follow-up investigations and cause analysis.

#### **5.3.4 Sampling method, preservation, and transport**

Sampling and sample transport procedures should follow international standards (e.g. ISO 5667 and ISO 19458) to ensure that the monitoring programme is reliable and representative. In most cases, samples are collected and transported for later analysis; thus, clear and distinctive sample labelling is important. After collection, it is imperative to maintain the integrity of the sample(s) to ensure that they do not become contaminated during transit to the testing laboratory. Normally, to prevent chemical and biological changes, water samples are cooled to  $5\pm 3$  °C immediately after sampling. Besides cooling, sample containers should be protected and sealed during transport to ensure that the samples do not deteriorate and their content is not lost.

Prolonged storage at low temperatures may result in reductions in microbiological counts. Therefore, it is recommended that samples for microbiological testing be stored (whether in transport or otherwise) at  $5\pm 3$  °C and that the maximum time lag between sampling and analysis be <18 hours (or 24 hours, depending on the microbiological indicator to be analysed). Samples should not be frozen as this reduces concentrations of faecal coliforms/*E. coli* or other indicator microorganisms.

In planning the sampling campaign, the following needs to be considered:

- appropriate sample container;
- the place and type of sample (freshwater, seawater, etc.);
- the method of sampling (immersion, directly from a tap, etc.);
- sampling record (e.g. sample submission form);

- means to maintain refrigeration of samples;
- temperature control during transportation; and
- maximum acceptable time lag between sampling and analysis (Rees *et al.*, 2010).

### 5.3.5 Quality assurance and quality control

A quality assurance and quality control programme for sampling is required to control sampling errors to levels acceptable to the data user. The programme should include procedures designed to prevent, detect and correct problems in the sampling process and to characterize statistical errors through quality control samples. Major errors to be avoided are contamination of sample containers, changes in the sample before measurement (contamination, chemical or biological changes), incorrect sample labelling and eventual faulty operation of the sampling device during field sampling. If there is chance of contamination during sampling, blank samples should be devised to detect and measure the contaminant. Besides blanks, other quality assurance measures include the use of duplicate samples and recovery procedures (WHO, 2022).

### 5.3.6 Sampling operators

Given the importance of sampling, it is essential to employ personnel that are qualified and trained in the correct procedures for collecting, labelling, packing and transporting samples and in collecting relevant information at sampling sites to help interpretation of laboratory results. Additionally, staff should be aware of possible hazards and safety measures that must be followed during sampling campaigns. Staff may also be required to assist with audits to laboratory and field procedures to ensure compliance with the relevant quality standards (WHO, 2022).

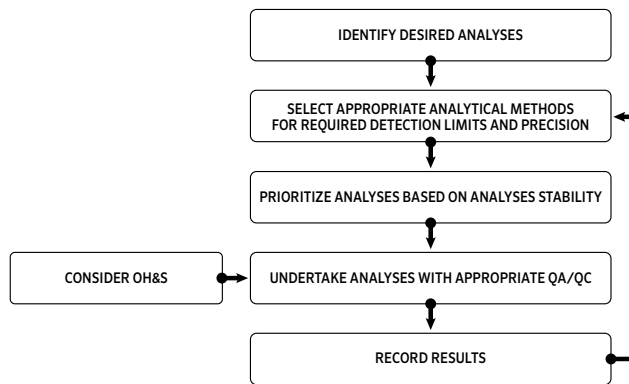
### 5.3.7 On-site analysis

Depending on the type of monitoring or laboratory location, *in situ* testing can be important for determining disinfectant residuals or other parameters such as pH and turbidity, which can change during sample transport and storage. It may also be appropriate to measure other quality parameters where laboratory support is lacking or where transportation problems render conventional sampling and analysis impractical (WHO, 2022).

## 5.4 LABORATORY ANALYSIS FOR MICROBIOLOGICAL WATER QUALITY

The aim of laboratory analysis is to obtain accurate and precise data in a safe environment. A framework for designing an analysis programme is given in **Figure 7**. Essential requirements for defining the programme are the selection of the testing method(s), requirements for laboratory accreditation, quality assurance and quality control, and training skills of analysts.

**FIGURE 7** A framework for designing a laboratory analysis programme



Source: adapted from ANZECC & ARMCANZ. 2000, Australian guidelines for water quality monitoring and reporting (National Water Quality Management Strategy no.7), Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

There are many testing methods available for microbiological water testing, including for detection and quantification of indicator organisms or pathogens (WHO, 2022). Other tests are used to identify the source of faecal contamination (Ahmed and Harwood, 2017). A summary of the various testing methods and their advantages and disadvantages is presented in Annex 3 of MRA37 (FAO and WHO, 2021).

Culture-based methods are considered standard for detection and quantification of bacterial indicators and pathogens. They can be used to assess cell viability and infectivity, have lower cost and are easier to use than molecular methods. However, culture-based methods are time-consuming, labour-intensive and sensitive to contamination.

A rapid method for detecting general microbiological activity in water is the ATP measurement, as all organisms contain ATP as their main energy source. The amount of ATP in a sample is directly proportional to its biomass, and it can be easily measured with high specificity through a firefly luciferase assay, using a luminometer. ATP measurement is thus a quantitative method to detect active cells. The main advantages of this method are the quick return of results (in minutes) and the detection of microbiological activity from any type of living microorganism.

Non-culture-based methods include PCR, reverse-transcription PCR (RT-PCR), real-time quantitative PCR (qPCR), digital droplet PCR (ddPCR) and RT-qPCR, nucleic acid sequenced-base amplification (NASBA), immunological methods, optical biosensors, next-generation sequencing (NGS), and flow cytometry, among others. A summary of the advantages and disadvantages of the different microbiological test methods are summarized in Annex 3 of MRA37 (FAO and WHO, 2021).

The selection of an analytical method for water testing largely depends on the information and management needs of the monitoring programme, and on the analytes themselves. The laboratory and human resources available, speed of analyses required, type of sample matrix and contamination potential are also important factors to consider (ANZECC and ARMCANZ, 2000). The selection of water quality parameters to be analysed should rely as much as possible on historical data from the specific water system, and parameters should be prioritized according to the outcomes of a risk assessment of the water system (WHO, 2018b).

Reference analytical methods for water analysis have been published by several international agencies and organizations such as the International Organization for Standardization, European Standards, and the American Society for Testing and Materials; publications include the Standard Methods for the Examination of Water and Wastewater (APHA, 1998) and the WHO Drinking Water Guidelines (WHO, 2022).

Laboratory accreditation (according to the standard ISO 17025) ensures that laboratories undertaking testing for specific purposes—for example, as part of an official control programme, achieve at least a minimum standard with respect to the control of internal procedures and the performance of analytical tests, ensuring the reliability of results.

#### **5.4.1 Quality assurance and quality control of laboratory testing**

The objective of a quality assurance and quality control programme in a laboratory is to minimize errors that can occur during subsampling and analytical measurement

and to produce data that are accurate, reliable and acceptable to the data user. Therefore, the quality assurance and quality control procedures are designed to prevent, detect and correct problems in the measurement process and to characterize errors through quality control samples and various checking processes (ANZECC and ARMCANZ, 2000).

#### **5.4.2 Analysis of certified reference materials and internal evaluation samples**

Certified reference materials are materials of known concentrations which have a matrix similar to that of the sample being analysed. These materials can be purchased from different suppliers worldwide. The accuracy of laboratory methods and procedures can be established by comparing the values for an analyte in the certified reference material against the results obtained by the laboratory for the same analyte. Confidence limits for each reference material are specific and given by the supplier (ANZECC and ARMCANZ, 2000).

#### **5.4.3 Proficiency testing programmes (interlaboratory comparisons)**

Interlaboratory comparison of unknown samples is used for testing instrument calibration and performance, and the skills of the operator. Generally, only a modest degree of sample preparation is required to restrict the range of sources of variance between laboratories. Any individual laboratory taking part in a proficiency testing programme compares its results against the reference values given by the supplier to determine the accuracy of its results and, therefore, the accuracy of the whole set of laboratory procedures (ANZECC and ARMCANZ, 2000).

### **5.5 RECOMMENDATIONS**

- Besides regulatory monitoring defined by the competent authorities, operational monitoring of the water used in the production and processing of fishery products should be implemented by the operators to provide insight into operational performance and water quality issues therefore enabling rapid remedial action in the event of nonconformity.
- Water sampling and analysis should be based on international standard procedures and preferably be carried out by accredited laboratories.
- Monitoring plans should be designed based on risk assessment and risk management procedures such as WSPs or an equivalent framework.
- Since water disinfection, in particular chlorination, is commonly used to ensure water safety, frequent monitoring of this stage, or on-line measurement of the disinfectant residual, is recommended.



- Monitoring plans commonly include a recommendation to test for faecal indicator organisms to verify the potential presence/absence of enteric pathogens. Besides regular monitoring of indicators, producers are advised to test other waterborne biohazards of relevance to the safety of fish and fishery products (e.g. viruses, protozoans, helminths).





# 6

## Risk assessment and risk management

Different risk assessment approaches may be applied for managing the safety and quality of fish and fishery products and for determining if water is fit-for-purpose. The principles of these approaches are outlined in the Codex Guidelines (FAO and WHO, 2013, 2014) and the WHO Guidelines for Drinking Water Quality (WHO, 2022) and the FAO/WHO Microbiological Risk Assessment Series 37 (FAO and WHO, 2021). The risk assessment approaches and tools encompass a continuum from simple and qualitative to fully quantitative assessments. They extend in scope and scale from product-pathogen specific to multihazard, and from location-specific to watershed and food network scale. The main types of risk assessment relevant to water safety described by WHO include:

- qualitative sanitary inspection: on-site visual evaluation of features and conditions at or near the water supply and/or fish production area and upstream catchment that may present a hazard to water quality;
- risk matrix: qualitative or semiquantitative evaluation of the likelihood that a hazardous event will occur and the severity or consequences of the hazard, combined into a categorical risk score or rank; and
- quantitative microbial risk assessment (QMRA): mathematical modelling of a water system or an empirical approach, combining quantitative information about the type and occurrence of pathogens, their potential fate and transport, routes of exposure to humans and health effects via consumption of contaminated fish or fishery products that may result from exposure, as well as the effect of natural and engineered barriers and hygiene measures.

Qualitative risk assessment models sit between simple risk matrices and QMRAs concerning the amount of information required and the qualitative/quantitative nature of the output risk estimates. These risk assessment models can help identify system components and risk-relevant steps, but only assign a qualitative estimate of risk that is contributed by each step. In addition to mechanistic risk approaches, correlative epidemiological studies, such as cohort and case-control studies, can help identify risk factors to determine the effectiveness of large-scale interventions.

Risk managers should consider several factors when selecting a risk assessment approach for determining when water is fit-for-purpose in food production. WHO (2016a) lists the following:

- The approach should provide the information that risk managers need as the basis for informed, evidence-based risk management decisions or to design risk management policies.
- The approach should be feasible to implement in the context of available resources (personnel, skills, analytical and laboratory facilities, access to support institutions).
- Managers should also consider whether the type of data or information can reasonably be expected to be available (e.g. knowledge of the water supply system, types of hazards and hazardous events, exposure routes, water quality data on indicator organisms or pathogens) and whether it is sufficient to conduct a reliable risk assessment.

The choice of a risk assessment for water is based on the guiding principle of continuous improvement. For example, a progressive inquiry process to assess whether the water from a river is fit-for-purpose for fish production may start with a visual assessment of the candidate water and a review of potential contamination sources that could impact its quality. Alternative water sources that could be used should be identified and compared. This process could then lead to follow-up questions that can be answered by additional information, for example:

- Risk factors: There is extensive cattle pasture in the upstream watershed: What is the potential impact on water quality at the point of use?
- Water quality measurements: Is the river water of better or worse quality than alternate shallow well water, based on sampling results?
- Seasonal effects: Is river water cleaner in spring than in summer?
- Potential interventions: Can river water be used for fish production without any additional treatment, or what type of intervention is needed to improve its quality and reduce risk?

As additional resources become available, further data could be used iteratively to move the risk assessment along the qualitative-quantitative continuum and to integrate observational and measured variables. Over time, a more detailed and comprehensive assessment could lead to more accurate identification and prioritization of potential risk reduction measures, to the implementation of evidence-based practices or policies, and thus to a reduction in hazard exposure.

Qualitative risk assessments are based on descriptive or observational information and aim to evaluate the likelihood and/or severity of events that may compromise the safety of water. Qualitative assessments have been widely used to support the identification and management of high priority risk factors in small water supply systems and to enhance knowledge of the water supply system (technical, operations, local conditions and practices), identify potential sources and pathways of contamination, and thus point to required improvements and additional controls.

Sanitary inspections and surveys are typically based on standardized forms and checklists to identify the most common issues that may lead to the introduction of hazards into a system. This approach has been developed and promoted as a simple and effective tool for small water supplies and as part of WSPs for small supplies (WHO, 2016). No sanitary inspection specific to water use during fish production or fish processing was cited. However, when a risk management plan with prerequisite programmes and HACCP-based programmes is established during production at an establishment, there are steps that have similarities with water safety plan (WSP) activities—for example, conducting the hazard analysis and determining the critical points (FAO and WHO, 2020c). Water use in fish production and processing and cleaning of equipment and facilities should be included in prerequisite programmes and HACCP product flow diagrams.

A sanitary inspection can be repeated to identify changes in hazards and their risk factors and/or risk levels that occur over time and to evaluate the impact of improvement policies. Results from sanitary inspections are useful at an individual supply level and when applied as part of a large-scale monitoring programme to inform regional and national priorities on water safety. It is possible to combine sanitary inspection scores with microbiological monitoring results, such as the presence or enumeration of faecal indicator bacteria and/or bacteriophages and gradually include a larger set of variables and more quantitative information.

Semiquantitative risk assessments involve more systematic assessment of the likelihood and severity of adverse impacts of health hazards in a water system and require more information and expertise compared to a qualitative assessment. Semiquantitative assessments are included in several WHO water-related guidelines, either alone or as part of a more comprehensive approach such as WSPs (WHO, 2009) and Sanitation Safety Plans (WHO, 2015b).

QMRA is a quantitative mechanistic modelling approach or an empirical approach to estimate exposure and risk of adverse health impacts from an identified microbiological hazard and exposure route (WHO, 2016). While QMRAs can be deterministic, they are most useful when accounting for variability and uncertainty in variables and parameters, yielding a distribution of risk outcomes. The WHO Guidelines for drinking water quality provide resource material for identification and quantification of health risks related to waterborne pathogens and for establishing health-based targets for water treatment technologies (WHO, 2022). Examples of the implementation of QMRA in WSPs can be found in: Guidelines for drinking-water quality (WHO, 2022); Guidelines on the use of wastewater in agriculture (WHO, 2006); Quantitative microbiological risk assessment: application to water safety management (WHO, 2016); Evaluating household water treatment options: health based targets and microbiological performance specifications (WHO, 2011); Potable reuse: Guidance for producing safe drinking-water (WHO, 2017). A similar approach is also implemented in Sanitation Safety Planning (WHO, 2015b).



## Case studies

### **7.1 CASE STUDY 1: HARVESTING AND PROCESSING OF LIVE OYSTERS (THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND)**

#### **7.1.1 Microbiological hazards**

Many areas used for commercial harvesting of bivalve molluscs are impacted by wastewater and land runoff containing a wide variety of contaminants. Consequently, the consumption of contaminated bivalves can result in illness due to the presence of pathogenic microorganisms in the growing waters. Post-harvest contamination of bivalves can also occur and has been linked to large outbreaks of illness. Among the various species of bivalves, oysters present greater risk of illness because they are often consumed raw or lightly cooked (Potasman, Paz and Odeh, 2002; Campos and Lees, 2014). In the past, the most important illnesses associated with oysters were typhoid and paratyphoid fevers. Following the implementation of shellfish sanitation programmes and the reduced frequency of the causative pathogens in many parts of the world, these illnesses are now much less prevalent. Currently, the most common illnesses are due to viruses (NoV, Hepatitis A) and *Vibrio* bacteria (*V. parahaemolyticus*, *V. vulnificus* and, to a lesser extent, *V. cholerae*), including in countries with comprehensive sanitation programmes (Potasman, Paz and Odeh, 2002; Bellou, Kokkinos and Vantarakis, 2013; Baker-Austin *et al.*, 2018). *Vibrio* risks are not discussed in detail in this case study.

## 7.1.2 Microbiological controls during primary production

Most oysters produced in the United Kingdom of Great Britain and Northern Ireland are distributed and sold live and are frequently eaten raw or sometimes lightly cooked, as is the case in most other European countries (Stroud, 2001). The main species produced are the native oyster (*Ostrea edulis*) and the Pacific oyster (*Crassostrea gigas*). Public health controls on the commercial production of these bivalves are essentially based on assessments of sources of pollution likely to affect the sanitary quality of the growing areas (sanitary surveys or growing area assessments) and classification of the areas based on monitoring of faecal indicator organisms in water/bivalves (FAO and WHO, 2018). Essentially, sanitary surveys are qualitative assessments of the likely contribution of each pollution source and rely considerably on “weight of evidence” and expert judgement approaches. Some elements of the surveys such as modelling of the circulation of microbiological contaminants in the growing areas can be fully quantitative (Cefas, 2014).

Monitoring of faecal indicator bacteria (*E. coli* in the United Kingdom of Great Britain and Northern Ireland) provides an indication of the risk of faecal contamination and the requirement for additional, short-term measures to reduce risk to an “acceptable” level. The classification determines whether the production areas can be used for commercial harvesting and the post-harvest treatment (relaying, depuration, cooking) required, if any, before the bivalves can be marketed for human consumption. The classification criteria used in the European Union (EU) under the Food Hygiene Regulations<sup>1</sup> is summarized in **Table 7**. Illness cases associated with bivalves from class A/Approved areas occur regularly (EFSA, 2012b).

Countries that export bivalves to the European Union must use a system that complies with the requirements of the destination market (Lee and Reese, 2014). A few studies have compared the classification criteria of the EU system with systems in other countries (European Commission, 1996; Lee and Reese, 2014; Taylor *et al.*, 2015; de Souza *et al.*, 2017) since this is important evidence to support international trade agreements and strengthen and harmonize consumer protection across different geographies.

In addition to the criteria prescribed by the Food Hygiene Regulations, the United Kingdom of Great Britain and Northern Ireland applies a guideline standard of 300 faecal coliforms/100 ml of flesh and intravalvular fluid in 75 percent of samples, as required by Directive 2006/113/EC (European Parliament and Council of the European Union, 2006).

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<sup>1</sup> The requirements of the EU Food Hygiene Regulations still apply in the United Kingdom of Great Britain and Northern Ireland at the time of writing. However, the requirements are likely to change in the near future as a result of the United Kingdom of Great Britain and Northern Ireland leaving the European Union.



**TABLE 7** Criteria for classification of shellfish production areas in the European Union

CLASS <sup>a</sup>	MICROBIOLOGICAL STANDARD <sup>b</sup>	TREATMENT REQUIRED
A	Samples of live bivalve molluscs from these areas must not exceed, in 80% of samples collected during the review period, 230 <i>E. coli</i> /100 g of flesh and intravalvular liquid. The remaining 20% of samples must not exceed 700 <i>E. coli</i> /100 g of flesh and intravalvular liquid. <sup>c</sup>	None
B	Live bivalve molluscs from these areas must not exceed, in 90% of the samples, 600 MPN <i>E. coli</i> /100 g of flesh and intravalvular liquid. In the remaining 10% of samples, live bivalve molluscs must not exceed 46 000 MPN <i>E. coli</i> /100 g of flesh and intravalvular liquid. <sup>d</sup>	Purification, relaying or heat treatment by an approved method
C	Live bivalve molluscs from these areas must not exceed 46 000 <i>E. coli</i> MPN/100 g of flesh and intravalvular liquid. <sup>e</sup>	Relaying or heat treatment by an approved method

<sup>a</sup> The competent authority (= responsible authority) has the power to prohibit any production and harvesting of bivalve molluscs in areas considered unsuitable for health reasons. Harvesting may not be undertaken from areas not meeting the requirements for Class A, B or C.

<sup>b</sup> The reference method is given as ISO 16649-3.

<sup>c</sup> Regulation (EC) No 854/2004 as amended by Regulation (EU) 2015/2285.

<sup>d</sup> Regulation (EC) No 854/2004 as amended by Regulation (EC) No 1021/2008.

<sup>e</sup> Regulation (EC) No 854/2004.

Source: FAO & WHO. 2018. *Technical guidance for the development of the growing area aspects of bivalve mollusc sanitation programmes*. Food Safety and Quality Series No. 5. Rome.

This guideline standard, which is less stringent than the class A standard, aims to protect shellfish growing waters from pollution and has been a major driver of pollution reduction programmes targeted at improving shellfish water quality in the United Kingdom of Great Britain and Northern Ireland. In addition to the microbiological guideline standard, the Directive prescribes other physical and chemical parameters that affect growth and survival of the bivalves.

Concentrations of microbiological contaminants vary markedly in the environment and between sampling occasions. Variations exceeding one log<sub>10</sub> can occur over a period of hours in growing areas influenced by rainfall-dependent discharges and/or areas subject to strong currents. Concentrations of viruses in the environment also vary according to their prevalence in the community and are excreted more episodically than indicator bacteria (Campos *et al.*, 2015). Consequently, many studies have reported a lack of correlation between concentrations of indicator bacteria and pathogens in growing areas on a sample by-sample basis (Serracca *et al.*, 2010; Younger *et al.*, 2018). Comparisons of faecal indicator bacteria with other indicators show that the former are poor predictors of virus presence and abundance in bivalves at the point of harvest (Miossec *et al.*, 2001).

Risk factors associated with norovirus (NoV) contamination in oysters are seasonal (winter is the high-risk period in temperate climates), community outbreaks of gastroenteritis, and discharges of untreated/partially treated wastewater following rainfall events (Campos and Lees, 2014).

### 7.1.3 Microbiological controls during processing

Depuration is commonly used as post-harvest treatment for many species of bivalves, including oysters. This treatment consists basically in placing the bivalves in tanks with clean seawater under conditions that maximise the natural filtering activity and result in the expulsion of intestinal contents from the animals thus promoting their decontamination (Lee, Lovatelli and Ababouch, 2008). Depuration is effective in removing faecal indicator bacteria from shellfish, but less effective in removing viruses and marine vibrios (Lee, Lovatelli and Ababouch, 2008; Lees, Younger and Doré, 2010; Dorothy-Jean & Associates Ltd., 2018).

Depuration facilities use large quantities of seawater. Water volumes used depend on the size of the facility, tank design and volume of bivalves to be depurated and number of depuration cycles. Most commonly, depuration facilities rely on a local source of natural seawater for depuration. Where the locally available natural seawater is not of the required characteristics or quality, or where the depuration plant is located some distance from the sea, artificial seawater is used instead (Lee, Lovatelli and Ababouch, 2008). In some countries, seawater is reused from one depuration cycle to another. If this is undertaken, a higher standard of water treatment is advisable to remove metabolic by-products and maintain depuration efficiency (Lee, Lovatelli and Ababouch, 2008).<sup>2</sup>

In the European Union, different countries stipulate different requirements with respect to the quality of the water to be used in depuration, and there is no commonly accepted definition of “clean seawater” for this purpose. In the European Union, Regulation (EC) No 852/2004 defines clean seawater as being:

*natural, artificial or purified seawater or brackish water that does not contain microorganisms, harmful substances or toxic marine plankton in quantities capable of directly or indirectly affecting the health quality of food*

(European Parliament and Council of the European Union, 2004).

The lack of specific limits and guideline values in this definition has caused some practical problems with the interpretation and implementation of the requirement for clean seawater to be used in depuration of bivalves (Lees, Younger and Doré, 2010).

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<sup>2</sup> Artificial seawater may not be suitable for the depuration of all species (Lee, Lovatelli and Ababouch, 2008).

If treatment of the seawater is necessary, then the treatment method must be authorized by the national authority as part of the approval process for the depuration system. If the depuration system is recycling water, then steps must be taken to ensure that the recycled water is of adequate quality.

Process control parameters for depuration include tank loading, concentrations of dissolved oxygen, water flow rate, temperature, salinity, turbidity and pH. To achieve the required microbiological quality parameters, water entering and recirculating within depuration systems is usually disinfected through chlorination, UV light, ozonation or iodophors (Lees *et al.*, 2010). Generic guidance produced by FAO (Lee, Lovatelli and Ababouch, 2008) makes the following recommendations with respect to natural seawater for use in depuration:

- If it is to be subjected to disinfection prior to use: be taken from an area that at least conforms to the requirements for a production area suitable for depuration (EU class B, US Restricted).
- If it is not to be subjected to disinfection prior to use: be taken from an area that at least conforms to the requirements for a production area suitable for direct human consumption (EU class A, US Approved).
- Be free of chemical contaminants in such concentrations that may either interfere with the physiological functioning of the animals or, following uptake, result in the possibility of taints or human health effects.
- Be taken from an area free of significant concentrations of potentially toxic phytoplankton species or biotoxins.
- Have a salinity between 19 and 35 ppt (depending on species to be depurated and the salinity of the harvesting area).
- Have a turbidity less than or equal to 15 NTU (Nephelometric Turbidity Units).

Water used in depuration facilities for purposes other than the depuration itself should be of potable quality, in other words should conform to the WHO recommendations for potable water quality<sup>3</sup> (Lee, Lovatelli and Ababouch, 2008). The Code (FAO and WHO, 2020b) recommends the use of clean seawater when:

- washing bivalves to remove mud/detritus before depuration;
- washing bivalves after the depuration process;
- conditioning and storage of bivalves in tanks, floats, natural sites and rafts;
- decoupling and grading bivalves; and

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<sup>3</sup> *E. coli* or thermotolerant coliform bacteria must not be detectable in any water directly intended for drinking, in treated water entering the distribution system, or in treated water in the distribution system.

- washing bivalves for heat shocking.

Shellfish sanitation systems in the European Union recommend that an HACCP system be implemented to control the functioning of the whole depuration process. The system should include regular microbiological checks, ideally performed on shellfish both before and after depuration and through checks on the seawater (Lee, Lovatelli and Ababouch, 2008; Lees *et al.*, 2010). In the European Union, depurated bivalves are required to comply with an end-product standard of 230 *E. coli*/100 g of shellfish flesh (equivalent to class A) and the absence of *Salmonella* spp. in 25 g under Regulation (EC) No 2073/2005 (European Communities, 2005).

#### 7.1.4 Risk management measures

Routine monitoring of NoV in oysters before they are placed on the market is not legally required at present. In 2015, the EU Reference Laboratory for Monitoring Bacteriological and Viral Contamination of Bivalve Molluscs noted:

*...a target for products placed on the market is unlikely to be successful unless measures are also taken to constrain the degree of norovirus contamination of products entering the processing chain from primary production. Virus contamination of LBMs [live bivalve molluscs] occurs during primary production and this is the key point in the production chain where the risk needs to be better managed* (Cefas, 2015, p. 3).

In this respect, EFSA recommended that:

*Control measures for norovirus in oysters should focus on avoiding contamination by either preventing human faecal contamination in mollusc production areas, or restricting commercial harvesting from faecally-contaminated areas* (EFSA, 2012b, p. 32).

However, some authorities have implemented interim measures to control this risk. For instance, the Food Safety Authority of Ireland requires that, in order for oysters from a production area implicated in an NoV outbreak to re-enter the market, food business operators must demonstrate that the oysters contain less than 200 genome copies/g of NoV (with or without post-harvest treatment) (Food Safety Authority of Ireland, 2013). On this matter, EFSA considers that microbiological criteria for NoV in oysters are useful for validation and verification of HACCP-based systems and can also be used as an additional control to improve risk management in production areas, during both processing and retail (EFSA, 2012b). Another study in Ireland demonstrated that the relaying of oysters for 17 days in a “clean seawater” site

followed by depuration at elevated temperatures (15–17 °C) over a minimum of four days reduced the concentrations of NoV in oysters to background levels detected in the production area before the gastroenteritis incident associated with oysters from that same area (Doré *et al.*, 2010). Depuration at elevated temperature (18 °C) alone has been shown to significantly improve the removal rate of NoV genogroup II from oysters, by comparison with depuration at 8 °C (Younger *et al.*, 2020).

## **7.2 CASE STUDY 2: FISHING AND PROCESSING OF PELAGIC FISH (NORWAY)**

### **7.2.1 Fish products and microbiological hazards**

Pelagic species such as herring (*C. harengus*), Atlantic mackerel (*S. scombrus*), blue whiting (*M. poutassou*) and Barents Sea capelin (*M. villosus*) constitute most of the fish landed in Norwegian ports (ICES, 2021). Norway has to a large extent been – and still is – a producer of raw materials and semiprocessed products for the seafood industry. Most of the processing of pelagic fish consists of filleting, packing and freezing. However, there is also some production of processed products such as frozen fish fingers, fish balls and fish cakes (FAO, 2011).

To maintain high fish quality during on-board storage and transportation, and to delay bacterial spoilage, the fish are placed into tanks containing refrigerated seawater shortly after capture. In the processing plants, the fish are transported on conveyor belts, washed with potable water, sorted through sorting machines, and processed through filleting or trimming machines, before packing and finalizing of the product. Along the production line, the fish are exposed to surfaces, production waters and handled by trained workers, where required.

The Norwegian Quality Regulations Relating to Fish and Fishery Products contain requirements on the use of water and ice in fishing, transport and freezer vessels. These are:

*Clean water shall be used for rinsing of fish on board. The same water quality shall be used for production of ice for use on board. Ice must be stored in such a way as to avoid contamination. Vessels with decks shall be equipped with a seawater pump that has sufficient capacity for rinsing fish and cleaning the vessel. The seawater intake must be placed and used in such a way that it does not take in water that has been contaminated by wastewater, cooling water or other sources of contamination*

(Norwegian Ministry of Fisheries, 1999, p. 19).

The Quality Regulations, the Law of Food Production and Food Safety (Food act) (LOV2003-12-19-124) and the Food Hygiene Regulations (FOR-2008-12-22-1623; FOR-2013-0628-844) require that all fish processing plants have internal controls based on HACCP plans. HACCP is not required for fishing vessels because they are considered “primary producers”. However, they are still required to provide appropriate equipment for safe handling during capture, storage and delivery (Svanevik, 2015).

Internationally, where fish and fishery products have been implicated in cases of human illness, they are typically associated with cross-contamination during handling and processing, improper conditions of storage and preparation or reheating of the product. Human infections from cross-contaminated products can be caused by *Staphylococcus aureus*, *Salmonella enterica*, *Escherichia coli* and *Campylobacter jejuni*. Some other pathogens, such as *Aeromonas hydrophila*, *Clostridium botulinum*, *Vibrio cholerae*, *V. parahaemolyticus*, *V. vulnificus*, *V. alginolyticus*, *Mycobacterium marinum*, *Photobacterium damsela*, *Erysipelothrix rhusiopathiae* and *Listeria monocytogenes* have also been recognized as causative agents linked to fish handling or consumption (Novotny *et al.*, 2004). Scombroid poisoning caused by histidine decarboxylation by *C. perfringens*, *Morganella morganii*, *Photobacterium phosphoreum*, and other mesophilic bacteria, is also important with respect to mackerel (Hungerford, 2010).

## 7.2.2 Safety and quality of fish products and processing operations

Svanevik *et al.* (2015) used ten years of spot sampling undertaken in the Norwegian pelagic fish sector to assess the microbiological conditions of fresh fish, surfaces and production water along the production and processing chains. The aim of the study was to improve the quality of fish products and mitigate health risks to consumers. Sample results were assessed against various quality, hygiene and safety parameters. The study included data from purse seiners and trawlers from the Norwegian fishing fleet (ocean going fleet; all with laboratory facilities) and various fish processing factories.

Samples were collected from the surfaces of equipment and water associated with fishing and processing activities, i.e. water and surfaces in contact with the fish (Svanevik *et al.*, 2015). In vessels, surface samples were collected from the pump nozzle, sift box, sorting chamber, refrigerated seawater in storage tanks, tubes and outlets, primarily before capture. Occasionally, purse seine or trawl bags were also sampled. Seawater samples were taken during on-board pumping and from the refrigerated seawater tanks prior to and after storage of fish. In the factories, surface samples included conveyor belts, sorting and filleting machines, in addition

to surfaces of water drains in the production area. Water samples were taken from the landing tanks, either seawater or tap water and different washing tanks inside the factory holding potable water. Some samples were collected from the clothing of the workers that were in contact with the fish.

Fish, surface and water samples were tested for heterotrophic plate counts (including H<sub>2</sub>S producing bacteria), faecal indicator organisms (thermotolerant coliforms, enterococci, presumptive *E. coli*) and *Listeria monocytogenes*. Results were assessed against the guideline values presented in **Table 8**. Most of these guidelines were derived from European Union Food Hygiene Regulations (EC) No 853/2004 and (EC) No 2073/2005<sup>4</sup> and, where appropriate, from the Norwegian Quality Regulations for Fish and Fish Products and Norwegian Food Hygiene Regulations. With respect to water quality parameters, the guidelines used were from the European Directive 98/83/EC on the quality of water intended for human consumption.

**TABLE 8** Quality, hygiene and safety guideline values used in the microbiological assessment for Norwegian pelagic fishing industry

SAMPLE	QUALITY		HYGIENE (FAECAL INDICATOR BACTERIA)				SAFETY	
	HETEROTROPHIC PLATE COUNT		THERMO-TOLERANT COLIFORMS		ENTEROCOCCI		<i>L. MONOCYTOGENES</i>	
	<i>m</i>	<i>M</i>	<i>m</i>	<i>M</i>	<i>m</i>	<i>M</i>	<i>m</i>	<i>M</i>
Fish (log <sub>10</sub> CFU/g)	5.7	6.7	0.6	1.3	2.7	3.1	Neg.	Neg.
Surface (log <sub>10</sub> CFU/cm <sup>2</sup> )	0.8	1.7	0.3	0.8	-	-	Neg.	Neg.
Water (log <sub>10</sub> FU/100 ml)	2 (log <sub>10</sub> CFU/ml)	-	0	0	0	0	Neg.	Neg.

CFU: colony forming units; Neg.: negative.

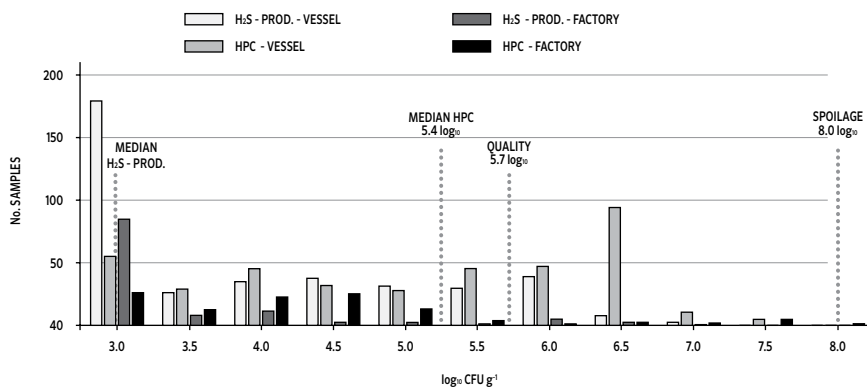
NB. Sample results were evaluated against good conditions (<*m*), acceptable conditions (between *m* and *M*) and unacceptable conditions (>*M*). The number of fish and surface samples with values between *m* and *M* must not exceed 60 percent and 40 percent of heterotrophic plate count (HPC) and faecal coliforms, respectively. No sample should be positive for *L. monocytogenes*. Water used in production must be of potable quality, with no faecal indicator organisms, and HPC must not exceed *m*.

Source: Svanevik, C.S, Roiha, I.S., Levsen, A. & Lunestad, B.T. 2015. Microbiological assessment along the fish production chain of the Norwegian pelagic fisheries sector - results from a spot sampling programme. *Food Microbiology*, 51: 144-153. <https://doi.org/10.1016/j.fm.2015.05.016>. (Reproduced under the terms of the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND), <https://creativecommons.org/licenses/by-nc-nd/4.0/>, for original language only.)

<sup>4</sup> Norway is not a member of the European Union but has adopted the requirements of the EU Food Hygiene Regulations.

The frequency distributions of median values of HPC and H<sub>2</sub>S-producing bacteria are shown in **Figure 8**. HPC are used as a quality indicator since increased bacterial concentrations may indicate poorer storage conditions or improper handling. In total, 36 percent of the fish samples collected from vessels exceeded *m*, and 1.4 percent of the fish samples exceeded *M* (not acceptable). Routine washing with potable water appeared to reduce HPC concentrations since only 12 of the 120 samples (10 percent) from processing facilities exceeded *m*. Surprisingly, fish samples from landing tanks had significantly lower HPC than fish collected during processing steps and fish collected from the refrigerated seawater tanks in vessels (**Figure 9**). The researchers attributed these results to a reduction in HPC contamination when fish are exposed to water in the landing tanks and additional contamination acquired later in the processing chain (Svanevik *et al.*, 2015).

**FIGURE 8** Number of samples corresponding to 0.5 log<sub>10</sub> intervals of heterotrophic plate count and H<sub>2</sub>S-producing bacteria in samples taken from fishing vessels and fish processing facilities

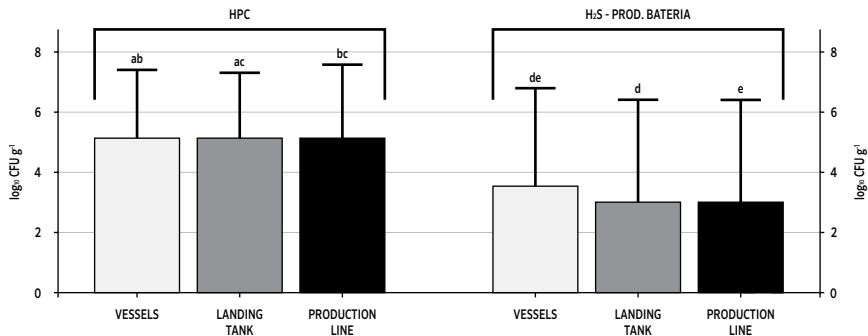


Note: Dotted lines represent the median heterotrophic plate count and H<sub>2</sub>S producing bacteria, the good quality heterotrophic plate count limit (*m*=5.7 log<sub>10</sub> CFU/g) and the level at which fish are considered spoiled (8 log<sub>10</sub> CFU/g).

Source: Svanevik, C.S, Roiha, I.S., Levsen, A. & Lunestad, B.T. 2015. Microbiological assessment along the fish production chain of the Norwegian pelagic fisheries sector - results from a spot sampling programme. *Food Microbiology*, 51: 144-153. <https://doi.org/10.1016/j.fm.2015.05.016>. (Reproduced under the terms of the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND), <https://creativecommons.org/licenses/by-nc-nd/4.0/>, for original language only.)



**FIGURE 9** Median concentrations of heterotrophic plate count and H<sub>2</sub>S-producing bacteria in fish collected from fishing vessels, fish landing tanks and production lines in factories



Note: Letters indicate statistically significant differences.

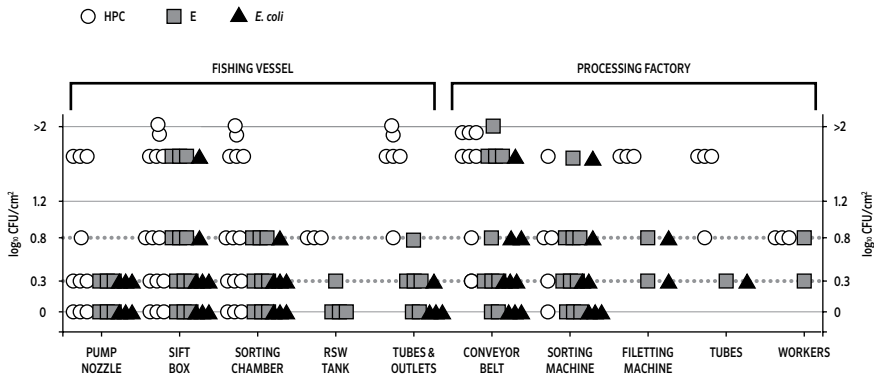
Source: Svanevik, C.S, Roiha, I.S., Levsen, A. & Lunestad, B.T. 2015. Microbiological assessment along the fish production chain of the Norwegian pelagic fisheries sector - results from a spot sampling programme. *Food Microbiology*, 51: 144–153. <https://doi.org/10.1016/j.fm.2015.05.016>. (Reproduced under the terms of the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND), <https://creativecommons.org/licenses/by-nc-nd/4.0/>, for original language only.)

All water samples collected at the factories, landing tanks and washing tanks had bacterial concentrations that were too numerous to count (>2.5 log<sub>10</sub> CFU/ml). Council Directive 98/83/EC does not prescribe an upper limit for HPC in production water; however, samples >2 log<sub>10</sub> CFU/ml must trigger an investigation to determine the contamination source.

Of the 115 contact point samples collected from vessels and tested for *E. coli*, four had values above *M* (not acceptable) (**Figure 10**). One of these, collected from a sift box, had 1.7 log<sub>10</sub> CFU/cm<sup>2</sup> *E. coli* indicating considerable faecal contamination. Among the 57 water samples collected from vessels, 15 were positive for *E. coli*, with five samples >1.7 log<sub>10</sub> CFU 100/ml. These samples were collected from the refrigerated seawater tank at two vessels.

In factory, fish and equipment are more likely to be exposed to human contact. In total, 89 contact point samples were analysed for *Enterobacteriaceae* and *E. coli*. Concerning surface samples, *E. coli* was detected in 3 samples (out of 71), from a sorting machine and from conveyor belts, with value >*M* (0.8 log<sub>10</sub>CFU/cm<sup>2</sup>). Nine of the 18 water samples collected at factories were positive for coliform bacteria, and five of these samples had *E. coli*, with concentrations ranging from 0.9 and 1.7 log<sub>10</sub> CFU/ml (**Figure 10**).

**FIGURE 10** Median concentrations of heterotrophic plate count, *Enterobacteriaceae* and *E. coli* in samples collected from surfaces in fishing vessels and processing facilities



Note: Dotted reference lines represent relevant guideline values. HPC: heterotrophic plate count; E: *Enterobacteriaceae*;

Source: Svanevik, C.S, Roiha, I.S., Levsen, A. & Lunestad, B.T. 2015. Microbiological assessment along the fish production chain of the Norwegian pelagic fisheries sector - results from a spot sampling programme. *Food Microbiology*, 51: 144-153. <https://doi.org/10.1016/j.fm.2015.05.016>. (Reproduced under the terms of the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND), <https://creativecommons.org/licenses/by-nc-nd/4.0/>, for original language only.)

Of the 605 fish samples tested for *L. monocytogenes*, of which 450 were from fishing vessels, the pathogen was detected in six samples. Among the 155 samples collected from 1 189 processing facilities, two were positive for *L. monocytogenes*. During spot sampling, fish samples were positive for the pathogen on three occasions. The bacterium was also found on the surface of fishing gear and in water samples from the refrigerated seawater tank, and on a conveyor belt at the factory (Table 9). In addition, four sampling runs had surface samples and water samples positive for *L. monocytogenes*.

Overall, the occurrence of *L. monocytogenes* in fish from vessels and factories in this study was <0.8 percent. This is lower than the percentage reported for a number of fishery products in the European baseline survey undertaken by EFSA in 2010–2011 (2.2 percent) (EFSA, 2013).

**TABLE 9** Number of samples positive for *Listeria monocytogenes*

SAMPLING	5		6		9		10		11		13		20		22		23	
	u	m/M	u	m/M	u	m/M	u	m/M	u	m/M	u	m/M	u	m/M	u	m/M	u	m/M
<b>Fish</b>	11	4	8	2	14	0	8	0	9	0	9	0	4	2	23	0	16	0
<b>Surface</b>	10	6	6	1	4	1	5	1	5	1	7	2	6	1	21	0	10	0
<b>Water</b>	6	1	2	0	2	1	2	0	6	0	3	1	-	-	3	1	3	1

NB. Since no samples should be positive for this bacterium, any positive sample that did not comply with the microbiological quality assessment criteria is shown in bold.

Source: Svanevik, C.S, Roiha, I.S., Levsen, A. & Lunestad, B.T. 2015. Microbiological assessment along the fish production chain of the Norwegian pelagic fisheries sector - results from a spot sampling programme. *Food Microbiology*, 51: 144-153. <https://doi.org/10.1016/j.fm.2015.05.016>. (Reproduced under the terms of the Creative Commons Attribution-NonCommercial-No Derivatives License (CC BY NC ND), <https://creativecommons.org/licenses/by-nc-nd/4.0/>, for original language only.)

### 7.2.3 Risk management measures

The results of the risk assessment demonstrate the importance of controlling bacterial contamination throughout the entire pelagic fish processing chain, from catching and handling to processing. It also demonstrated that there is large scope to improve the hygiene conditions of fish held on board the vessels and in processing factories. This is considered critical because bacteria established early during the process can be retained throughout the chain and adversely affect the quality and safety of the end-product (Svanevik *et al.*, 2015).

On-board pumping was found to increase the bacterial load of fish gills and skin. The mechanism of contamination was found to be the release of faecal matter from the fish due to crowding during on board pumping and the associated stress, contaminating the outer surfaces of the fish and the refrigerated sweater used in the tanks (Svanevik, 2015).

Maintaining constant subzero temperatures during storage combined with proper recirculation and good hygiene practices in refrigerated water systems together with a reduction in fish densities in tanks would contribute to reduce the risk of contaminating the whole catch. These measures have also been proposed for salmon (Chan *et al.*, 2020). In considering this matter, the Good Practice Guide for Establishments Producing Fish Oil Intended for Human Consumption recommends rapid unloading and landing of the fish, the use of equipment that does not damage the fish and the identification of specific control measures in HACCP plans (Norwegian Seafood Federation, 2010).

## 7.3 CASE STUDY 3: FISH PROCESSING IN THE CANNING INDUSTRY (PORTUGAL)

### 7.3.1 Production of canned sardines

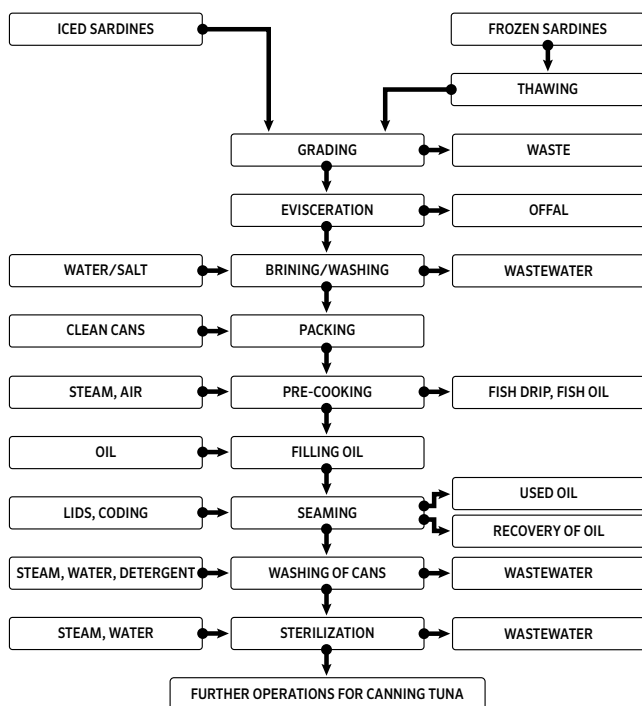
Fish canning has a long tradition and is the main sector of the fish processing industry in Portugal. Currently, there are approximately 20 units processing tuna, sardines and mackerel for internal and export markets (Fórum Oceano, 2017). This industry consumes large volumes of water in operations such as cleaning, washing, cooling, thawing, and ice production and removal. **Figure 11** shows the main steps involved in the production of canned sardines in oil. Temperature control is important both in the storage of raw material and in the subsequent sterilization operations. Critical operations include double seaming, sterilization and sanitation of cooling water when applied directly to cans.

These operations generate large quantities of wastewaters with high content of organic matter, salts, oil and grease. These factors, together with the large variations of wastewater produced between fish processing operations/plants/type of raw material processed, result in difficulties in meeting the effluent emission limits for industrial wastewaters set out in the national legislation (Decree-Law No. 236/98) (Cristóvão *et al.*, 2012). It has been proposed that sedimentation, coagulation-flocculation and aerobic biological processes could be used to reduce the content of suspended solids, oils, greases and organic matter present in wastewater from fish canning industries. Further treatment of the clarified effluent could involve Fenton oxidation, RO, and UV radiation disinfection, to obtain water with quality consistent with its reuse in the industrial process (Cristóvão *et al.*, 2012).

### 7.3.2 Microbiological hazards

In the canning of fish products, it is necessary to obtain a condition during heat processing known as commercial sterility. This implies the destruction of all pathogenic microorganisms, including those that are more heat resistant which could cause spoilage under ambient conditions likely to be encountered during storage and distribution of the products. Fish canning has been implicated in a relatively low number of cases of food poisoning (Ababouch, 2002). Among the microbiological hazards mentioned in Case Study 2, the most important in canned fish are botulism, histamine poisoning and staphylococcus enterotoxin poisoning. In particular, the thermal processes used in the canning industry must ensure the destruction of the heat resistant *Clostridium botulinum*. Canning is typically conducted at a sterilization temperature of 121.1 °C. At this temperature, the  $D_{121.1}$  value for this pathogen is 0.1–0.23 minutes, i.e. if  $10^4$  spores of *C. botulinum* were subjected to 121.1 °C for 0.23 minutes,

**FIGURE 11** Flow diagram of steps involved in the production of canned sardines in oil



Source: Bratt, L. 2013. *Technical guide to fish canning. Volume III*. Rome, FAO, Globefish Research Programme. [www.fao.org/3/bb214e/bb214e.pdf](http://www.fao.org/3/bb214e/bb214e.pdf)

the population would be reduced by one log<sub>10</sub>. However, it is essential that all contents of a can are fully sterilized (Bratt, 2013).

Regulation (EC) No. 2073/2005 on the microbiological criteria for foodstuffs prescribes maximum values for histamine in fish products. For fish species associated with a high amount of histidine (e.g. tuna, mackerel, sardines), the mean value is ≤100 mg/kg of histamine and the maximum value is 200 mg/kg. In commercial operations, however, it is likely that the major retail or trading organizations would impose a maximum concentration of 50 mg/kg (Bratt, 2013).

### 7.3.3 Risk management measures

In Portugal, the main pieces of legislation regulating the quality and safety of canned products are the Food and Hygiene Regulations, namely Regulation (EC) No. 852/2004, Regulation (EC) No. 853/2004 and Regulation (EC) No. 854/2004.

The full regulatory framework is presented in Appendix IV. Regulation (EC) No. 852/2004 requires food manufacturers to implement an HACCP system for food safety management purposes, and there are specific requirements relative to the manufacture of heat-processed products:

- Any heat treatment is to raise every part of the product to a given temperature for a given period of time and to prevent the product from becoming contaminated during the process.
- Food business operators must check regularly the main relevant parameters (particularly temperature, pressure, sealing and microbiology), including the use of automatic devices.
- The process should conform to an internationally recognized standard (e.g. for pasteurization or sterilization).

As part of the required HACCP plan, fish canning operators are required to examine each step of the manufacturing process and consider the associated physical, chemical and biological hazards that could affect the safety and quality of the product(s). Based on the identified hazards, operators are required to determine the associated critical control points. In the canning industry, common CCPs are double seaming, sterilization, and sanitation of cooling water in direct contact with sterilized cans (Bratt, 2013).

## **7.4 CASE STUDY 4: PRODUCTION OF RAINBOW TROUT (*ONCORHYNCHUS MYKISS*) IN FLOW-THROUGH TANK SYSTEMS/RACEWAYS (BRAZIL)**

### **7.4.1 Fish production and water use**

Brazilian aquaculture is becoming increasingly competitive in international markets, with production continuing to increase on an industrial scale, accompanied by a constant improvement in product quality (FAO, 2021). Farming of rainbow trout (*Oncorhynchus mykiss*) in raceways is an important sector of the aquaculture industry in this country. Most farms are concentrated in the south and southeast regions. Production in 2020 was estimated at approximately 2 100 tonnes (FAO, 2021). About 200 of these trout farms are concentrated in the state of Minas Gerais. In southern states (Rio Grande do Sul and Santa Catarina), the release of juveniles from these farms into rivers for recreational fishing is common while in the southeast public visits to trout farms and trout-related gastronomy are also important sources of revenue (Valenti *et al.*, 2021).

Simply defined, raceways for fish culture resemble flumes and are shallow tanks that rely on high flows of water to sustain aquatic life. High-quality water flows into and through the tanks supplying the required oxygen and flushing away wastes. For successful aquaculture, the inflowing water must be within the temperature tolerance of the species being cultured and should match the optimum temperature for the target species as closely as possible (Fornshell *et al.*, 2012).

Water for these systems is usually groundwater coming to the surface in the form of springs or surface water from rain runoff from higher elevations. The water can be reused several times as it flows through multiple raceways in series. Inputs to the system come in the form of high-quality feeds, simple aeration between raceways, cleaning of raceways, size grading of the animals, and easy observation of the fish for disease problems and efficient feed utilization (Tidwell, 2012). Dissolved metabolites from animals in the system are carried out in the effluent, while settleable particulate wastes can be captured by settlement, or less frequently, by other means of filtration. Wastes produced in raceways can be passed on downstream for further treatment and processing or to onsite treatment units. Retention times are low; therefore, temperature changes little within the system. Raceways using groundwater have water temperatures the same as the region's groundwater, which is directly correlated to proximity to the equator. Exceptions include raceways utilizing surface waters or deep source geothermal waters.

Since high-quality water is not always available, locating and securing a proper water supply is a major consideration. Another limitation compared to conventional fish cultivation ponds is the release of high volumes of effluent containing metabolites. While ponds largely process fish wastes within culture systems, raceways do not.

Valenti *et al.* (2021) identifies several constraints on the development of raceway systems for trout farming in Brazil, including the lack of processing plants with sanitary certification. The most common methods of effluent treatment from these farms are settlement tanks, biofilters and constructed wetlands (Silva, Losekann and Hisano, 2013; Lima, 2016).

#### **7.4.2 Microbiological quality of the water in raceways**

According to CONAMA Resolution No. 357/2005 and Decision COPAM/CERH-MG N°1/2008, effluent discharges from fish tanks must be of equal or better quality than the source water used in the tanks. The water quality parameters applicable by the national legislation are presented in **Table 10**.

**TABLE 10** Physical and chemical parameters applicable to Class II waterbodies for production 1 360 rainbow trout and other fish prescribed by CONAMA Resolution No. 357/2005

PARAMETER	PATTERN CLASS II	RELEASE PATTERN	COMFORT ZONE FOR FISH	TROUT
Dissolved oxy-gen (mg/L)	6-9	>5	3-5	>5.5
Temperature (°C)		<40	15-35	15
pH	6-9	6-9	7-9.5	5.5-9.5
Turbidity (NTU)	<100	<100	30-80	
Alkalinity (mg/L)			50-100	20-200
Total ammonia (mg/L)		<20	0-0.05	<0.02
Nitrite (mg/L)	<1.0	<1.0	0.02-2	<0.055
Nitrate (mg/L)	<10	<10	0-10	<100
Phosphate (mg/L)		<0.10	0.03-2	2-100
BOD <sub>5</sub> (mg/L)	<5	<60		

Source: Funck, A.P.M., Simões, J.A.B., Ferreira, M.G., Martins, E. De F.F., Oliveira, F.A.S., Rodrigues, L. Dos S., Melo, M.S. & Filho, K.C.M. 2019. Water quality and effluents generated during rainbow trout culture in a raceway system. *Biomedical Journal of Scientific & Technical Research*, 16(5): BJSTR. MS.ID.002921. (Reproduced without any changes, under the terms of the Creative Commons Attribution 4.0 License [<https://creativecommons.org/licenses/by/4.0/>] with permission from Biomed)

Funck *et al.* (2019) investigated the physico-chemical and microbiological quality of the waters in two commercial rainbow trout farms (A, B) in Minas Gerais. Farm A had lower variation in flow than farm B due to the presence of a controlled floodgates system. Farm B is mainly used for production of juveniles. The main characteristics of the two experimental sites are presented in **Table 11**.

The microbiological part of the study comprised testing of water samples taken from different steps of the production process for thermotolerant coliforms and *E. coli*. Concentrations of thermotolerant coliforms were higher during the rainy season than during the dry season (**Figure 12**) indicating the influence of surface water runoff from agricultural land in increasing the microbiological loading to the source water. At both sites, coliform concentrations in farm effluents were higher than those in influent water but lower than concentrations at downstream sites. However, considering the full dataset, the results from both farm sites were compliant with the microbiological standard for Class II waters of Decision COPAM/CERH-MG N°1/2008 (80 percent results <1 000 CFU/100 ml in six samples). The pattern of *E. coli* contamination at the same farm sites was similar for farm B. In farm A, mean *E. coli* concentrations were higher at farm sites than at upstream and downstream sites.



**TABLE 11** Characteristics of the rainbow trout farms

FEATURES	TROUT FARM A	TROUT FARM B
Type of system	Raceway	Raceway
Water source	River	Stream
Cultivated species	<i>Oncorhynchus mykiss</i>	<i>Oncorhynchus mykiss</i>
Main activity	Grow out	Reproduction and fry culture
Production	120 000 kg/year	-
Average stocked fish	26 000 kg/month	1 350 kg/month (breeders)
Food consumption/day	625 kg	30 kg
Total tanks and volume	23 (approx. 65m <sup>3</sup> )	6 (approx. 7m <sup>3</sup> )
Daily water volume	86 227 m <sup>3</sup>	1 469 m <sup>3</sup>
Total turnover	58 times/day	35 times/day
Average flow (period)	1 047 L/s	17.7 L/s
Management	Manual	Manual

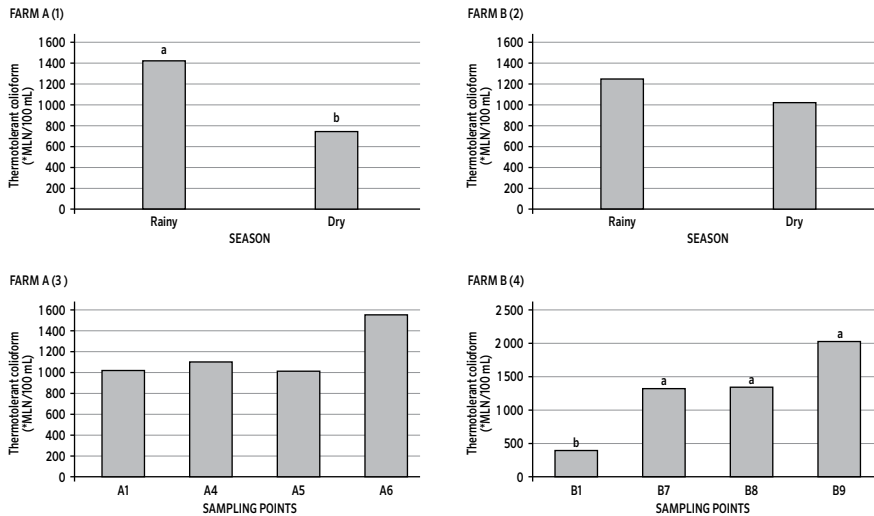
Source: Funck, A.P.M., Simões, J.A.B., Ferreira, M.G., Martins, E. De F.F., Oliveira, F.A.S., Rodrigues, L. Dos S., Melo, M.S. & Filho, K.C.M. 2019. Water quality and effluents generated during rainbow trout culture in a raceway system. *Biomedical Journal of Scientific & Technical Research*, 16(5): BJSTR. MS.ID.002921. (Reproduced without any changes, under the terms of the Creative Commons Attribution 4.0 License [<https://creativecommons.org/licenses/by/4.0/>] with permission from Biomed)

In considering the physico-chemical results, Funck *et al.* (2019) found that both farms were compliant with the national standards for fish production and represented low risk of eutrophication to downstream rivers. They also noted that changes in water quality occurring between source waters and farm effluents are related to the stocking density, quantities of feed used and fish excretion rates. Tank washing was also found to affect water quality in the tanks, particularly during prolonged rainfall.

### 7.4.3 Risk management measures

Raceway systems require considerable water exchange to maintain suitable water quality for fish production and rely on water flow for the collection and removal of metabolic wastes. The water supply for these systems is diverted from streams, springs and flows through the farm by gravity. Diversion of surface waters is considered a non-consumptive use. The discharge of a high-volume, dilute effluent from raceway systems greatly limits the treatment options available to fish producers.

**FIGURE 12** Median concentrations of thermotolerant coliforms in water samples taken from two rainbow trout farms in Minas Gerais, Brazil

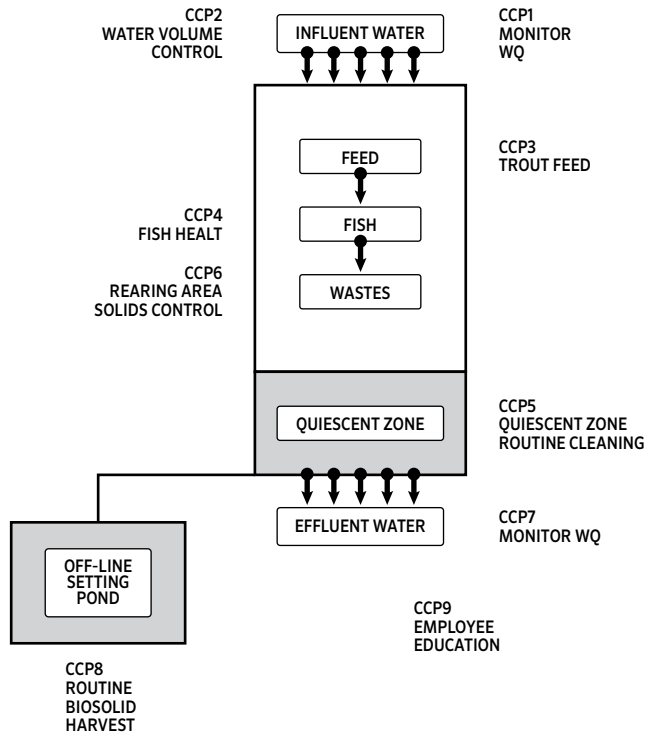


Notes: a, 1, 2: seasonal results (rainy season; dry season) b, 3, 4: individual sampling points. c, A1, B1 - source water, influent d, A4, B7 - farm effluent e, A5, B8 - upstream of the farm f, A6, B9 - downstream of the farm. \*MLN: most likely number.

Source: Funck, A.P.M., Simões, J.A.B., Ferreira, M.G., Martins, E. De F.F., Oliveira, F.A.S., Rodrigues, L. Dos S., Melo, M.S. & Filho, K.C.M. 2019. Water quality and effluents generated during rainbow trout culture in a raceway system. *Biomedical Journal of Scientific & Technical Research*, 16(5): BJSTR. MS.ID.002921. (Reproduced without any changes, under the terms of the Creative Commons Attribution 4.0 License [<https://creativecommons.org/licenses/by/4.0/>] with permission from Biomed)

Because microbiological contaminants that may have infectious properties can remain in the source water for a considerable time and affect its use for fish farming, farmers should take every precaution to prevent contamination of the source water. They should also assess the potential for contamination arising from possible sources located in the immediate area of the catchment; this can be done through sanitary surveys and profiling. Regular water quality testing of source water is critical for determining temporal changes in water quality due to the presence of pollution sources and seasonal and climatic factors. Risks can be mitigated by developing farm-specific Best Management Practices using HACCP principles. An example of a water pollution diagram based on these principles identifying critical control points along the fish production system is shown in **Figure 13**. Note in the figure the presence of an offline settlement tank used to collect biosolids from the quiescent zone via vacuum pumping. The biosolids are subsequently spread onto agricultural fields.

**FIGURE 13** Schematic representation of a water pollution plan with identified critical control points developed for a rainbow trout farm in the United States of America



Source: MacMillan, J.R., Huddleston, T., Woolley, M. & Fothergill, K. 2003. Best management practice development to minimise environmental impact from large flow-through trout farms. *Aquaculture*, 226: 91-99. (Reproduced with permission from Elsevier)

## 7.5 CASE STUDY 5: FARMING AND PROCESSING OF SHRIMPS (*PENAEUS MONODON*) IN MADAGASCAR

Madagascar has vast areas of mangrove forest, estimated at 52 800 ha on its western coastline, which, concerning soil properties and the physico-chemical characteristics of the water, provide favourable conditions for shrimp farming. The national production has been estimated at 58 000 tonnes/year (Coûteaux *et al.*, 2019). The aquaculture of *Penaeus monodon* has been practiced in Madagascar since the early 2000s. A period of rapid development of farming activities was

observed with the opening of seven companies by 2002 which together used 2 100 ha, expanding to 9 500 tonnes in 2004 (Coûteaux *et al.*, 2019). Since 2019, there have been only three companies in full operation exploiting 1 050 ha due to a decrease in the price of shrimp, an increase of feed and fuel prices, and particularly the occurrence of the white spot virus in 2012.

The farmed shrimps produced in these aquaculture sites are certified under organic label or red label (Coûteaux *et al.*, 2019). They are intended for export mainly to the European Union and also to Asia and the United States of America. Over the last two years, export volume was around 4 300 tonnes/year (Table 12) (Autorité Sanitaire Halieutique, 2021).

**TABLE 12** Total production (tonnes) of *P. monodon* exported from Madagascar to overseas markets in 2019 and 2020

MARKET DESTINATION	2019	2020
European Union	4 206	4 089
Asia	92	254
United States of America	10	6
<b>Total</b>	<b>4 308</b>	<b>4 349</b>

Source: Authors' own elaboration (Reproduced with the permission from Autorité Sanitaire Halieutique of Madagascar).

### 7.5.1 Farming system

Each farm comprises a hatchery, nursery and grow-out to control the shrimp's biological cycle to ensure continuity of production. The implementation of the research and development centre and hatchery on site ensures the production of pathogen-free and pathogen-resistant broodstock and production of healthy shrimp nauplius and larvae (Coûteaux *et al.*, 2019). In hatchery, the eggs are obtained from local selected broodstock and tested pathogen-free/pathogen-resistant (Ranaivoson, Rabaonarijaona and Blanc, 2013; Coûteaux *et al.*, 2019). In nursery, nauplii are grown using two methods:

- in tanks with an adjustable aeration system inside a shed, from which nauplii are transferred to ponds; and
- in ponds built in the tannes (clayey areas) with a natural soil bottom (Coûteaux *et al.*, 2019).

To reduce the risk of contamination, the hatchery is installed some distance away from the area of the ponds (Coûteaux *et al.*, 2019).

At grow-out stage, the farming system is semi-intensive with a low density (6–8 units/m<sup>2</sup>) at the end of the farming cycle. The grow-out takes place in ponds, built in the tannes located behind the mangroves. The farming site, including the processing plant, are located in secluded areas, away from the local area of residence of the farmers. In the processing units located on the edge of the ponds, healthy full-grown shrimp are packed. Shrimps are highly perishable, and the time lag between harvesting from the ponds and the processing in the packaging plant must not exceed 30 minutes (Coûteaux *et al.*, 2019).

### **7.5.2 Primary production water (farming)**

Clean seawater is pumped and undergoes treatment (light desalinization followed by chlorination/dechlorination). Where desalinization is not used, a volume of freshwater is pumped from the river and mixed with seawater to obtain brackish water. The target salinity varies according to the stage of the rearing. The seawater is pumped at approximately 18 m<sup>3</sup>/sec and distributed by gravity to each pond (Coûteaux *et al.*, 2019). The supply is done by means of water inlet structures (monks) located on the water supply canal. The water is discharged through the same structures located on the opposite side of the canal, which also serve as harvesting structures.

Ensuring good water quality at source and throughout the supply process is critical as microbiological contamination can spread rapidly. Consequently, in the event of contamination, pathogen control and elimination can be very complex. In 2012, the white spot virus carried by sea currents from the Indian Ocean through the Mozambique Channel reached the farming ponds of some Malagasy sites and caused a production loss of 1 000 tonnes (Ranaivoson, Rabaonarijaona and Blanc, 2013; FAO, 2016). The control and management of the water quality during the shrimps' rearing is thus critical to obtain the optimal conditions necessary for growth and to avoid stress and subsequent infection. As part of the farm control measures, physico-chemical parameters are regularly monitored according to the level of biomass in the farm. Water is kept in the tanks over 3–7 months and renewed during the grow-out period to maintain appropriate quality. The volume of water exchanged is calculated according to the shrimp biomass, dissolved oxygen, phytoplankton quality and turbidity (Coûteaux *et al.*, 2019). The water in the ponds must also comply with nationally prescribed food safety microbiological criteria.

### 7.5.3 Microbiological hazards

Microbiological hazards relevant to shrimp farming can originate from various sources. Vibrios and zoonotic pathogens (parasites, viruses) originate primarily from seawater intakes (Union du Mareyage Français, 2022). Freshwater taken from catchment sources may be contaminated with *Vibrio cholerae*, *Salmonella*, staphylococci and enteric viruses. Enterobacteria and zoonotic pathogens may be introduced in farm areas from bird faeces and land runoff during the rainy season. According to the Laboratoire d'Hygiène des Aliments et de l'Environnement of the Institut Pasteur de Madagascar, the following hazards are widely prevalent in children with symptoms of enteric disease: *Campylobacter* spp., *Shigella* spp., *Salmonella* spp.; viruses such as adenovirus, NoV, and rotavirus; parasitic protozoa such as *Giardia* spp. and helminths such as *Ascaris* (Bastaraud, 2021).

### 7.5.4 Risk management measures

Measures to control the risk of microbiological contamination include the installation of protective dikes around the ponds, pumping stations and monk outlets. Stakes and fences help prevent the passage of pirogues in the vicinity of pumping stations, and nets are placed above settlement ponds to provide protection against birds. Prior to pumping, decanting and installation of mesh filter of different porosity also help eliminate physical and biological contamination.

Chlorination of the water after filtration reduces the risk of microbiological contamination, and a dechlorination step is applied before arrival in the ponds. While the seawater supplying the hatchery and nursery goes through a series of sand and cartridge filters, chlorination and dechlorination and, in some cases, UV treatment are effective in reducing contamination of broodstock and nauplii.

According to information provided by one of the producers, redox potential, free chlorine, total microbiological flora and the ratio of yellow: green colonies in *Vibrio* analysis are monitored as indicators of good farming practices (Table 13 and Table 14). The presence of luminescent green colonies of *Vibrio* indicates the presence of potentially pathogenic vibrios (Ruangpan, 2022). The optimal pH range for shrimp farming is 7.5–8.5. If pH decreases significantly, the risk of disease increases significantly (Aquaculture in Africa, 2022). Disease monitoring and diagnostics in animals captured in the sea helps to detect the early presence of disease in the environment (Ranaivoson, Rabaonarijaona and Blanc, 2013). Additionally, epidemiological surveillance of diseases in the local population helps to put in place measures to prevent the contamination of water sources. The health centres, which cater to the local population as well as the workers, contribute to accomplish this goal (Coûteaux *et al.*, 2019).

The principle of forward flow is followed to avoid any water backflows (mixing between supplied water and used water, including infiltration) during all farming steps to maintain acceptable water quality. The frequency of water quality monitoring usually increases during the rainy season, and harvesting of shrimps may be delayed in the event of episodic water quality deterioration until quality parameters are restored. Staff are regularly trained to undertake these checks and apply biosecurity measures (Ranaivoson, Rabaonarijaona and Blanc, 2013).

**TABLE 13** Results of chemical controls on treated water used in *P. monodon* farming units

PARAMETER	MINIMUM	AVERAGE	MAXIMUM
Redox potential (mV)	673	745	798
Free chlorine (ppm)	0.19	0.77	1.38

Source: Group UNIMA Madagascar, personal communication. (Reproduced with permission from Group UNIMA Madagascar)

**TABLE 14** Results of microbiological controls on treated water used in *P. monodon* farming units

PARAMETER (production stage)	CONCENTRATION (CFU/mL)		
	MINIMUM	AVERAGE	MAXIMUM
Total microbiological flora (treated water)	0	10	36
Vibrios (treated water)	0	0	0
Total <i>Vibrio</i> (ponds)	0	42	90
Yellow <i>Vibrio</i> (ponds)	0	35	72
Green <i>Vibrio</i> (ponds)	0	7	18
Luminescent green <i>Vibrio</i> (ponds)	0	0	0

Source: Group UNIMA Madagascar, personal communication. (Reproduced with permission from Group UNIMA Madagascar)

### 7.5.5 Processing water

Freshwater of potable quality is used in all processing steps. The water, either sourced from the river or boreholes, undergoes various stages of treatment. A preliminary treatment consists of decanting during which dolomite may be added

for neutralization. Water from both sources then passes through a series of sand filters and/or activated carbon filters and chlorination (in some cases additional UV treatment is applied). The ratio of freshwater consumed varies from 35 to 50 m<sup>3</sup>/tons, depending on the type of production. The monitoring undertaken in processing water includes Cl<sub>2</sub>, pH and colour (**Table 15**).

**TABLE 15** Results of physico-chemical controls on treated water used in *P. monodon* processing units

PARAMETER	MINIMUM	AVERAGE	MAXIMUM
Cl <sub>2</sub> (ppm)	0.3	0.7	1.5
pH	7.3	7.69	9.31
Colour	Limpid	Limpid	Limpid

Source: Group UNIMA Madagascar, personal communication. (Reproduced with permission from Group UNIMA Madagascar)

### 7.5.6 Microbiological hazards

Considering the self-check plan established by the producer, the microbiological hazards considered in treated water are total coliforms, *E. coli*, spores of sulfite-reducing anaerobes (clostridia) and vibrios (**Table 16**). Official control monitoring of coliforms, *E. coli*, *Enterococcus faecalis*, clostridia and *Clostridium perfringens* is also undertaken. Bacteria are normally eliminated through the different stages of water treatment, but contamination may occur in clogged filters and runoff water, potentially infiltrated into old pipes or leaky junctions, which are frequent during the rainy season. The development of *Pseudomonas* spp. may occur in stock held in tanks with insufficient water circulation or tanks that have not been used for a long time or in the event of disinfection failure.

### 7.5.7 Risk management options

The processing of shrimps uses large volumes of water, and ensuring its quality is critical for the safety and quality of finished products. A prerequisite document for water quality is mandatory for the approval of a processing plant. In the document, the producer must specify the control procedures and corrective measures in the event of elevated risk of water contamination. Cleaning and disinfection plans are executed at different stages of the water treatment and supply. Mechanical filters and piped systems are cleaned between harvesting periods; storage tanks are cleaned on a monthly basis, and automatic backwash are cleaned on a daily basis. Additionally, at each stage of the water treatment process, there is a specific control procedure to detect any system failure.



**TABLE 16** Results of microbiological controls on treated water used in *P. monodon* processing units (self-testing)

Type of water	TOTAL COLIFORMS (<30/100 ml)			<i>E. COLI</i> (0/100 ml)			SPORES OF SULFITE-REDUCING ANAEROBES (<1/20 ml)			<i>V. PARA-HAEMOLYTICUS</i> (absent/100 ml)			<i>V. CHOLERA</i> E (absent/100 ml)		
	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
Freshwater	<3	<3	0	0	0	0	0	0	0	abs	abs	abs	abs	abs	abs
Ice	<3	<3	0	0	0	0	0	0	0	abs	abs	abs	abs	abs	abs

abs: absent.

NB. The results of microbiological controls on treated water used in *P. monodon* processing units from official control testing were all below the limit of quantification of the testing methods.

Source: Group UNIMA Madagascar, personal communication.

Inside of the processing plant, the microbiological water quality is monitored on a weekly basis using a rotating sampling plan. The EU Directive 98/83/EC was adopted as a reference for water potability as part of this control. Other essential controls are carried out by the operator such as pH, colour and free chlorine measurements made twice a day.

The bacteria *E. coli*, thermotolerant coliforms and faecal streptococci are used by the producer as indicators of faecal contamination while total coliforms and *C. perfringens* are considered as indicators of water treatment efficacy.

During intense rainy periods, the turbidity and the presence of suspended solids in the raw water increase and filters may become clogged. This requires higher frequency of cleaning, disinfection and control. In case of non-compliant monitoring results, shrimp processing is stopped and an investigation is triggered to identify the origin of nonconformity and the appropriate corrective actions or measures. Processing is not resumed until the quality of the water is restored and its potability proven by analytical results. Batches of product processed on the day of the incident and the previous two batches are identified and go through reinforced controls.

### 7.5.8 Risk management applied to products for direct consumption

One of the farms produces cooked and sashimi-quality shrimps. Extra quality shrimps are reserved for these processes, and specific measures are implemented to reduce the risk of microbiological contamination. First, the products are processed separately in time and space from all the other products to prevent

cross-contamination issues. The frequency of cleaning and disinfection operations in the processing environment is increased, and only dedicated single-use equipment is used for each processing step. Finally, the surfaces and atmosphere environment in the processing area are monitored for the presence of total microbiological flora, faecal coliforms, *Staphylococcus aureus*, *Salmonella* spp. and *Listeria* spp.

### **7.5.9 Microbiological criteria for farmed shrimps**

In Madagascar, the EU Regulation No 2073/2005 was adopted for microbiological criteria for all fish and fishery products intended to be exported. Any product affected by non-compliant results with *Listeria* spp. or *Salmonella* spp. are destroyed. Additional treatments such as peeling or heading may be applied by the business operator if hygiene or commercial parameters are not met in the batches of harvested shrimps.

### **7.5.10 Potential for reusing water**

Given the logistical difficulties and the cost of importing equipment to Madagascar, as well as the limited number of specialists in water reuse and recycling, reuse of wastewater is not yet practiced. The opportunity to reuse water from the farming ponds could be explored, particularly to irrigate plant fields or to produce watercress or water mint after a period of settlement. As Madagascar experienced the white spot outbreak in 2012, recycling wastewater from shrimp farming for later reuse is considered to present a risk to Malagasy shrimp production. Currently, national regulations stipulate that wastewater from crustacean processing units must be treated. In addition, since Madagascar has abundant sources of water (underground, surface waterbodies, rain and seawater), recycling water is not considered as important as protecting and ensuring the sustainability and health of these water sources.

### **7.5.11 Conclusion**

The risk for water safety used in shrimps farming and processing depends upon the environment of the water sources (characteristics of sourcing point, local population practices, absence of protection perimeter, unprotected wells) and on the complexity of the treatments put in place. In this case study, the risk management system set by the food business operator is considered effective in ensuring water safety and quality. Since water is the most important input during farming and processing, the quality of the final product always reflects the quality of the water. As contamination through water happens easily and spreads fast, it is important to monitor water quality at all steps of farming and processing shrimps and implement controls to mitigate any possible risk of contamination.

This is done by implementing a combination of risk assessment and management procedures and monitoring plans according to recognized guidelines and standards. Risks are managed and validated through self- and official-control monitoring of water and finished products.

Madagascar possesses abundant unexploited water sources. However, the country lacks water management and supervision strategies to protect and effectively use these sources to provide for regions with low water availability. As water recycling and reuse are currently not practiced due to technical and financial barriers, ensuring the protection and sustainability of natural sources should be a priority. This may be a similar scenario in other developing countries.

### **7.5.12 Recommendation**

To reinforce the need to protect water quality at source, practices and initiatives should be implemented to reduce pollution from human activity, particularly focused on littering and open defecation. The construction of water wells and toilets for local populations will further reduce the use of vital water sources and will help regulate access to key sources. Continued implementation of internationally recognized guidelines will help ensure that water used in farming and processing shrimps is fit-for-purpose.





# Conclusions

## 8.1 GENERAL CONCLUSIONS

- Water is a key element in the production and processing of fish and fishery products, and there is a need to implement more sustainable practices of water use.
- Any type of water (fresh, brackish and sea) can be used in primary production of fish and other aquatic organisms, provided that the risks of contamination have been previously assessed, the quality of the water is monitored, and the water complies with pre-defined quality criteria, as determined by a risk assessment.
- Most water sources can be used for producing fish, except treated wastewater. The level of treatment and potability of the water need to be determined to obtain quality and safety levels for reuse.
- Freshwater and seawater in coastal areas are prone to contamination from animal or anthropogenic sources.
- Fish and fishery products can cause infections or intoxications mediated by viruses, bacteria and parasites. They can also carry antibiotic resistant bacteria.
- Microbiological hazards indigenous to the aquatic environment (e.g. vibrios, *Aeromonas*) and *Anisakis* spp. parasites are of high relevance to fish and fishery products.
- The burden of waterborne disease is highly variable between countries and regions because of differences in epidemiological surveillance and reporting, pathogen prevalence and other factors. It is obvious from epidemiological studies that water is an important vehicle for disease attribution purposes.

- There are many opportunities for water reuse in the fishery sector, especially in processing activities, but they have not been fully realized by the industry.
- While there are commercially available technologies to achieve any desired water quality for specific applications, economic, safety and environmental impact assessments are needed to facilitate decision-making for fish processors.
- Sanitary surveys and profiling and risk assessment and risk management approaches (such as WSPs) comprising water from the abstraction point and surrounding catchment area to the point of water use are important to determine the safety of water for fish production and the likelihood of contamination in the production and processing systems.
- The use of water in the production and processing of fishery products should be subject to a risk-based approach covering the whole water system from the source or catchment area to the storage and distribution of water, within the processing facilities, and to the point of use.
- In aquaculture, selecting a source that continuously supplies safe and high-quality water is critical to determining the quality of the production water and the success of the farm operation.
- To maintain the sanitary quality of fish on vessels and in processing factories, precautionary measures must be applied to limit contamination from leaked faecal matter, to avoid temperature rise and to control any cross-contamination from capture.
- Every canning process should comply with internationally recognized standards for the control of physical, chemical and biological hazards that could affect the safety and quality of the products.
- Monitoring of water is a core element of food safety management systems and is required for ensuring water quality and safety and defining fit-for-purpose water in the fisheries sector.
- Monitoring of indicator microorganisms (process indicators, faecal indicators and index organisms) has been successful in assessing the fitness of water for the various intended uses and reducing human exposure to microbial hazards.
- Linear correlations between the numbers of indicator organisms and enteric viruses in freshwater and seawater are infrequent.
- Linear correlations between the numbers of faecal indicator bacteria and viruses in fish and fishery products are infrequent.
- The presence of vibrios in fishery products is not indicated by the presence of faecal bacteria.
- Application of HACCP in combination with good manufacturing practices helps to control the quality of water used in the production and processing of fish and fishery products.

## 8.2 GENERAL RECOMMENDATIONS

- More research is needed to define suitable criteria for describing the quality and safety of water used in the production and processing of fishery products.
- Relevant information on source water quality can be obtained from water suppliers.
- A supply of drinking (potable) water should exist in any fish and fishery product's processing industrial site, comprising proper facilities for storage and distribution to ensure the safety and quality of fishery products.
- There is a need to harmonize the types and quality of water used in the different steps of fish production and processing (including fishing vessels facilities).
- There is a need to improve analytical methodologies and to establish quality criteria for verifying the quality of seawater used for production and processing of fishery products. This includes improvement of methods for pollution source tracking.
- Efforts should be made to harmonize regulations on the use of brackish and seawater during transport and processing, and to revise guidelines for the safe use of water in the fishery sector.
- The increased focus on antibiotic resistance seen internationally should consider fish and fishery products and the environments where the organisms live.
- The pathways of transmission of pathogens in fresh fish and associated products and packaging materials (e.g. plastics) and the horizontal transfer of antibiotic resistance genes among the associated microbiota should be more carefully examined.
- Regulatory agencies and other relevant organizations should provide examples and training on how to use food safety plans and risk assessments to define water quality targets for fit-for-purpose water.
- Regulators, fish processors and consumers have a negative perception about the use of fit-for-purpose water. Strategies to overcome misconceptions should be developed.
- Operational monitoring of the water used in the production and processing of fishery products should be implemented by the operators to provide insights into performance and water quality issues, enabling rapid remedial action in the event of nonconformity.
- Further research should be undertaken to determine the relationships between water quality parameters tested in fish production environments, pathogen infectivity and health effects on fish producers, processors and fish consumers.
- Operators must ensure the safety of water used in the production and processing of fishery products using a risk-based approach covering the whole water system from the source to the point of use.

- In risk assessments, operators should take into account the specific waterborne hazards (e.g. bacteria, viruses, parasites) that may affect the safety and quality of the fishery products. Where necessary, operators should implement a risk assessment/risk management approach, such as a simplified and adapted WSP framework for water used in processing steps.
- Where disinfection forms part of the water treatment, operators must ensure that the efficacy of the disinfection applied is validated. The same applies to all other water treatments that may be applied to the water in the industry.
- Operators should elaborate risk assessment and risk management procedures and implement monitoring plans according to recognized guidelines and standards.
- Good hygiene practices should be implemented to maintain the highest standards of water quality and safety because human activities often contaminate the environments where fish are produced and processed. Operators should provide specific training to staff on good hygiene practices.
- Possible contamination risks from the immediate area of the catchment and seasonal and climatic factors should be assessed through regular water quality testing and by developing farm-specific precautionary measures. Every precaution should be taken to protect source waters from any contamination, especially during the rainy season, in tropical areas.
- A safety management system should be developed and implemented for the production and processing of fish, especially those produced in rivers, lakes, nearshore waters and facilities on land. Such a safety management system should be risk based and consider the available data and the knowledge of the safety manager.

### **8.3 GENERAL KNOWLEDGE GAPS AND LIMITATIONS**

- Little information exists on technologies and quantities of water used in artisanal production and processing of fish and fishery products. Consequently, the impacts and sustainability of water reuse are difficult to quantify.
- There is a need for new regulations on the quality and safety of water, including regulations with minimum requirements for water use in the production and processing of fish products.
- There is a lack of information on hazards and hazardous events in the catchment area in relation to different water sources, namely surface water and groundwater.
- Limited data are available on seawater used in fish processing, including water on board fishing vessels.
- Information on the impacts of public (municipal) wastewater reuse in the primary production of fishery products is also lacking, namely in aquaculture.



- Considering the diversity of seafood production methods and consumption habits globally, there are still large gaps in knowledge on the relative importance of microbiological hazards of fish and fishery products.
- Many regulations do not sufficiently consider the widespread use of brackish water and seawater in the fish and fishery sector.
- Detailed physical, chemical and microbiological characterization of water used in fish production operations is limited in the literature. Such information is critical to design effective water conservation strategies, assess the need for treatment and conduct robust safety plans, risk assessments and risk management for hazard control.
- While the basic elements of a monitoring programme are implemented by most seafood industries worldwide, there is lack of definition of what constitutes an appropriate monitoring programme for direct and indirect contact waters in the fish processing environment.
- There is a lack of information on how to design operational water monitoring plans. These should be site specific and must consider the relevant hazards, hazardous events and the outcomes of a risk assessment of the water system.
- There is a requirement for clear and simple standard operating procedures for water monitoring in vessels, primary production and processing facilities of fish and fishery products.
- Despite significant developments in molecular methods (PCR-based and other) for detection and quantification of enteric pathogens in water, there is currently insufficient information on method performance, harmonization and standardization to enable the use of these methods in regulatory monitoring.
- Qualitative and quantitative data for use in water quality risk assessments are very limited and, in some geographical areas, non-existent.
- Some countries lack regulations and policies for effective protection and use of water sources.
- Data on physical, chemical and microbiological controls undertaken in fish production and processing facilities should be widely available.



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In 2020, the 43rd Session of the Codex Alimentarius Commission approved the “Development of Guidelines for the Safe Use and Reuse of Water in Food Production” proposed at the 51st Session of the Codex Committee on Food Hygiene. To support this work, JEMRA was asked to provide scientific advice on sector-specific applications and case studies for determining appropriate and fit-for-purpose microbiological criteria for water sourcing, use and reuse in fish and fishery products from primary production to retail.

This report presented the outcome from the JEMRA meeting, which includes the: Situation analysis concerning water use and reuse in the production and processing of fish and fishery products, analysis of case studies for different risk-based water use and reuse processing scenarios and species, water quality monitoring and the use of non-culture based microbiological methods, recommendations concerning the safety and quality of water used in fish production and processing, and critical research gaps and policy developments.

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