Seafood-borne disease

Daddy: why are we going to the toilet so frequently? Was it those oysters we ate together last night?

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Storyline

Seafood contributes a significant proportion of the world food supply. It is nutritious, tasty, and offers essential components for a healthy diet. Consuming seafood two to three times per week is reported to reduce the risk of death from any health-related cause by 17 percent. Consuming seafood is also good for the brain, including baby brain development, and eye health.

About 3.3 billion people in the world depend on wild-caught and farmed seafood as a principal source of proteins. In recent years, more and more people have abandoned the consumption of red meat in favor of fish. As a result, seafood harvesting, farming and trade have grown exponentially globally.

Seafood includes mollusks (*e.g.*, mussels, oysters and clams), finfish (*e.g.*, sea-bass, tuna, salmon, anchovies), crustaceans (*e.g.*, shrimp, crab, and lobsters) and fish eggs (*e.g.*, caviar).

Tasty and nutritious cooked seafood

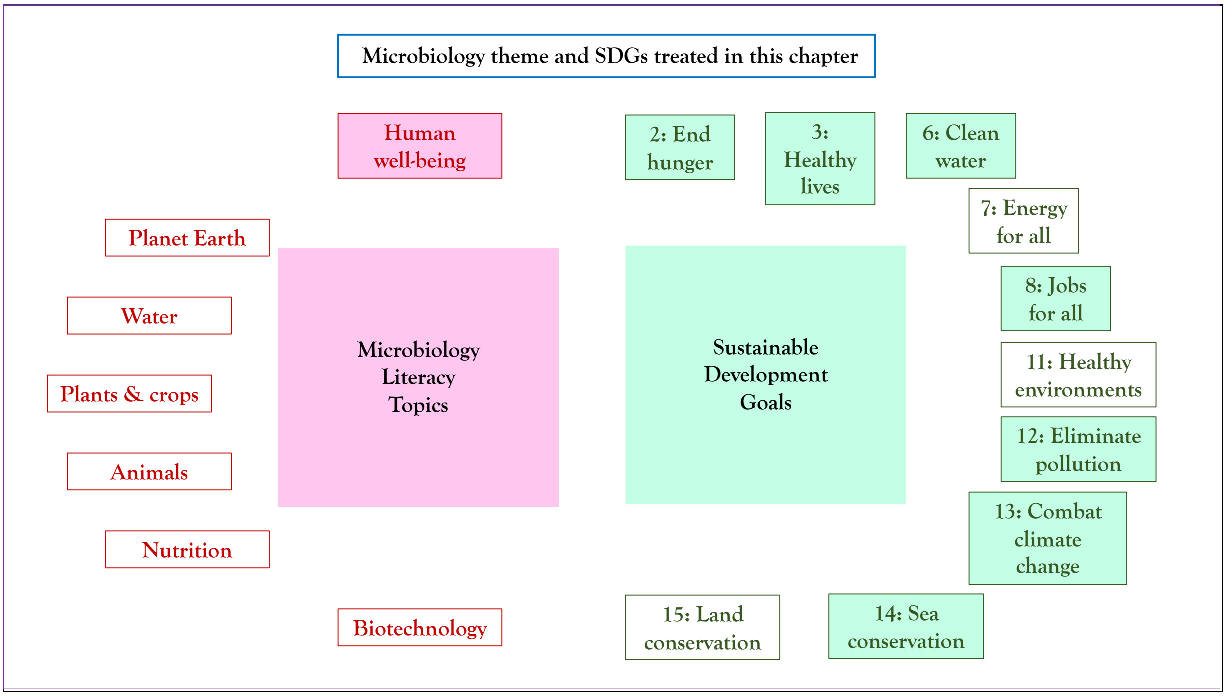
Microbiological risk associated with seafood can be related to the environmental conditions and microbiological quality of the water from which seafood items are caught or farmed. In fact, some pathogens live in the aquatic environment and may contaminate fish or shellfish before their harvest. Others may be introduced during transportation, storage, and processing at improper temperatures or by contamination by food handlers.

Some seafood is more risky than others for human health, depending on the aquatic environment from which it originates, its mode of feeding, the season during which it is harvested, and how it is stored and processed. Although cooking at proper temperatures destroys most pathogens, some seafood items are eaten raw or prepared in ways that do not kill microorganisms.

Here, we will focus on bivalve mollusks that are often eaten raw or undercooked, and are associated with the greatest number of seafood-borne diseases.

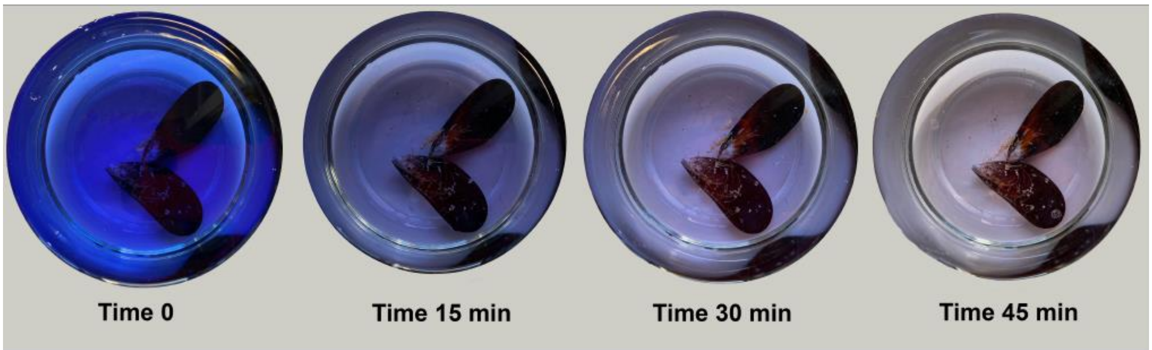
The Microbiology and Societal Context

The microbiology: bacteria indigenous in the aquatic environment; enteric viruses and bacteria present in the water; main pathogens involved in seafood borne diseases; more risky seafood for transmission of pathogens to humans; spread of bacterial resistance to antibiotic in the aquatic environment; controls of water and seafood microbiological quality; response of indigenous bacteria to sea surface temperature increase. *Peripheral issues for completeness of the storyline*: fish and shellfish farming industry; farm crowded conditions; bivalve diseases. *Sustainability issues:* safe food; healthy lives; water and sanitation management; economy and employment; environmental pollution; education (from processors to consumers); global warming; sustainable use of seas and their resources.



Seafood-borne disease: the Microbiology

1. ***Microbial contamination of seafood.*** As with other types of food, seafood is not free of microorganisms and can contain microbes that may cause disease. Contamination of seafood can originate from the aquatic environment. Two groups of microbial pathogens are involved: those naturally living in the water (indigenous or autochthonous), and those (allochthonous) introduced into the water through contamination by animal excreta and/or human wastes (enteric bacteria and viruses). In general, contamination from the aquatic environment is a greater problem for bivalve mollusks than other seafood due to their filter-feeding habit (see glossary): they feed by drawing surrounding water in and filtering out particulate matter, including microbes that they digest. During such activity, bivalves also capture any pathogens present in the water, which can reach numbers dangerous for human health, especially when bivalves are eaten raw or lightly cooked.



Mussels filtering water. Mussels and other bivalves are remarkable filter feeders and pump large amounts of water through their body; during this activity, they remove particles from the water making it increasingly clear. The Figure shows an easy experiment performed by immersing two mussels (*Mytilus galloprovincialis*) in seawater (18°C) stained with blue ink.

Microbiological contamination of seafood can also occur after harvesting, during inappropriate transport, handling and processing and can come from the environment, other contaminated food, contaminated containers and utensils, or an infected food handler. All seafood items can be contaminated in this way, but this is how finfish become contaminated most often.

Storing seafood products after harvesting at inadequate temperatures promotes the growth of bacteria deriving from both water and other sources.

2. ***Pathogenic bacteria and viruses of concern in seafood diseases.*** Both viruses and bacteria can be transmitted to humans through seafood. The microorganisms most often responsible for seafood borne diseases include norovirus, *Vibrio*, *Salmonella*, then hepatitis A virus, *Listeria monocytogenes*, *Shigella* and *Aeromonas.* Differences in the frequency with which these pathogens are involved in seafood - related diseases depend, among other things, on the food product, the country and its sanitation levels.

Disease results from the ingestion of products containing the above microorganisms that, after passing the acidic environment of the stomach, reach and multiply in the human intestinal tract. Depending on pathogen properties and host susceptibility, the diseases range from mild gastroenteritis to life-threatening conditions. Most common symptoms are diarrhoea, vomiting, nausea, abdominal cramps, fever and headache. Some bacterial pathogens when ingested can produce potent exotoxins (see glossary) responsible for all or some of the symptoms (one of the most potent exotoxins is *Vibrio cholerae* enterotoxin responsible for the massive, watery diarrhoea characteristic of cholera disease).

3. ***Preformed toxins.*** Disease may also result from ingesting seafood containing preformed toxins produced by certain bacteria when they grow in the seafood after harvesting (the bacterium does not need to be ingested alive!). It is worth mentioning, among others, the potent *Clostridium botulinum* neurotoxin (see glossary) that is produced when bacterial endospores (see glossary) (deriving from the water and sediment and present in fish intestine) germinate, and reactivated bacteria grow in anaerobic conditions. Two principal seafood processes are associated with the illness – botulism – caused by *C. botulinum* neurotoxin: canning, when insufficient heating during the canning process does not kill all spores, and fermentation of fish products, when inadequately cleaned fish are fermented for long times. *Staphylococcus aureus* enterotoxin is

produced by certain strains present in the nose and skin of operators that may contaminate seafood during processing. S *aureus* causes the majority of fish-associated outbreaks in this way.

4. ***Histamine poisoning.*** A particular disease associated with the consumption of seafood is "histamine fish poisoning". When certain harvested fish are not properly stored, some bacteria found in their gills and gastrointestinal tracts, can grow and convert the amino acid histidine, which is present in fish tissues, to histamine and related compounds. These substances are responsible for symptoms similar to those of an allergic reaction and which may be very serious. Marine fish most commonly associated with the disease are tuna, herring, and mackerel. Histamine production can also occur in other foods, such as cheese and other fermented foods (*e.g.* wine, dry sausage, sauerkraut, etc.). Importantly, once histamine is produced, it is highly resistant to cooking, smoking, freezing, and canning. Ideally, fish should be kept at a temperature of 0 °C or below, so that the bacterial growth and histamine production are minimized.

5. ***Other seafood-borne diseases.*** Lastly, it is worth mentioning some biological contaminants of seafood other than bacteria and viruses, namely algal biotoxins and parasites. Some naturally occurring marine algae produce biotoxins; ~ 5% of the thousands of algal species are toxic or otherwise harmful to human health, aquaculture and ecosystems. During an algal bloom, when nutrient concentration in the water is high enough to support a burst of algal growth, bivalves can accumulate sufficient amounts of algal toxin to be dangerous for human health by filter feeding for only 24h. Fish may also consume toxic algae and cause disease in humans. Depending on their own chemical structure, concentration and host susceptibility, algal biotoxins cause poisoning symptoms in humans of various severity, from gastrointestinal effects to paralytic phenomena and in extreme cases coma or death. Toxin-producing algae can also cause mass mortalities of fish, birds and marine mammals. Biotoxins are not a new phenomenon but their frequency, severity and distribution are changing due to environmental and global changes.

Parasites, like nematodes (roundworms), cestodes (tapeworms) and trematodes (flukes), may be present in finfish and if this is consumed raw or undercooked, as may be the case cooking unfrozen seafood, they can also present a human health hazard. Cooking raw fish at temperatures that kill bacterial pathogens also kills parasites.

6. Main properties of some pathogens.

a. *Vibrios* are among the most common bacteria inhabiting surface waters throughout the world. A common property of vibrios is their ability to lead multiple lifestyles: a planktonic, free-swimming state and a sessile existence on a surface. They are often associated with a variety of living organisms (*e.g.*, plankton organisms, aquatic plants, protozoa, bivalves) and abiotic substrates (*e.g.*, sediments). Due to the capability to specifically adhere to chitin (see glossary), zooplankton organisms with a chitin exoskeleton (*e.g.*, copepods) are important aquatic reservoir for many vibrios.

Depending on species, vibrios tolerate a wide range of salinities; in addition, they thrive when water temperatures rise above 17°C, and are more abundant during summer months when water is warmer. Therefore, the concentration of vibrios on the surface and inside harvested fish and shellfish, particularly those from brackish, estuarine and coastal environments, reaches the highest values at these times. Interestingly, these bacteria often show the capacity to adapt to changes in salinity, temperature, and availability of nutrients, thus successfully occupying a variety of habitats (*e.g.*, coastal waters, marine sediment, animal host).

It is noteworthy that vibrios play critical roles in preserving life in the oceans, contributing to nutrient cycling. An example of this refers to chitin, one of the most abundant and important sources of nutrients and energy in the marine environment. Vibrios, like other marine microorganisms, produce enzymes that degrade this insoluble polysaccharide: without this important microbial activity, oceans would be depleted of carbon and nitrogen, necessary for marine life, in a relatively short time!

Only a small proportion of vibrios present in the aquatic environment belong to species potentially pathogenic for humans, and only few isolates of such species may possess the pathogenicity traits that enable them to cause disease. These bacteria, thanks to the capability to survive in adverse conditions and the presence of cell structures functioning in different settings, exhibit two distinctive lifestyles, one inside the milieu of the human intestine and the other in the aquatic environment.

The major human health microbial hazards are *V. parahaemolyticus, Vibrio vulnificus*, and *V. cholerae*, mainly for people who consume raw or undercooked seafood such as oysters, which represent the most common vehicle of *Vibrio* transmission to humans in developed countries. *V. cholerae* can cause cholera, a severe diarrhoeal disease that can be fatal; it is transmitted via contaminated drinking water, person-to-person close contact, and through food. Cholera represents a serious sanitary problem in developing countries where *V. cholerae* is endemic, population density is high, sanitation is poor and access to safe drinking water is scarce. Non-cholera vibrios (*e.g.*, *V. parahaemolyticus* and *V. vulnificus*) cause vibriosis — infections normally acquired through exposure to seawater or through consumption of raw or undercooked contaminated seafood. Non-cholera bacteria can lead to several clinical manifestations, most commonly mild, self- limiting gastroenteritis, with the exception of *V. vulnificus*, that is particularly virulent among patients with underlying medical conditions such as chronic liver disease, immunodeficiency and iron storage disorders, who are at increased risk of invasive disease.

Vibrio-related infections associated with the consumption of contaminated water and seafood are increasing worldwide. Such increases have been linked to the rise in global sea surface temperature, which is approximately 1°C higher now than 150 years ago and is one of the primary physical impacts of global warming. Increasing temperatures favor the growth of vibrios, including pathogens that prosper in warm waters and reach concentrations that can pose a threat to human health. Climate-sensitive environmental variables (sunlight, temperature, salinity and nutrients) can also influence the properties and ecology of environmental reservoirs of vibrios (*e.g.* zooplankton), thus further influencing the proliferation of these bacteria that live in association with them.

The infectious dose (see glossary) of human pathogenic vibrios may be relatively high: from 100 to more than 1 million (for comparison, it can be as low as 1 for *Shigella*, which causes bacterial dysentery). However, inside filter feeding bivalves, which concentrate ambient water particles, vibrios can easily reach high concentrations that are dangerous for human health.

It is noteworthy that human pathogenic vibrios naturally contaminating bivalve mollusks are less easily removed by depuration practices, which involve storing the seafood in tanks of clean seawater for periods of time to allow purging of impurities like microbes and sand/silt (see glossary), than are other microorganisms. Such processing methods may therefore not provide the necessary level of public health protection if significant levels of pathogenic vibrios are present in harvested products.

b. *Salmonella* bacteria are found in the guts of humans and animals and polluted environments. The faecal wastes from infected animals and humans are important sources of bacterial contamination of the environment and the food chain. Most types of *Salmonella* cause an illness called salmonellosis, characterized by diarrhea, fever, and stomach cramps. Some other types of *Salmonella* that live only in humans, cause typhoid fever or paratyphoid fever that are life-threatening diseases.

Outbreaks of seafood-borne infections due to *Salmonella* have been most commonly associated with raw and undercooked finfish, crustaceans and bivalves. Seafood can acquire *Salmonella* from polluted waters receiving untreated sewage, or can become contaminated with *Salmonella* post-harvest during processing. Due to more effective surveillance of water quality, the incidence of *Salmonella* in shellfish has declined in developed countries but infections continue to occur in different parts of the world.

The infective dose in healthy people varies according to the specific bacterium, the food items and susceptibility of the individuals; it is relatively high for healthy individuals and very low for the elderly or medically compromised individuals. Hazards from *Salmonella* can be prevented by adequate cooking, storage and processing of food products.

c. *Norovirus* is a highly contagious virus and an important cause of food-borne illness. Humans are the only known reservoir; norovirus is spread by person-to-person contact through the fecal-oral route or through contaminated water or food. Norovirus enters the marine environment through untreated human sewage. It persists in the water for a long time, and is accumulated inside bivalves thanks to their filter-feeding activity. All bivalve shellfish such as oysters, clams, mussels, and scallops can transmit norovirus; however, illness outbreaks are most often linked to oysters because they are commonly eaten raw. Insufficient cooking, such as steaming bivalves only until they open rather than cooking them at higher temperatures that kill noroviruses, has contributed to illness and outbreaks.

Anyone can get norovirus. People who eat raw oysters or undercooked shellfish are at higher risk of a norovirus illness. Noroviruses persist longer in colder marine water and more shellfish-related norovirus illnesses are seen in November through March.

7. Bivalve mollusks: risky seafood when eaten raw or poorly cooked. Outbreaks of infections associated with seafood vary according to the seafood item. The greatest numbers of seafood-associated illnesses are caused by consumption of raw or partially cooked bivalve mollusks (*e.g.*, oysters, mussels, clams), followed by fish and crustaceans.

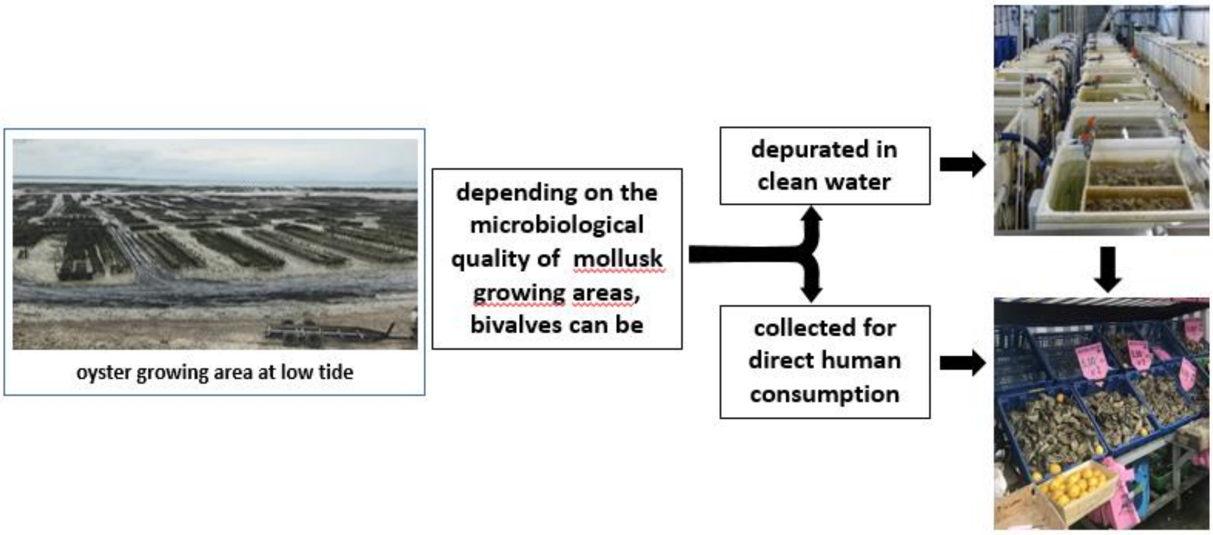
Worldwide, bivalve mollusk production is an important and growing industry, which accounts for about 10% of the total world seafood production. Bivalve farming presents unique opportunities for sustainable and ecologically friendly aquatic food production. Bivalves do not require any artificial food input since they obtain their nutrition from plankton and different types of detritus from their growing waters. Interestingly, filter feeding may help reduce water turbidity and quality, improve light penetration, and combat eutrophication in aquatic environments.

Harvested bivalves can be sold live or can be shucked. The shucked meat, in turn, can be sold fresh or frozen or after further processing and canning. Thus, bivalves can be contaminated by pathogens in the harvesting area, and during improper processing and storage. However, due to their filter-feeding activity, the microbiological quality of bivalves is mainly dependent on the quality of the water where they live; the preparation and packaging steps are considered as the secondary source of contamination.

Water physical and chemical properties (*e.g.*, temperature, sunlight, pH, salinity, organic matter, O2 content) may change drastically, both temporarily and spatially, due to seasonality, human activities, etc., with great impacts on the survival and spread of microorganisms and their accumulation inside bivalves. Climate-linked variables exert significant and interconnected effects on the abundance, growth, spread and survival of many pathogens that can contaminate bivalves. For example, there is a strong link between the rise in sea surface temperature, which is one of the most important effect of global warming, and the increased occurrence of diseases (including those seafood – related) due to members of *Vibrio* species that thrive in warm waters. Changes in other environmental factors, such as salinity (which varies in estuaries and coastal waters impacted by river outflows, with changes in drought/rainfall/snow melts in watersheds which, themselves are impacted by global warming-triggered extreme weather events) and pH, may affect pathogen distribution and virulence; episodes of drought can concentrate microorganisms and rain can disperse them. All this can in turn greatly affect pathogen density inside bivalves.

Depurating bivalves in clean water may reduce the risk of microbial illness deriving from the consumption of mollusks harvested from waters with low levels of microbiological contamination. However, it is noteworthy that the depuration process does not efficiently eliminate all pathogens (*e.g.*, vibrios).

The improvement of wastewater treatment techniques, progress on both bivalve farming technology and microbiological control of harvesting areas, have reduced the incidence of diseases transmitted with seafood, especially those due to microorganisms of faecal origin. Nevertheless, raw or undercooked bivalves continue to be a danger for human health.



Bivalve production, from farm to market

8. ***Shellfish and finfish can also become diseased.*** As is the case with animal husbandry on land, industrial production of shellfish and finfish often involves crowded conditions that generate greater susceptibility to infectious diseases and promote pathogen transmission. Pathogenic viruses and bacteria originate not only from farms' local areas but also from distant areas, spreading from one region to another. In this way, even animals that live in the wild can be infected. Of note, some bacteria that ordinarily colonize fish and other marine organisms without causing damage, and indeed playing beneficial roles for the host, can become harmful to animals and cause diseases under the typical stress conditions of crowded farms.

Although historically there have been various episodes of disease in cultivated bivalves, since 2008 massive mortality outbreaks affecting oysters have occurred in different areas. These outbreaks generally happen in summer when mortality can reach 80–100%, especially among oyster juveniles. Causes triggering the outbreaks are still only partially understood and are attributed to complex interactions occurring among oysters, pathogens (mainly ostreid herpesvirus and bacteria belonging to the *Vibrio* genus) and environmental parameters (*e.g.*, increasing sea surface temperature, water pollution). The control of farmed shellfish health, based on a combination of microbiology, physiology and biochemistry assays, remains one key element to keep the competitiveness and sustainability of bivalve farming, and to produce seafood of good quality.

9. ***Aquaculture and antimicrobial resistance***. Although discouraged, and prohibited in many countries, the control of infectious diseases in aquaculture is often based on the use of antibiotics. Such drugs may persist in the water and sediments for long times, providing ideal conditions for the selection of resistant bacteria. The potential public health risks associated with the use of antimicrobials in aquatic environments arise mainly from selection of resistant bacteria that can either directly infect humans or transfer resistance to human pathogens. In addition, antibiotic residues can remain in the edible tissues of marketed fish and crustaceans with toxic effects for consumers.

To avoid the spread of bacterial resistance to antibiotics, which represents one of the most pressing public health problems in the world, and the occurrence of drug residues in aquaculture products, overuse of antimicrobials in aquaculture must be prevented. At the same time, alternative disease prevention and treatment measures must be encouraged (*e.g.*, good farming conditions, avoiding high densities of farmed animals, formulation of adequate fish diets, development of affordable vaccines, etc.).

10. ***How to avoid seafood-associated diseases.*** The saying "prevention is better than cure" applies to seafood-borne diseases too. Strategies to prevent diseases associated with seafood include reduction of pollution of marine systems, monitoring of the microbiological quality of harvest waters, appropriate controls during all processes associated with the production of the different seafood items, and education of both processors and consumers.

National and regional Health Protecting Agencies have the primary responsibility for the safety of seafood products, and provide consistent standards and regulations for the various industry sectors involved in seafood production. Routine examination of water and seafood items for the presence of enteric pathogens is based on the evaluation of the presence of indicator organisms – also named faecal indicators (see glossary) – since historically, faecal contamination was the primary source of infections. With the development of effective water treatment plants and massive reduction in discharge of contaminated wastewater into surface waters, this is now much less of a problem. Moreover, as the presence of vibrios is not associated with fecal contamination, checking waters or seafood items for fecal indicators is not effective as an indicator of the presence of these bacteria. Tests that more specifically target vibrios and, in particular, pathogenic isolates are available, and must be applied.

Shellfish Control Authorities classify waters in which bivalves are cultured and harvested based on the presence and concentration of faecal indicators. Accordingly, shellfish harvesting is allowed from some waters, not from others, and only at certain times and under certain conditions. Shellfish Control Authorities then exert the necessary controls to ensure that shellfish harvesting takes place only in the permitted areas and during the established periods. In some cases, the bivalves can be transferred to depuration plants to lower the microbial concentration; it is of note that different microorganisms have different sensitivity to purification processes.

People should be educated about how to avoid the potential health risks associated with eating seafood. For example, they should be advised that to prevent the growth of pathogenic bacteria, seafood must be stored in the refrigerator at a low temperature (≤ 4 ° C), that proper cooking destroys the pathogens present in the seafood, and that good personal hygiene practices are key elements of food safety.

Although cooking ensures the elimination of pathogens, some seafood (*e.g.*, oysters) is eaten raw or undercooked. People with underlying medical conditions such as liver disease, diabetes, or immunosuppressive conditions, need to be particularly cautious, being at a higher risk of getting serious infections. Educational strategies must be specifically directed to those people.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of the issue of seafood- diseases relates to several SDGs, including

- **Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*end hunger and malnutrition, increase agricultural productivity*). Large-scale production of farmed seafood items can significantly contribute to ending hunger by providing low cost, tasty and nutritious food. Application of all presently available measures to control and monitor the presence of human pathogens, before and after harvesting, is of crucial importance for the production of safe seafood items.
- **Goal 3: Ensure healthy lives and promote well-being for all at all ages** (*improve health, reduce preventable disease and premature deaths*). Pathogens may contaminate seafood products anytime from harvest to fork. Strategies to prevent and control microbial contamination must be applied to maintain the microbiological water quality, to guarantee appropriate post-harvest processing and adequate hygienic condition and, ultimately, to protect human health. Continuous surveillance must assess the effectiveness of such strategies. Consumers must be informed about the risks associated with consuming raw or partially cooked seafood and educated on appropriate hygiene practices in handling seafood products.

  Bacterial resistance to antimicrobials is one of the world's most urgent public health problems. Aquaculture uses hundreds of tonnes of antimicrobials annually to prevent and treat bacterial infections. Antimicrobials may persist in water and sediments providing ideal conditions for the selection of resistant bacteria that can spread to humans, with harmful effects on our health. To avoid this risk, it is essential to minimize antimicrobial overuse or misuse in aquaculture by applying new strategies to prevent and/or control fish and shellfish diseases (*e.g.*, vaccines, probiotics, and phage therapy). Programs to monitor antimicrobial usage and antimicrobial resistance in bacteria and their environment should be implemented and national databases should be developed to achieve efficient communication.
- **Goal 6: Ensure availability and sustainable management of water and sanitation for all** (*assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management*). World aquaculture production has grown tremendously over the past 60 years and nearly half of the seafood we eat comes from fish and shellfish farms. This important development can only be accepted with the utmost respect for the environment. Fish farming has many benefits in respect to wild fish capture such as preventing overfishing, rebuilding depleted stocks, and preserving fish habitats. To reduce the microbial impact on the marine environment of farmed fish and shellfish some actions can be taken, *e.g.*, improving farm location sites by choosing non-contaminated areas, implementing farming technologies (*e.g.*, offshore farming, healthy feed, and drastic reduction of antibiotic use). Moreover, ensuring

controls on marine environments that represent the capture areas of wild resources may contribute to improve water quality and reduce pollution.

- **Goal 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment and decent work for all** (*promote economic growth, productivity and innovation, enterprise and employment creation*). The expansion of sustainable fishing and aquaculture activities promotes safe working conditions and opportunities. Another job opportunity is linked to the development/improvement of the network of microbiological quality control services for both the environment and seafood products. Technical innovations are essential for improving infectious diseases diagnostics and anti-infective treatments.
- **Goal 12: Ensure sustainable consumption and production patterns** (*achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the environment, attain zero waste lifecycles, inform people about sustainable development practices*). Sustainable aquaculture and fishery practices, improvement of water microbiological quality controls, will increase water and seafood safety.
- **Goal 13: Climate change** *(energy transition, reducing CO2 concentrations).* Climate change affecting both global and local environments, with a combination of higher temperatures, lower salinities, hypoxia and ocean acidification, has the potential to increase the density and spread of several seafood - associated pathogens. In this scenario, public health authorities have to take adequate measures, both in terms of prevention and control, to ensure the safety of fish products and to support consumer confidence in fish consumption. International networking may help countries to prevent, control and mitigate climate change impacts on environmental and, consequently, animal and human health.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** (*reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance ; sustainable use of oceans and their resources*). Human activities influencing global pollution of the coastal and marine environment (*e.g.*, through the release of organic and chemical pollutants in seawater), practices of seafood industry (e.g., overuse of antibiotics), and climate-related processes (*e.g.* sea surface temperature increases) can deeply affect fish and shellfish, both in the wild and aquaculture, promoting pathogen spread and associated diseases. Strategies to protect the oceans, seas and marine resources, and prevent seafood-associated illnesses include, among others, continuous monitoring of harvest waters and aquaculture practices, and implementation of process controls.

Potential Implications for Decisions

1. *Individual*

a. Eat freshly harvested seafood as often as possible.
b. Eat cooked seafood as often as possible
c. Refrigerate purchased seafood at temperatures below 4°C as soon as possible
d. Handle and process seafood with clean hands and clean utensils.
e. Check for labels on the seafood item that certify its origin of the seafood
f. Ask the fish suppliers where the product you intend to buy comes from

2. *Community policies*

a. Harvesting in an area of shellfish culture must occur only when detection methods have confirmed that human pathogenic microbes are within acceptable safe limits.

b. Monitor the presence and concentration, both in water and seafood products, of indigenous human pathogens, such as vibrios, whose concentration does not correlate with that of faecal indicators

c. Improvement of technology for wastewater treatment to reduce the input of enteric pathogens in the water.

d. Improvement of depuration practices and technologies to reduce the number of bacteria in shellfish.

e. Good education (from processors to consumers) to promote the knowledge of the risk associated with seafood contamination by pathogens.

f. Adopt environmentally friendly practices to reduce greenhouse gas emissions by actors involved in seafood sector, avoid environmental stressors like overcrowding, overfishing, and adopt an appropriate use of drugs in terms of safety, quality and amounts.

3. National policies

a. Strengthening of actions for routine monitoring of the quality of water, fishery products and seafood.

b. Devote resources to provide adequate training and infrastructures so that the presence of harmful organisms and biotoxins in water and seafood is subject to best practices.

c. Implementation of existing surveillance systems at national and international level, harmonization and standardization of procedures

d. Developing national and international database on seafood pathogens and seafood-related diseases, if and where missing, to achieve efficient communication

e. Control of antibiotic resistance in aquaculture, by monitoring antimicrobial usage and antimicrobial resistance in bacteria from farm-raised aquatic animals and their environment

f. Funding research programs to study new measures, other than antibiotics, for prevention and treatment of diseases in cultured animals

g. Improvement of long-term, national and international actions to enhance the knowledge on climate change and its impacts on pathogen biology, ecology and transmission to humans, and development of effective management and mitigation strategies to ensure the safety of seafood resources

Pupil participation

1. **Class discussion of the issues associated with seafood diseases.**

2. **Pupil stakeholder awareness**
    a. What do you think are the most important measures to take in handling fish or bivalves at home to avoid the risk of seafood-associated diseases?
    b. Can you think of anything that could be done to reduce the presence of human enteric pathogens in aquaculture plants?
    c. What measures can be taken to stop the rise in global sea surface temperature and its impact on the spread of pathogens in the water?
    d. What do you think are significant consequences on the environment of large-scale aquaculture?

3. **Exercises**
    a. Show pupils images of bacteria and viruses of different shape and size, pathogenic and non-pathogenic for human and animals.
    b. Show pupils heat map of the Earth and video showing temperature change in the last 50 years
    c. Organize a class excursion to a local aquaculture plant

The Evidence Base, Further Reading and Teaching Aids

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Video.
Environmental Drivers for Cholera and Other Vibrio Diseases- Rita Colwell:
https://www.youtube.com/watch?v=pS4DRs6r8sE

Glossary

Chitin: a long-chain polymer of N-acetylglucosamine, a derivative of glucose. This polysaccharide is a primary component of cell walls in fungi, the exoskeletons of arthropods, such as crustaceans and insects, the radulae of mollusks, cephalopod beaks, and the scales of fish. The structure of chitin is comparable to another polysaccharide, cellulose. (Wikipedia)
Depuration of seafood: the process by which marine or freshwater animals are placed into a clean water environment for a period of time to allow purging of biological contaminants (such as bacteria) and physical impurities (such as sand and silt). The most common subjects of depuration are bivalves as oysters, clams, and mussels.(Wikipedia)
Endospore: bacterial endospores are metabolically inert structures produced by some bacteria under unfavorable environmental conditions. A bacterium forms a single endospore inside the cell. After cell lysis, the endospore is released into the environment where it can survive in a dormant stage indefinitely (thousands or millions of years!). The endospore is very resistant to many harsh environmental conditions such as lack of nutrients, desiccation, high temperature, UV radiation, chemical agents. Under triggering environmental stimuli, the endospore reactivates (germinates) giving rise to a bacterium identical to the one that produced it.
Enterotoxin: a bacterial exotoxin (see below) that targets the intestine
Exotoxin: a protein secreted by bacteria that can cause damage to the host by destroying cells or disrupting normal cellular functions

Faecal indicators: microbes whose presence in a water or seafood sample indicates the presence of fecal matter, and thereby potential intestinal pathogens.
Filter feeding habit: bivalves filter seawater through their bodies to get food floating in the water.
Infectious diseases: disorders caused by pathogens — such as bacteria, viruses, fungi or parasites. Some infectious diseases can be spread directly from person to person by direct contact; others are transmitted by insects or other animals, or by consuming contaminated food or water, or being exposed to aerosolization of infected particles in the environments.
Infectious dose: the amount of a pathogen that is required to establish an infection
Neurotoxin: a bacterial exotoxin (see above) that targets central and peripheral nervous system
Pathogen: any microbe that can produce disease
Pathogenicity: the capacity of a microbe to cause damage in a host (*or* to cause disease)
Virulence: the degree of damage caused by a microbe