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To the Inspector-General of the Netherlands Food and Consumer Product Safety Authority
And to the Minister of Agriculture, Nature and Food Quality and the Minister of Health, Welfare and Sport

Advice from the Director of the Office for Risk Assessment & Research on

Risks to humans, animals and nature in the fish supply chain

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'Fish' is a common collective term for fish, fish products, crustaceans, molluscs and other aquatic animals. Consumers regularly eat fish. It is included in the Dutch Wheel of Five guidelines on nutrition and is considered a healthy food choice. Nevertheless, there are public health risks associated with the consumption of wild-caught and farmed fish, crustaceans and molluscs. The processing and preparation of fish products introduces additional risks. Moreover, catching and farming fish poses risks to animal welfare, animal health and nature. This supply chain risk assessment on fish identifies and assesses the main risks to humans, animals and nature. Its focus lies on fish, crustaceans and molluscs.

1. Introduction

Fish forms part of the Dutch Wheel of Five guidelines on healthy nutrition. The Netherlands Nutrition Centre recommends eating fish at least once a week, especially oily fish such as mackerel, herring, sardines, or salmon due to the positive effect of fatty acids on cardiovascular health. More information is available on the website of the Netherlands Nutrition Centre.

In popular language and in this supply chain assessment, the term 'fish' is the collective name for vertebrate fish and other aquatic invertebrates such as crustaceans and molluscs. Molluscs, usually referred to as oysters and mussels (bivalves), also include cephalopods and gastropods. Where relevant for the supply chain risk assessment, fish, crustaceans, molluscs and other aquatic animals will be mentioned separately. Similarly, the assessment will also make a distinction between organisms from fresh, brackish and salt water as well as between wild-caught and farmed species.

Only a portion of the fish consumed in the Netherlands is also caught or farmed in Dutch waters. A substantial portion is imported from other European countries or from outside the European Union (EU), while at the same time a considerable portion of fish caught or farmed in the Netherlands is consumed abroad. For example, cod - a popular fish for consumption - is largely imported from outside the EU, while much flatfish is exported. Given the diversity of species and their areas of origin, the differences in fishing methods and processing techniques as well as the availability of relevant data, the level of substantiation of risks varies for different fish species and types of fish products. Nonetheless, there is a number of generic public health risks caused by microbiological, chemical and physical hazards that are found not only in different types of fish and fish products but also in other foods. There are also specific public health hazards associated with fish, such as fish-related allergies and the formation of biogenic amines that can arise from the spoilage of fish and fish products. A number of hazards to animal welfare and animal health can also be identified. Finally, there are threats to nature associated with fishing or fish farming that are of relevance in the Dutch fish supply chain. The assessment of the animal welfare holds a prominent position in this supply chain risk assessment, even though scientific literature on this subject is limited and not always unambiguous. The animal welfare risk assessment, like the risk assessment for nature, is therefore qualitative in its approach. Moreover, for fish, little is yet legally regulated in the area of animal welfare.

The risk assessment for fish, crustaceans and molluscs carried out by the Office for Risk Assessment & Research (BuRO) of the Netherlands Food and Consumer Product Safety Authority (NVWA) is part of a BuRO risk assessment programme focusing on risks to public interests within all domains and production chains supervised by the NVWA. This BuRO programme provides systematic and periodic overview of and insight into the risks to humans, animals, plants, and nature. The fish supply chain assessment focuses on risks to public health, animal welfare and animal health, and nature associated with the capture, farming, preparation and processing, transport, and consumption of fish.

The key question in the fish supply chain risk assessment is:

- *What are the biggest risks in the fish supply chain for public health, animal welfare, animal health and nature?*

The answer to this question is translated into recommendations on how knowledge-driven and risk-oriented supervision of the fish supply chain can be improved. The recommendations are addressed to the Inspector-General of the NVWA, the Minister of Agriculture, Nature and Food Quality and the Minister of Health, Welfare and Sport.
In general, the volume of scientific literature on the risks of fish to public health and other public values is expanding daily. Moreover, insights into and the acceptance of risks in the fish supply

chain are subject to change, as are the regulations for fisheries and the techniques of farming, fishing, processing and preparation of fish. Therefore, the appendices of this fish supply chain risk assessment will be regularly updated based on the newly available information and research outcomes.

1.1 Document structure

Section 2.1 of Chapter 2 introduces the fish supply chain and the public interests at stake for the risk assessment. Section 2.2 identifies the main risks to humans, animals and nature. Section 2.3 presents recommendations based on these risks that are addressed to the Inspector-General of the NVWA, the Minister of Health, Welfare and Sport and the Minister of Agriculture, Nature and Food Quality. The substantiation of the risk assessment is included in Chapter 3, which also provides a description of the approach, a glossary and bibliography. In addition, the details of risk assessment are provided in the following appendices: 1. the approach of the risk assessment, 2. the production of fish, crustaceans and molluscs, 3.1 the consumption of fish, crustaceans and molluscs, 3.2 the chemical food safety, 3.3 the microbiological food safety, 3.4.1 animal welfare, 3.4.2 animal health, and 3.5 nature.

2. Risks to humans, animals and nature in the fish supply chain

In brief
Fish, fish products, crustaceans and molluscs are regularly eaten in the Netherlands. Some people are allergic to fish products. The spoilage of fish products can also lead to histamine poisoning after consumption. Moreover, fish, fish products, crustaceans and molluscs may contain microbiological organisms (pathogens) not harmful to themselves but which may pose a health risk to consumers.
The habitats of fish, crustaceans and molluscs contain chemical substances, including natural substances as well as contaminants from, for example, industrial discharges. Chemical substances most critical to health risks are (methyl)mercury (particularly in predatory fish), arsenic, cadmium, biotoxins, dioxins and dioxin-like polychlorinated biphenyls (PCBs), and perfluorinated compounds (PFAS, PFOS, PFOA). Many chemical substances can accumulate in fish, crustaceans and molluscs, and hence the health-based guidance values may be exceeded even with a limited intake.
Based on scientific literature, there is evidence that fish, and at least the largest crustaceans, i.e. lobsters, crabs, langoustines and large shrimp, are sentient and capable of experiencing pain. All parts of the fish supply chain, both wild capture and farming, pose considerable risks to animal welfare. In terms of numbers, it amounts to hundreds of thousands tons of fish per year, and thus billions of organisms. Especially fish and crustaceans experience severe stress and physical problems due to killing without stunning, crushing, injuries, exposure to heat stress and hypoxia, physical malformations, (tissue) damage or reduced immunity that lead to diseases and early death.
The natural aquatic environment is under pressure due to fishing and farming of fish, crustaceans and molluscs; in fresh, brackish and salt water alike. Overfishing forms a risk of populations' decline and disappearance due to the capture of larger individuals and hence the reduction of population's ability to recover. Different fishing and farming methods entail different risks to nature, as for example the variable rate of seabed disturbance through bottom trawling in the North Sea. In addition, fisheries contribute to the introduction of invasive alien species that threaten the native biodiversity.

2.1 Introduction

Fish supply chain
The Dutch fish supply chain is diverse. It comprises many species of fish, crustaceans, molluscs and other aquatic animals and involves many different businesses in the sector in which hundreds of millions of animals are caught or farmed for consumption each year. The activities in the supply chain include marine, coastal and inland fisheries, aquaculture (note that this risk assessment only includes farmed fish), crustaceans and molluscs fisheries (including farming), processing and preparation of fishery products, trade, and storage and transportation of fishery products. *To read more about this, please see the integrated supply chain analysis on fish (IKA Vis, in Dutch only): information sheets on links in the Dutch fish supply chain, on composition and size of the Dutch fishing fleet, and on core data on companies processing and selling fish.*
In the Netherlands, marine fishery is many times larger than inland fishery and aquaculture in terms of production volume/weight and numbers. The relatively small fleet (number of vessels) of pelagic fisheries (catching pelagic fish that inhabit the water column) provides the largest annual fish production with a volume of over 200 million kilograms. This mainly involves herring, blue whiting, Atlantic horse mackerel and mackerel. The much larger fleet of demersal fisheries (catching demersal fish that live and feed on or near the bottom of water bodies) accounts for an annual production of about 80 million kilograms, and mainly includes plaice, sole and shrimp. The annual production of farmed fish in the Netherlands is well under ten million kilograms per

year, while the production of molluscs is about 50 million kilograms. More information is available on the website of [Visbureau](#).
A large part of the fish consumed in the Netherlands, such as cod, is imported from countries outside the EU. In addition, almost half of the volume of mussels consumed in the Netherlands does not come from domestic production. The import and export volumes from and to third countries, i.e. countries outside the EU, are also much higher for certain species of fish than their production in the Netherlands. For example, the vast majority of the near 150 million kilograms of cod imported each year - mainly from Russia – is subsequently mainly re-exported to China. *To read more about this, please see the integrated supply chain analysis on fish (IKA Vis): data on the imports of fish from the Netherlands and the EU, data on the imports from third countries, and data on the exports of fish from the Netherlands to third countries.*

The living environment of fish, crustaceans and molluscs
The fish, crustaceans and molluscs consumed in the Netherlands are partly caught or farmed in Dutch waters (Appendix 2). *To read more about this, please see the integrated supply chain analysis on fish (IKA Vis): information sheets on international fishing areas on the imports and exports of fish, and on Dutch catch and landing of fish.*
The Netherlands is located downstream of the major international river catchments that are polluted with chemical substances and microorganisms. These pollutants originate from discharges of polluted (sewage) water, the intensive use of chemical substances and the production of waste materials on land that end up in the water through seeping and discharge. Furthermore, the concentrations of industrial pollutants in rivers are also higher in coastal waters than in waters further away from the coast. For crustaceans, molluscs and resident fish in particular, water quality can have a considerable impact on the contamination rate of fishery products. In fact, areas where the sediments are heavily contaminated with dioxins and dioxin-like PCBs are considered high-risk areas for both ecosystem effects and potentially unacceptable contamination levels in fish, crustaceans and molluscs. Therefore, a number of polluted areas in the Netherlands have been closed to fishing for eel and Chinese mitten crab.
Fish consumed in the Netherlands is often caught in international waters and then brought to the Netherlands. Another portion of the fish reaches the Dutch market via imports from other EU countries or is imported from countries outside the EU. As in the Netherlands, the chemical and microbiological pollution of fish living environment and fishing grounds is usually lower further away from the coast and human activities. For imported fish, crustaceans and molluscs, water quality and their living environment also play a crucial role in terms of food safety, animal welfare and animal health.
There is a certain correlation between the (quality of) nature, animal welfare and animal health, and public health, particularly in inland and coastal waters. Not only industrial and urban activities on land but also fishing and farming in open waters have a strong impact on the living environment of fish, crustaceans and molluscs. Fishing and farming activities can thereby both degrade the ecological value of nature and affect ecosystem services, of which fisheries itself is one.

2.2 Risks to public interests in the fish supply chain

Food safety
For many people fish forms an important part of their diet. On average, calculated over the entire Dutch population, 16 grams of fish and fish products are consumed per day. Some people, however, eat much more than that. Dutch people most commonly consume salmon, tuna and cod.
A wide variety of hazards in the fish supply chain can affect consumer health. Those hazards can be of a microbiological, chemical or physical nature. Some of those hazards, such as allergens, biotoxins, biogenic amines and some microorganisms, can cause severe and acute health effects. The probability of very serious effects is low. In some cases, fish contain considerable levels of heavy metals and/or persistent organic pollutants that pose health risks to consumers even at

very low intakes. This not only applies to fish caught commercially, it holds also true for fish caught by recreational fishermen or for recreationally harvested molluscs. International studies show that fish can contain dioxins, PCBs and perfluoroalkyl substances (PFAS, PFOS, PFOA) at concentrations that in particular make regular fish consumers (e.g. twice a week or more often) consume more than the amounts considered acceptable from a health perspective by the European Food Safety Authority (EFSA). An average portion of fish for an adult person is about 114 grams. The single consumption of such a portion alone can exceed the Tolerable Weekly Intake (TWI) for dioxins, PFAS, arsenic or (methyl)mercury in adults. Children who eat fish face an additional risk because they have a lower body weight and are still developing.

The Netherlands Nutrition Centre recommends pregnant women to avoid or eat less of certain species of fish, crustaceans and molluscs during pregnancy. It also recommends that pregnant women avoid consumption of fish, crustaceans and molluscs caught or harvested recreationally, because the water they were swimming in may have been polluted. More information for pregnant women on eating fish can be found on the website of the Netherlands Nutrition Centre.

Because chemical substances cause mainly long-term adverse health effects, no reliable burden of disease can be estimated from their intake. Consequently, frequent fish consumption may, unjustifiably, be perceived as 'healthy', while at the same time health-based guidance values can be frequently exceeded.

The health risks associated with the consumption of fish caught in Dutch rivers, estuaries and coastal waters cannot be accurately estimated. Given that the major Dutch rivers all flow through densely populated industrial areas, it is essential to carry out further exploratory research into concentrations of persistent organic pollutants in fish, particularly predatory and oily fish. More information is available in the RIVM report Consumption of products contaminated with PFAS from the Western Scheldt.

For a small group of consumers, fish allergy can be very serious, although the probability of death is small. Allergic reactions can be triggered not only by the consumption of fish, crustaceans and molluscs but also by the inclusion of small amounts of fish, crustaceans and molluscs in other food products. Most people suffering from allergies know that they are sensitive to fishery products. Citizens are, however, not able to verify how food products were prepared. It is therefore important for consumers with food allergies to be able to rely on proper product labelling containing information about allergens in fish, crustaceans and molluscs.

Biotoxins occur naturally in fish, crustaceans and molluscs. Some of these biotoxins are extremely toxic and already at very low exposure levels can lead to severe adverse health effects, and even death. The probability of exposure is, however, low in the Netherlands. It is also closely monitored in the fish supply chain, especially for molluscs from the Eastern Scheldt. The occasional findings of biotoxins are then followed by immediate risk management measures. Continuous alertness in industry and supervision to manage risks is therefore of paramount importance. The presence of biotoxins in the environment vary throughout the year and higher concentrations are especially found in the warmer months. In addition, changing climate conditions influence water currents in oceans and seas, which can lead to an increase in the number and concentrations of different biotoxins, such as PlTx (palytoxins) and cyclic imines (CI).

For the most part, the supervision of food safety focuses mostly on the control of the microbiological health risks, which requires considerable effort. Fishery products are easily spoiled if they are inadequately refrigerated or preserved. Spoilage can lead to the formation of biogenic amines (especially histamine) that can cause food poisoning. This can result in mild cases of illness, but occasionally severe adverse effects can also occur. The spoilage of fish products can happen quickly, but it can also occasionally be masked by staining of the (not) fresh fish. The storage conditions may be especially inadequate for large expensive fish that are traded and processed in smaller pieces. If spoilage is masked, consumers will likely not be able to properly assess food safety, and thus they are dependent on supervision. In cases in which spoilage is evident, consumer education can help to reduce health risks. Once histamine has been produced, it cannot be eliminated by cooking or frying the fish.

Much burden of disease from microorganisms attributed to fish consumption involves mild effects (including nausea, headache, vomiting, diarrhoea) of short duration (several days). To a large extent, these foodborne infections are not specific to the fish supply chain; contaminations with viruses and bacteria are sometimes caused during food preparation due to an inadequate hygiene. Moreover, particularly for a number of viral infections caused by, for example, the norovirus and rotavirus, it is not always clear whether they concern a foodborne contamination. These viruses can also come in contact with consumers through other routes of contamination, such as contaminated equipment, cutlery and crockery. Food handlers and their facilities, e.g. buildings, machinery and tools, can thus be a source of food contamination; also in the fish supply chain. For example, *Listeria monocytogenes* primarily enters the fish supply chain from the processing facilities. Food contamination incidents may be then reduced by proper hygiene practices during fish processing and good health and hygiene of food handlers. Furthermore, much of the fish consumed in the Netherlands, such as cod and salmon, is imported. Therefore, a part of the burden of disease in the Netherlands may be caused by the poor hygiene practices abroad. Active supervision of the hygiene practices abroad is, however, not directly possible for the Dutch government. Imports are therefore checked for EU-required food safety guarantees as issued by authorities in third countries. The European Commission monitors the control systems used by supervisory authorities in these countries.

The microorganisms that pose the most significant risk to public health worldwide through the consumption of fish, crustaceans and molluscs include bacteria: *Salmonella* spp., *Listeria monocytogenes*, *Vibrio* spp. and *Clostridium botulinum*, viruses: norovirus and hepatitis A virus, and parasite: herring worm (*Anisakis*). Although not in the Netherlands, Chinese liver fluke (*Clonorchis sinensis*) forms a significant risk globally and is relevant for people travelling to Asian countries where this parasite is endemic.

Fish, crustaceans and molluscs become infected with microorganisms either in the aquatic environment or at a later stage of the supply chain. *Vibrio* spp. and *C. botulinum* appear naturally in the aquatic environment, while *Campylobacte*r spp., *Salmonella*, norovirus, and hepatitis A virus may be introduced at a later stage of the supply chain.
Due to accumulation, high concentrations of pathogens can particularly be found in crustaceans and molluscs, increasing the probability of infecting fish-eating consumers. This mostly applies to bivalves such as oysters and mussels, as they are consumed raw or sometimes poorly heated, and to a lesser extent to shrimps. These public health risks can be significantly reduced by preventing water pollution with sewage and drainage water containing faecal or vomit residues.

For the supervision of food safety of bivalves in the Netherlands, the presence of *E. coli* is used as a water quality indicator. Other pathogens, especially viruses, do not fully correlate with this *E. coli* indicator; meaning that bacteriological safety and virus safety might not always be identical. The analytical methods for detection and monitoring of norovirus in live bivalve molluscs have been, however, recently developed.

The consumption of fish, crustaceans and molluscs is the only alimentary exposure route for *Vibrio* spp. The incidence of *Vibrio* infections is currently estimated to be low. Rising water temperatures due to climate change may, however, increase the level of contamination of fish, crustaceans and molluscs, both in terms of frequency and concentration. The probability of infection may thus increase as well.

Parasitic worms are frequently found in fish, especially freshwater fish from tropical and subtropical regions, such as tilapia. Public health risks from these parasites can be well controlled because worms are killed during the freezing (as it is also regulated by law for fish intended to be consumed raw) and when heated sufficiently. In marine fish, parasitic worms are much less frequent, with the exception of the herring worm *(Anisakis simplex)* in herring.

Most microorganisms are inactivated by adequate heating. Consequently, consumption of raw fish products, or products that have been insufficiently heated, poses a much greater risk to public health than that of properly heated products. Adequate consumer education is and will remain important, especially given the increasing popularity of the consumption of raw fishery products, such as sushi. In this regard, it is also important to consider that more and more consumers are eating sushi at home or at non-specialist restaurants offering sushi.

Resistant bacteria can be found in farmed fish and shrimp that have been exposed to antibiotics. Its contribution to the total resistance found in humans seems limited but may increase with the growth of the production of farmed fish.

Health risks from physical hazards are estimated to be very low, although there are annually over one hundred cases of choking or suffocating caused by fish bones in particular. Public health risks from the presence of nano- and microplastics in fish, crustaceans and molluscs cannot be adequately estimated at present due to a lack of information.

Animal welfare and animal health
The scientific evidence of animals being sentient is strong for fish, weak for crustaceans, and – with the exception of cephalopods – lacks for molluscs. However, weak evidence or its absence do not exclude the possibility of an animal being sentient. It is therefore important to consider a high degree of uncertainty about the estimated prevalence of animal welfare consequences and hazard exposure.

The size of Dutch fisheries is many times larger than aquaculture (farmed fish); consequently, more individual animals are involved. The risk period during which fish is exposed to man-made processes affecting animal welfare is, however, much longer for farmed fish than for wild-caught fish and crustaceans.

Primary welfare risks for wild-caught animals are the actual catch, the storage of live fish (for example many herring die when stored alive), and the killing without stunning in general (e.g. gutting, placing in ice or freezing alive). Furthermore, animal welfare risks for farmed fish arise from inadequate feed composition (not matched to fish species or production stage), inadequate fixed housing parameters (such as no shelter and resting opportunities), sub-optimal water quality and temperature (e.g. during transport). Moreover, in some cases, pathogens (bacteria, parasites and viruses) also affect animal welfare. However, there is still a lack of basic knowledge, in particular with respect to nutrition and behaviour in farmed fish in relation to animal welfare. Nor are there many effective and registered veterinary medicines available for farmed fish. Veterinarians can issue prescriptions in accordance with the cascade policy. The Dutch supervision of veterinary medicines focuses mainly on environmental contamination and residues in fish after slaughter but not on welfare of live fish.

There is a great pressure on the animal welfare of catfish and eel populations within the Dutch aquaculture (fish farming). However, when the Dutch consumption of farmed fish is considered, the animal welfare of pangasius farmed in Asia seems to be under the greatest pressure; especially due to a high risk of animal diseases resulting from the open nature of the farming systems. The use of vaccines in Asian farms may have already reduced fish welfare problems.

As far as is known, Atlantic salmon is the only fish species used in aquaculture for which a comprehensive scientific list of needs has been drafted. These needs concern the environment (respiration, osmotic balance, thermoregulation, good water quality), health (body care, hygiene, safety and protection), behaviour (behavioural control, social contact, tranquillity, exploration, sexual behaviour), and food sources (feeding and nutrition). The diversity of fish species makes it difficult to apply the information on salmon needs to other farmed species, e.g. catfish. There are differences in requirements such as water quality and nutrition. The natural behaviour of fish varies also substantially. Little or no research has been conducted into the needs of crustaceans and molluscs.

Animal welfare indicators or criteria for each farming system, fishing method or species have not yet been sufficiently researched or validated. Proper standards and indicators per fish species for assessing fish welfare within the fish supply chain are lacking, making governmental supervision difficult. For animal health, the Netherlands has primarily a passive animal disease monitoring.

Based on the information from this risk assessment, several potentially valuable animal-based welfare indicators are suggested for the use in supervisory activities. For farmed fish these include: an affected or detached mucus layer on skin, tissue damage, presence of diseases (due to weakened immune system), reduced feed intake, and early death, whereas for wild-caught animals the following indicators are suggested: open/external wounds, indication of hypoxia such as gasping, and early death.

Additionally, post-mortem measurements could provide insight into the presence of acute stress prior to the killing of the fish. The market size of sustainability-labelled products seems to be increasing and there is a trend for inclusion of animal welfare criteria in certification schemes, especially for farmed fish, such as in the Aquaculture Stewardship Council (ASC) label. Certification systems could become part of the animal welfare supervision system.

Environmental indicators that can be used in supervision of aquaculture depend on the species being farmed. Potentially valuable for farmed fish are, for example, lack of shelter and resting facilities, the levels for acidity, oxygen, carbonic acid and ammonia (as these are important for all species and production phases: nursery, transport and in catfish place of slaughter), and animal density (stocking density). For wild-caught fish, environmental indicators such as oxygen level in storage tanks and animal densities are potentially valuable.

Nature
Fishing and farming of fish, crustaceans and molluscs have a detrimental effect on species and their natural living environment in many different ways. The ecological value (species, biodiversity, ecosystems) is under pressure. The fishing industry is also predominantly not sustainable. The biggest risks arise from overfishing, bycatch/discards, seabed disturbance and the introduction of alien species.

Knowledge-driven and risk-based supervision is already being used against overfishing. The European Common Fisheries Policy sets out fishing quotas, and the size of the quotas is advised by ICES working groups. Wageningen Marine Research also carries out a lot of policy-supporting research on topics from inland fisheries to marine Natura 2000 management plans. There are also European regulations for limiting bycatch and discards. The NVWA supervises compliance with these European regulations and illegal fishing activities. Supervision of the molluscs industry is mostly aimed at food safety.

Restrictions have been imposed on the fishing industry in terms of seabed disturbance in protected areas. At a detailed level, sharks and rays are a vulnerable group of cartilaginous fish that are under threat by both bycatch and bottom trawling. The Norway lobster (*Nephrops norvegicus*) population is also vulnerable due to overfishing.

There is still insufficient information available on the nature and extent of the introduction and spread of alien species in marine areas, the Delta waters (i.e. the large waters in the delta area of the provinces Zeeland, South Holland and North Brabant, such as Grevelingen, Haringvliet, Hollands Diep, Eastern Scheldt, Oude Maas, Veerse Meer, Western Scheldt and Saeftinghe) and the Wadden Sea. In many areas, fishing activities cause the introduction and spread of marine alien species. More research can provide a better overview of these risks, but the NVWA cannot start supervisory activities until targets or policy measures have been formulated. It appears that policies and supervision are effective in reducing risks only for molluscs movements.

There is also limited insight into the nature and extent of fish releases, because they are not recorded or reported. Knowledge-driven and risk-oriented supervision is thus hardly possible without a central registration. Consequently, fish releases may only become known after reports are made to the supervisory authority.

2.3 Recommendations for the fish supply chain

The answer to the question '*What are the biggest risks in the fish supply chain for public health, animal welfare, animal health and nature?'* is translated into the following recommendations on reducing the risks to food safety, animal welfare and animal health, and to nature. The recommendations are addressed to the Inspector-General of the NVWA, the Minister of Agriculture, Nature and Food Quality, and the Minister of Health, Welfare and Sport.

A fairly detailed set of policy and control measures has already been implemented to control the risks related to microbiological food safety. The risks faced by nature cannot be controlled in all areas, but even there, policy has already been made and supervision by NVWA has been implemented. If supervisory activities in these areas were to be decreased, there is a real chance that harmful effects for consumers and nature would increase. The NVWA is also doing a lot of work on chemical food safety, but the selection of priority substances relevant to food safety needs to be reviewed. The NVWA efforts in the area of fish welfare and health are limited, mainly due to the absence of legal and regulatory provisions.

The overarching outlook of the fish supply chain risk assessment is as follows:

- i) Data on risks to humans, animals and nature are of limited availability or have not been collected systematically for the Dutch situation, leaving much room to improve knowledge-driven and risk-oriented supervision. The possible use of data from 'smart' cameras (including online recording, 3D imaging, infrared) and sensor technology can make supervision simpler and better.
- ii) Good use could be made of public and private quality assurance systems in the fish, crustacean and molluscs industry for knowledge-driven and risk-oriented supervision in the fish supply chain if they are aimed at reducing risks to humans, animals and nature, and if information from these quality assurance systems is shared with chain partners and with the NVWA.
- iii) Consumption of fish, crustaceans and molluscs from waters heavily contaminated with PFAS, arsenic compounds, methylmercury, cadmium and other persistent environmental contaminants could jeopardise food safety. This could prompt the reinforcement of dietary advice on fish consumption.
- iv) Impairment of animal welfare is often severe and involves numbers of animals many times greater than those of large farm animals and poultry in the Netherlands.

Recommendations on public health

1. Together with the Ministry of Infrastructure and Water Management, expand research activities in Dutch inland and coastal waters for PFAS, dioxins, cadmium, methylmercury, and arsenic compounds. These chemical contaminants can accumulate in fish, crustaceans and molluscs in these habitats to levels that may pose an increased risk to consumer health. As part of this research, consider the relationship between the level of contamination, animal species and (capture/farming) locations.

2. Encourage the European Commission and other international authorities to map the concentrations of dioxins, cadmium, methylmercury, arsenic compounds, and particularly

PFAS in fish, crustaceans and molluscs and in their habitats, including fresh, brackish and salt water. Also, promote that these data are placed in a European database to gain insight into high-risk areas that are not suitable for catching and farming fish, crustaceans and molluscs.

3. Encourage RIVM, in collaboration with the Netherlands Nutrition Centre, to re-examine the dietary recommendations for the consumption of (oily) fish, crustaceans and molluscs. Also, request the Health Council of the Netherlands to investigate whether the dietary recommendations require an indication of an upper limit for fish consumption, with particular attention to fish consumption by pregnant women and children.

4. Continue to supervise adequate refrigeration/freezing practices and good hygiene practices at each step of the supply chain and enhance the supervision through the development and use of sensor technology. Also, continue to supervise the control of the presence of microorganisms, in particular *Listeria* in fish processing facilities that prepare fish, crustaceans and molluscs to be consumed raw. Improve data registration and data exchange across all stages of the fish supply chain.

5. Take action to oblige fish, crustacean and molluscs farmers in the Netherlands to implement risk-based quality assurance systems that focus on ensuring that farming systems incorporate adequate measures to control risks to food safety (including antibiotic resistance), animal welfare, animal health and nature.
   Also, take action to urge foreign authorities to implement risk-based quality assurance systems in their countries.

6. In the face of global warming, continue to monitor the presence of new and emerging marine biotoxins and intensify monitoring of *Vibrio* spp. in fish, crustaceans and molluscs.

7. Intensify the monitoring of the presence of antibiotic resistance in fish from aquacultures, especially from Asia. Based on this monitoring, investigate, preferably with European partners, whether specific fish products or specific regions, pose an increased antibiotic resistance risk.

8. Monitor developments in the presence of nano- and microplastics in fish, crustaceans and molluscs for food safety purposes and request EFSA to prepare an opinion on this.

9. Given the popularity of sushi consumption, request the Netherlands Nutrition Centre to provide consumers and non-specialised restaurants with information about the microbiological risks caused by eating raw or insufficiently heated fish, crustaceans and molluscs.

10. Request the Netherlands Nutrition Centre to increase effort in raising awareness amongst recreational fishermen and recreational harvesters of fish, crustaceans and molluscs of the microbiological risks if the caught or harvested animals come from polluted water. Also, request the Netherlands Nutrition Centre to raise awareness of the risks of chemical contaminants in fish, crustaceans and molluscs.

11. Have further research conducted on the incidence and burden of disease that may be caused by *Vibrio* spp.

Recommendations on animal welfare, animal health and nature

12. Develop policies and supervision methods to reduce the impairment of the welfare of billions of animals that are consumed annually as fish and crustaceans.

13. Promote research to improve management of animal welfare risks during farming of fish and by crustaceans, and also develop policies in this regard.

14. Invest in the development and validation of animal welfare indicators and criteria for each farming system, fishing method and animal species.

15. Invest in the development of capture, harvest, storage, transportation and killing methods that result in reduced animal welfare impacts on fish and crustaceans, including methods to reduce the time between capture and killing of animals.

16. Establish guidelines for the live storage, transportation and killing of fish and crustaceans in particular, to minimise impairment of animal welfare and thereby to limit the possibility that animals are filleted or processed without stunning.

17. Develop monitoring and control systems for animal diseases of fish, crustaceans and molluscs to identify new diseases at an early stage and prevent diseases from becoming endemic, in analogy to the system used for farm animals. This particularly applies to the farming of fish, crustaceans and molluscs.

18. Establish an animal disease monitoring system for fish, crustaceans and molluscs not only to monitor animal diseases but also to detect chemical or microbiological contamination, especially in wild-caught fish.

19. Have research conducted into the effects on nature and animal welfare caused by the extensive discards in coastal and marine fisheries.

20. Identify, in collaboration with the Ministry of Infrastructure and Water Management, the nature and extent of the introduction and spread of alien species in marine areas, the Delta waters and the Wadden Sea and have the risks assessed for the aquatic biodiversity and ecological water quality in order to establish policy objectives.

21. Register the nature and extent of fish releases and have the risks assessed for the aquatic biodiversity and ecological water quality.

3. Substantiation of assessment of risks to humans, animals and nature in the fish supply chain

3.1 Approach

A subdivision into physical, chemical and microbiological hazards to public health, animal health, and nature (including fish stocks) has been made for the purpose of this advice. Animal welfare risks have also been explored, even though there is very little scientific literature for the risk assessment of crustaceans and molluscs in particular. There is also very little data on the severity and prevalence of the hazards to animal welfare.
Plants (e.g. glasswort), macroalgae (seaweed) and microalgae are not included in the assessment, even though public health risks associated with their consumption could be similar to those associated with the consumption of mussels and oysters. Ornamental fish are not part of the supply chain risk assessment and neither is the feed for fish, crustaceans and molluscs.
The design of the risk assessment for each public domain is presented in the appendices. In most cases, research institutes were asked to identify the hazards of the fish supply chain to humans, animals and nature. Afterwards, a multidisciplinary team at BuRO drafted the assessment. External experts then reviewed the drafts for each of the risk assessments outlined in the appendices. The divisions of NVWA's directorate Enforcement and subsequently the representatives of sector organisations also checked the drafts for any factual inaccuracies. The basic information sheets of the fish supply chain supervision from the integrated supply chain analysis on fish (IKA Vis) were used once the drafts were reviewed. References to information from IKA Vis have been included in this document.

The method applied for the risk assessment follows the usual steps (*for more information please see Appendix 1)*: hazard identification, hazard characterisation, exposure assessment and risk characterisation, as stipulated by the act established on 26 April 2006 that regulates the independent performance of risk assessments by the Netherlands Food and Consumer Product Safety Authority (Wet van 26 april 2006 tot regeling van een onafhankelijke uitoefening van risicobeoordeling door de Voedsel en Waren Autoriteit. Bulletin of Acts and Decrees 2006, 247, last amended by Bulletin of Acts and Decrees 2018, 488). The risk characterisation reflects the degree of risk and is based on the severity of the hazard and the level of exposure to this hazard. For food safety, the risk characterisation is based on the guidelines for risk classification. *For more information, please see the NVWA BuRO website risk assessment methodologies.* The estimation of the chemical, physical and microbiological public health risks of fish, crustaceans and molluscs has strong similarities with those of other foods. Supplementary to this, specific hazards have been identified for fish, of which the risk is estimated for Dutch consumers. Bacteria are also present in the fish supply chain and may cause wound infections if the skin is damaged, for example during the preparation of crustaceans and molluscs. The risk to consumers will generally be very limited and is not considered in detail in this supply chain risk assessment.

A detailed description of the risk assessment methodology, the different risk assessments and the information/literature sources consulted can be found in the appendices.

3.2 Public health risks in the fish supply chain

In brief

Similar to other foods, in addition to the nutritional value provided by the consumption of fish, crustaceans and molluscs, their consumption may also contribute to an intake of chemical and microbiological contaminants that can be detrimental to consumer health. Spoiled fish may also introduce health risks. Moreover, similar to other foods, allergy to fish, crustaceans and molluscs may lead to a burden of disease for people prone to allergies. Finally, contaminants such as plastics, glass and metals (e.g. fish hooks) in fish, crustaceans and molluscs may also pose a risk to consumers.

The main food safety risks in the fish supply chain are described in Appendix 3.2. *For more information on food safety supervision, please see IKA Vis: particularly the information sheets on supervision of food safety in terms of fishing vessels and landing, on supervision of food safety in fish, crustacean and molluscs processing companies, on supervision of food safety for fish in the catering industry, craft and retail, on supervision of food safety involving production areas, reports of unsafe food products containing fish in the Netherlands and the EU, on inspection results of microbiology, additives, and chemical contaminants, and on laboratory tests on imports from third countries.*

3.2.1 The nutritional value of fish and fish products

Fish contains substances that can provide health benefits (Appendix 3.1). The Health Council of the Netherlands (2015) concluded that fish is an important source of the long-chain polyunsaturated fatty acids: eicosapentaenoic acid and docosahexaenoic acids (EPA and DHA, omega-3 fatty acids). Fish, crustaceans and molluscs are listed in the Dutch Wheel of Five guidelines on nutrition and are also recommended as sources of, among other things, vitamin B12, vitamin B6 and the minerals iodine, phosphorus, selenium and iron. Oily fish is a source of vitamin D, vitamin B12 and vitamin A. More information is available on the website of the Netherlands Nutrition Centre. Crustaceans and molluscs are also rich in iodine, phosphorus and selenium.
The dietary recommendations for a healthy adult in the Netherlands is based on a consumption of fish, preferably oily fish, once a week (Health Council of the Netherlands, 2015). Oily fish, such as herring, mackerel, sardines, halibut and Atlantic salmon, contain naturally more than 5% fat. Crustaceans and molluscs are not officially considered as fish, however, they are included as lean fish in the Dutch Wheel of Five guidelines on nutrition by the Netherlands Nutrition Centre.

On average, fish is eaten once every other week in the Netherlands. Calculated over the entire Dutch population, an average of 16 grams of fish per day is consumed. The average daily consumption of fish is almost 15 grams, crustaceans and molluscs 1.3 grams, and cephalopods 0.2 grams. On days when fish is eaten, consumption averages 115 grams per person. Fish consumption varies, however, considerably. Approximately 20% of the Dutch population does not eat fish on a regular basis, while about 10% does not eat fish at all. In contrast, 5% of the Dutch population consumes an average of more than 41 grams per day, and hence more than 290 grams per week. Most commonly consumed fish in the Netherlands are salmon, tuna and cod. *For more information on consumption, please see Appendix 3.1.*

3.2.2 Health risks related to the consumption of fish products

Similar to other foods, it is difficult to estimate the burden of disease of chemical substances in fish, as there is often a long period of time (e.g. of many years) between exposure and health effects. Moreover, people are exposed to many substances through different routes of exposure, whereby the different routes together may increase the health risk. Different substances may also have similar toxicological mechanisms of action, which may increase the health risks associated with exposure to mixtures compared with exposure to individual substances.

The burden of disease caused by microorganisms appears to be easier to estimate as the time between exposure and effects is often shorter and the course of disease can be easier to follow. Nevertheless, the estimates of the burden of foodborne diseases and public health risks are highly uncertain. It should also be noted that the chemical and microbiological contaminants of the fish caught or farmed in the Netherlands can hardly, if at all, be related to effects experienced by Dutch consumers. Large portion of fish that are consumed in the Netherlands is imported from other European countries or from outside the EU.

Public health hazards may be introduced during different stages of the fish supply chain. For example, fish naturally contains allergens that are hazardous to some consumers. Fish may also absorb contaminants present in the aquatic environment, or infections with certain pathogenic microorganisms may occur. These include heavy metals, pesticides, human and veterinary medicine residues, persistent substances such as PCBs and PFAS, biotoxins, and pathogenic microorganisms. Physical elements, such as (micro)plastics, can also enter fish, crustaceans and molluscs through the aquatic environment.
Moreover, fish, crustaceans and molluscs may come into contact with, for example, residues of detergents and disinfectants during and immediately after capture or harvest (farmed fish), landing, fish auction, transportation, import and storage, and preparation and processing.

Finally, during the preparation and processing of fish, crustaceans and molluscs, contamination can occur of chemical (e.g. formation of polycyclic aromatic hydrocarbons (PAHs) during smoking of fish), microbial (cross-contamination, unhygienic handling) or physical nature (glass fragments). Spoilage of fish products may also occur; increasing the probability of the presence of biogenic amines harmful to the health.

Burden of disease
Microorganisms
Estimates of the burden of disease caused by pathogenic microorganisms, which are attributable to specific routes of infection or food products, can be compared using a measure developed by the WHO: DALY (Disability-Adjusted Life Years). In 2019, the burden of disease in the Netherlands caused by microorganisms, including transmission to people via food, has been estimated at 10,870 DALYs. Of these, 4,170 DALYs have been attributed to foodborne infections, of which 300 DALYs (6-7% of the burden of foodborne diseases) to fish, crustaceans and molluscs. However, the attribution of the burden of disease to the different routes of infection is being revised, as it is based on insights from about 15 years ago. To what extent this burden of disease attributed to the fish supply chain is actually caused by fish, crustaceans or molluscs, is unknown. Infectious diseases can have a serious course in older people, young children and those with frail health. The fact that the population is ageing potentially leads to an increase of vulnerable people prone to a severe course of infections.

Chemical substances
For most chemical substances from the fish supply chain, it is difficult to make an estimate based on DALYs owing to the uncertainties in the attribution and the long period of time between exposure and effects. The health benefits and risks of fish consumption have been also assessed differently in the scientific publications. While most publications consider the effects of fatty acids and methylmercury, in some cases, a risk-benefit analysis is made for fatty acids in fish and environmental contaminants such as dioxins and PCBs. The concentrations and distributions of fatty acids and contaminants in different fish vary considerably. The risk-benefit analyses therefore are dependent on the choice of fish species as well as the selection of environmental contaminants and the fishing locations. Moreover, results of risk-benefit analyses differ for various population groups, i.e. men, women, pregnant women and children. For example, a meta-analysis has shown that the duration of pregnancy and birth weight improved with a mother's fish intake of 8-15 g/day. A positive cardiovascular effect was expected at an intake of 7.5-22.5 g/day. However, based on the Reference Dose (RfD) derived by the Environmental Protection Agency (EPA) for methylmercury of 0.1 µg/kg body weight per day, a fish intake of 27-65 g/day, depending on the fish species, would lead to adverse health effects. Furthermore, the outcome of a study that analysed different environmental contaminants in oily and lean fish indicated an optimal fish intake to be around 200 g per week for certain oily fish species and about 50 g per week for lean fish, crustaceans and molluscs. Research carried out in France showed that while it is feasible to follow the health recommendation of a daily intake of 0.5 mg

of long-chain polyunsaturated fatty acids, fish consumption at about 1.5 g/day already exceeds the maximum level of dioxins.

There is only a very thin line between a sufficient consumption of fish to benefit from the positive effects of fatty acids and a too high consumption leading to harmful effects. Moreover, consumption of fish from certain areas may possibly lead to both positive and harmful effects for consumers.

3.2.3 *Fish allergy and health effects of biogenic amines*

Allergy

Consumption of fish, crustaceans and molluscs may lead to (severe) allergies. Allergic reactions can be life-threatening and occur fairly quickly after ingestion of the allergenic food. An allergy to fish, crustaceans and molluscs usually develops later in life. The symptoms of food allergy in infants usually disappear after a few years, while food allergies that develop later in life are usually permanent. The prevalence is between 0.1% and 2.2% of the population. Food allergies are defined as the responses of human immune system to foods that generally involve immunoglobulin E (IgE). In contrast, food intolerance or non-allergic food hypersensitivity are reactions to foods in which the immune system is not involved. BuRO could not derive threshold doses for allergic reactions to fish but was able to do so for shrimp.
Workers in the fishing industry are at risk of developing an allergy to fish, crustaceans and molluscs as a result of intensive skin contact with the animals or through inhalation.

The major fish allergens are parvalbumins (i.e. muscle proteins in fish). Parvalbumins are resistant to heating and enzymatic treatments. Proteins from fish, crustaceans and molluscs are also insensitive to treatments with extreme pH.
Although all fish species have allergens, allergic reactions most frequently reported in the literature concern cod and salmon. It is estimated that 50% of people allergic to one fish species, are also at risk of reacting to other fish species.
The major mollusc and crustacean allergen is tropomyosin, although other proteins also play a role, e.g. arginine kinase. Cross-reactivity may occur with insects (e.g. cockroaches), arachnids (e.g. dust mites) and molluscs (e.g. squids, oysters, snails and mussels). Cross-reactivity means that IgE antibodies produced in response to one allergen can also bind to other allergens.
Mandatory labelling exists in Europe for fish (excluding fish gelatine), crustaceans and crustacean- and molluscs-based products. Molluscs are animals with a soft body, with external or internal (cephalopods) shells, as for example oysters, mussels, scallops, whelks and squids. Land snails and slugs also belong to molluscs, but they are not included in the fish supply chain risk assessment.

Anisakiasis

In addition to allergic reactions after the exposure to fish, allergic reactions can also be caused by various toxins and parasites. The only parasite in fishery products that causes an allergy is the nematode *Anisakis simplex*. Anisakiasis, or herring worm disease, is a parasitic infection of the gastrointestinal tract caused by the consumption of raw or undercooked fish containing the larvae of the nematode *Anisakis simplex*, the herring worm. The herring worm disease regularly occurred in the Netherlands before it became mandatory to freeze herring after capture. The disease can become chronic if the immune response does not manage to eliminate the worm and the patient becomes sensitised to *Anisakis*-derived allergens. Allergies to *Anisakis simplex* are still relatively common in Spain but are rarely reported in other European countries. Freezing or heat treatment are sufficient to kill the parasite. However, killing of *Anisakis* does not eliminate the risk of allergy. Allergy symptoms can also occur after exposure to processed products. Wild-caught and farmed fish from fresh and salt water may contain living parasites that pose a risk to human health if eaten raw or undercooked. EFSA considers the risk of infection to be negligible for farmed Atlantic salmon. Insufficient data are, however, available to make a statement on other farmed fish.

Biogenic amines

Biogenic amines are organic compounds formed from amino acids that can cause non-immunological reactions. The most common biogenic amine is histamine. Biogenic amines are produced by bacteria or fungi, for example, in spoiled fish; both fresh and canned fish are well-known examples. Histamine poisoning is also referred to as scombroid fish poisoning, pseudoallergic fish poisoning, histamine overdose or mahi-mahi flush. Spoiled fish of the *Scombridae* and *Scomberesocidae* families, e.g. tuna, mackerel, swordfish, bonito, albacore and skipjack, are often involved in incidents of histamine poisoning. Symptoms of histamine poisoning include nausea, vomiting, diarrhoea, a burning sensation in the mouth, itching, headache and hypotension (lowered blood pressure). Symptoms usually begin within minutes after ingestion and last from a few hours to a day. The symptoms are similar to those of an allergic reaction. Most symptoms disappear after 6 to 8 hours. Given that people usually do not seek medical help after histamine poisoning and that symptoms are often mild and short-lived, these symptoms are usually not reported to medical care.

Fresh fish is best stored frozen or at 0 °C to prevent the growth of bacteria involved in the formation of biogenic amines and the activation of enzymes. Once formed, histamine is resistant to cooking, smoking, freezing or canning. Consumption of fish with a histamine concentration of more than 50 mg per 100 g of fish (500 mg/kg) may lead to histamine poisoning. In European Member States, fishery products should not exceed 200-400 mg histamine/kg. The Rapid Alert System for Food and Feed (RASFF) has been set up to quickly exchange information about health risks related to food products and animal feed between national authorities. It frequently reports high concentrations of histamine in fish, particularly in tuna, followed by sardines, mackerel and anchovies. Nearly all reports on biogenic amines concern histamine, which may be partly a consequence of mandatory regulations; in addition, cadaverine and putrescine may also possibly play a role. More information can be found in the EU system *RASFF-food-and-feed-safety-alerts*.

3.2.4 *Microbiological public health risks in the fish supply chain*

The term microorganism includes bacteria, viruses, yeasts, moulds, algae, parasitic protozoa, microscopic parasitic helminths, as well as toxins and metabolites of these organisms, and prions. This food safety risk assessment in the fish supply chain describes only microorganisms that can cause disease in humans, known as pathogens. An inventory was made of pathogenic viruses, parasites and bacteria (the hazards) that occur in the fish supply chain worldwide and which could potentially pose a risk to food safety. This risk assessment of the microbiological hazards focuses on microorganisms present in the fish supply chain that may cause a relevant burden of disease. In order to cause disease in humans, it is necessary for pathogens to be present in the product at the time of consumption in quantities that could be harmful to health. Parasites can be found in fish, but they do not reproduce in dead fish after capture. In order to reach an infectious dose and to produce toxins, some bacteria always need to grow in the food product, while for other bacteria growth is not necessary. For a limited number of bacteria this depends on the quantity in which they are present in the product. Viruses only replicate in consumers after consumption of contaminated fish products. Whether, and to what extent, a fish consumer becomes ill after exposure to a pathogen also largely depends on the susceptibility of that person.

Based on RIVM's attribution studies, it is estimated that 6-7% of disease burden of foodborne infections is caused by products from the fish supply chain (Figure 1). While some pathogenic parasites are specific to fish and fish products, pathogenic viruses and bacteria that contribute to the burden of disease are also found in many other foods as sources of foodborne infections (Figure 2). Moreover, people are also exposed to microorganisms through other routes; for example, some viruses, such as norovirus, rotavirus and hepatitis A virus, are not typical foodborne pathogens. This also applies to a number of bacteria and parasites. The contamination of fishery products generally occurs only through faecal contamination of water in which the organisms live or through post-contamination during preparation and processing by producers and food handlers. In particular, the post-contamination route is not specific to fishery products.

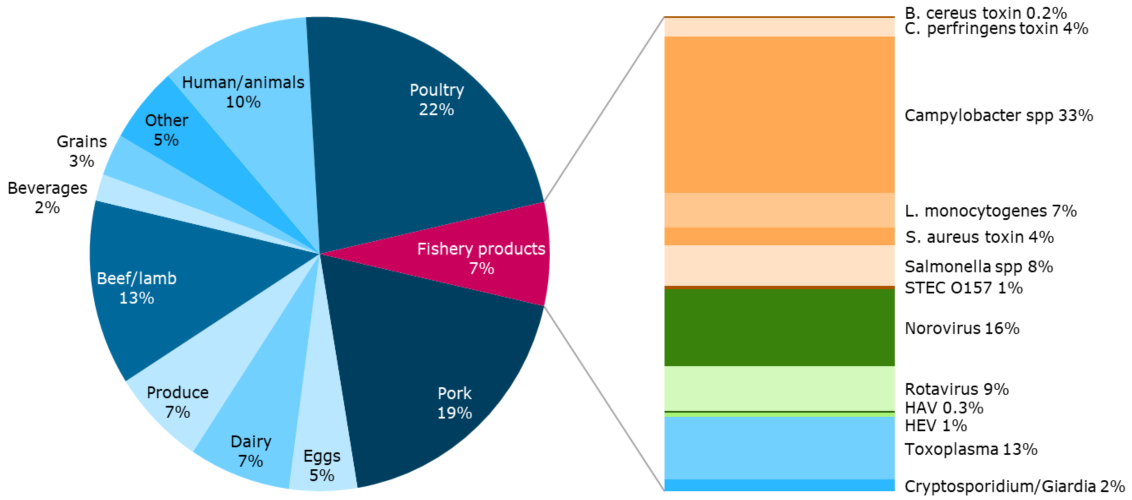

Figure 1. Burden of foodborne infections in the Netherlands in 2019 attributed to different product categories; broken down by burden of disease by pathogen for the fish supply chain.

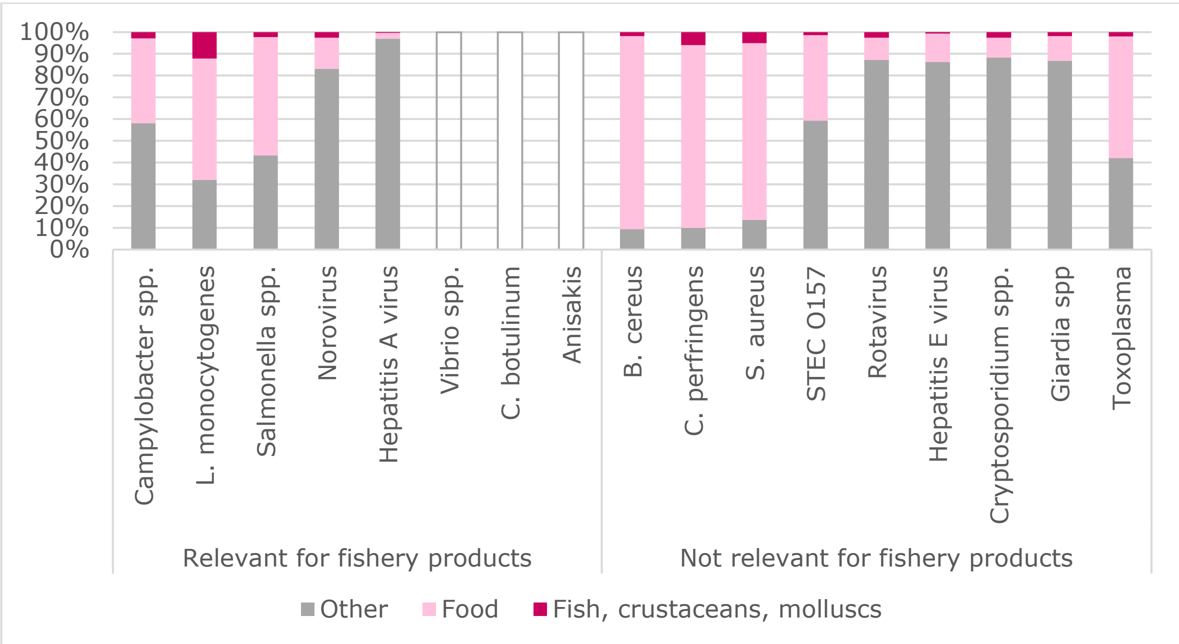

Figure 2. Burden of disease of foodborne pathogens in the Netherlands, 2019. Indicated is the proportion that is attributed to food and, within that, the proportion specifically attributed to the fish supply chain.

The causes of infection outbreaks are often unknown (in fact, in 87% of all outbreaks; Figure 3). Food-related outbreaks in the Netherlands are reported to the municipal health services (GGD) and the NVWA. The annual national overviews of the RIVM and the NVWA provide an insight into the number of reported cases of foodborne illness and infection outbreaks. Between 200 and 700 outbreaks were reported annually from 2013 to 2017. A causing agent was detected in 40 to 50 outbreaks corresponding to 6 to 16% of the total number of outbreaks per year. About 6 to 7% (n=24) of the outbreaks with a known cause resulted from consumption of fishery products. More than half (58%) of the fish-related outbreaks are attributable to norovirus and a quarter to histamine from the spoiled fish. A large nationwide salmonellosis outbreak caused by fishery products (smoked salmon) occurred in the period from 2009 to 2017. In 2012, 1,149 cases of illness were recorded during this salmonellosis outbreak. This outbreak is, however, an outlier in terms of the fish supply chain's contribution to the observed cases of foodborne illness. Norovirus and histamine, which can be identified as the sources in many fish supply chain-related outbreaks (combined approximately 83%), cause relatively few illnesses (combined about 1.5% of illnesses involved in foodborne outbreaks).

Mass catering in institutions can lead to a simultaneous exposure of a large group of people to a potentially contaminated food. Ready-to-eat products that are widely offered at retail, if contaminated, can also result in infection outbreaks; especially when these foods have undergone several processing steps before reaching consumers. In each processing step, potential microbiological hazards may be introduced; in particular when hand contact of food handlers with food happens. This also applies to imported food. Consumers more often choose to consume raw or short-cooked products, and they are not always aware of the microbial risks involved. Consequently, consumers need to rely on the fact that food was prepared following good hygiene practices and that the fish is safe for consumption.

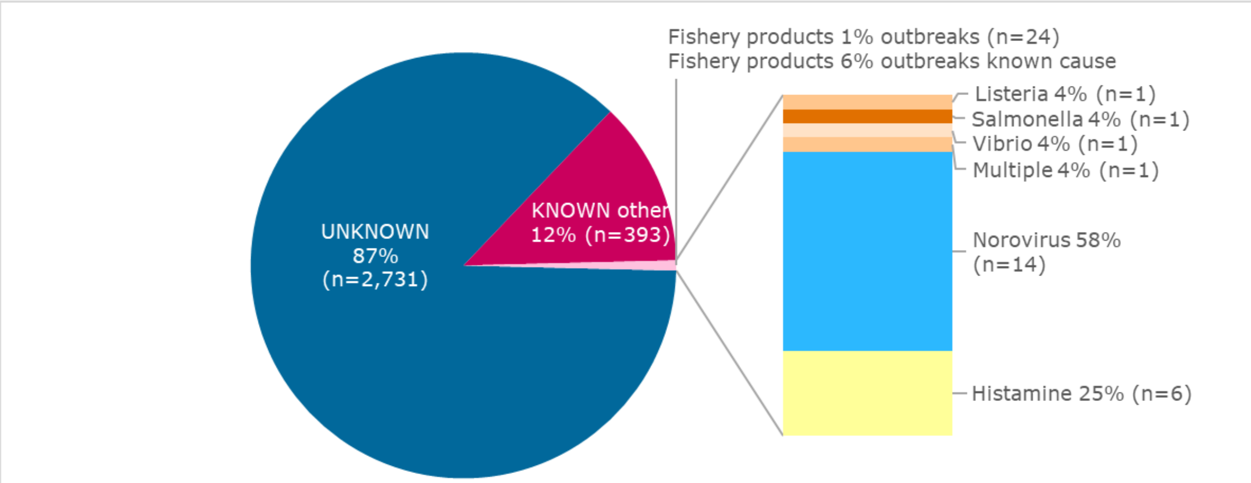

Figure 3 Overview of all foodborne outbreaks reported to NVWA/GGD/RIVM (2009-2017), broken down by unknown source (blue) and known source (shades of pink) where outbreaks caused by fish, crustaceans or molluscs are further broken down by the different agents: bacteria (orange shades), viruses (blue) and chemicals (yellow).

3.2.4.1 Introduction of the microbiological organisms in the fish supply chain

Many bacteria and parasites are naturally present in the habitats of fish, crustacean and molluscs. Consequently, the microbiota (i.e. microorganisms, such as bacteria, viruses and yeasts, found in and on the organisms) of these organisms, are largely determined by the quality of the habitat. In addition, fish, crustaceans or molluscs may become contaminated by microbiological organisms (i.e. bacteria, viruses and parasites) through human and/or animal vomit or faeces. Unhygienic handling after the capture or harvest, such as contact of the food with insufficiently washed hands during fish preparation and processing, can also lead to high-risk microbiological contamination. This also identifies the links through which pathogenic microorganisms may be introduced into the fish supply chain.
Many microorganisms are killed by appropriate heat treatment. Thorough heating of fish and fish products therefore constitutes an important protective measure for consumers against infectious

microbiological contamination. At the same time, an increase in the popularity of raw fish is observed in recent years, partly due to the rise of sushi restaurants, sushi bars and online shops. The demand for raw shrimp, currently mainly eaten in France, also seems to increase in the Netherlands. If these trends continue, the number of infections with microorganisms is expected to increase in the coming years, contributing substantially to the burden of foodborne disease in the Dutch population. To monitor these developments, it is necessary to trace the specific sources of infections.

link	potential microbial contamination routes
Living environment	More or less diluted contamination with bacteria, parasites and viruses in water, soil and food: vomit or faeces of humans and/or animals, proximity to water treatment/sewage systems, absence of control measures (unlike aquaculture). Contamination with diluted or undiluted substances that can lead to selection of resistant bacteria in water, soil and food: antibiotics, disinfectants.
Capture	Contamination with bacteria, parasites or viruses through contaminated rinse water, cross-contamination (visceral waste), unhygienic working practices, contact with insufficiently disinfected materials, proximity to water treatment/sewage systems, discarding untreated visceral waste that become a food source for predatory fish, fishing methods affecting parasite infestation, and post-mortem migration of anisakid nematodes.
Landing/import	Import of pathogens from endemic areas, warmer waters, imports from areas with reduced hygiene, increasing consumption of exotic products.
Transport/storage	Bacterial spore outgrowth dependent on cooling, biofilm on the scales, no parasite killing, cross-contamination.
Processing	Unhygienic work practices, cross-contamination, bacterial outgrowth on equipment, biofilm, insufficiently cooked products, convenience food, cold-smoked, belly flap (due to migration of *Anisakis* larvae).
Distribution	Ready-to-eat products, raw consumption, unhygienic work practices, storage temperature, cross-contamination, increasing consumption of exotic products, incomplete labelling, consumption of entire fish (including guts).

Figure 4 Different links in the sub-supply chain of marine/coastal/inland fisheries and potential microbial contamination routes.
NB Not all routes of introduction apply to all pathogenic microorganisms.

link	potential microbial contamination routes
Living environment	Contamination with bacteria, parasites and viruses in water, soil and food: vomit or faeces of humans and/or animals, proximity to water treatment/sewage systems, overflow after heavy rains. Accumulation with possible recombination of viruses due to filter-feeding property of molluscs, where rinsing is insufficiently effective, conditioning on pelleted feed to reduce parasitic infections. Contamination with diluted or undiluted substances that can lead to selection of resistant bacteria in water, soil and food: antibiotics, disinfectants.
Capture	Contamination with bacteria, parasites or viruses through contaminated rinse water, cross-contamination (visceral waste), unhygienic working practices (e.g. when peeling), contact with insufficiently disinfected materials, proximity to water treatment/sewage systems.

link	potential microbial contamination routes
Landing/import	Import of pathogens from endemic areas, warmer waters, imports from areas with reduced hygiene, increasing consumption of exotic products.
Transport/storage	Bacterial spore outgrowth dependent on cooling, no parasite killing.
Processing	Unhygienic work practices, cross-contamination, bacterial outgrowth on equipment, biofilm, insufficiently cooked products, convenience food.
Distribution	Ready-to-eat products, raw consumption, unhygienic work practices, storage temperature, cross-contamination, increasing consumption of exotic products, incomplete labelling.

Figure 5 Different links in the sub-supply chain of crustaceans and molluscs, and potential microbial contamination routes.
NB Not all routes of introduction apply to all pathogenic microorganisms.

link	potential microbial contamination routes
Living environment Animal feed	Contamination with bacteria, parasites and viruses in water, soil and food: vomit or faeces of humans and/or animals, proximity to water treatment/sewage systems, overflow after heavy rains, reuse of water, proximity to (fertilised) farmland, use of animal manure or human excrement ('night soil') as food, possibility for control measures. Use of substances that could result in a selection of resistant bacteria in water, soil and food: antibiotics, disinfectants, probiotics.
Catch	Contamination with bacteria, parasites or viruses through contaminated rinse water, cross-contamination (visceral waste), unhygienic working practices, contact with insufficiently disinfected materials, proximity to water treatment/sewage systems.
Import	Import of pathogens from endemic areas, warmer waters, imports from areas with reduced hygiene, increasing consumption of exotic products.
Transport/storage	Bacterial spore outgrowth dependent on cooling, biofilm on the scales, no parasite killing.
Processing	Unhygienic work practices, cross-contamination, bacterial outgrowth on equipment, biofilm, insufficiently cooked products, convenience food, cold smoking.
Distribution	Ready-to-eat products, raw consumption, unhygienic work practices, storage temperature, cross-contamination, increasing consumption of exotic products, incomplete labelling, consumption of the whole fish (including guts).

Figure 6 Different links in the sub-supply chain of farmed fish, and potential microbial contamination routes.
NB Not all routes of introduction apply to all pathogenic microorganisms.

3.2.4.2 Specific health risks caused by viruses

Illnesses caused by viruses of concern in the fish supply chain range from self-limiting stomach flu symptoms (vomiting, diarrhoea) to more serious infections, including the inflammation of the liver resulting in possible liver failure. Human-pathogenic viruses do not replicate in fish, crustaceans or molluscs. These viruses can, however, accumulate in bivalve molluscs in particular (i.e. mussels and oysters), as they feed by filtering the surrounding water. The concentration of viruses (as well as other microbes, algae and small particles) in the gastrointestinal tract of mussels and oysters can consequently be as much as 1,000 times higher than in the surrounding water. Furthermore, the fact that viruses may enter food early in the supply chain, and hence before capture, forms a public health risk. These viruses are namely not sensitive to environmental factors such as fresh or salt water, pH and processing steps such as freezing, drying and disinfecting with alcohol. Especially when the food is not heated, such as in the case of oysters, the probability of infection after consumption is relatively high. Once consumed, viruses replicate in the human body. A multitude of viruses can be released into the environment through faeces of infected individuals, who may or may not show any signs of illness.

Since filtering bivalve molluscs can accumulate viruses, these animals may possibly carry different types of a single virus or even different viruses. This mainly occurs when bivalves come from waters contaminated with faeces. If not inactivated before consumption, these viruses can replicate in the human body, and a new type of virus can emerge from the genetic material of the different types of viruses. How likely it is, and whether it contributes to the food safety risks, is not yet known. Although any virus found in water can reach humans via this route, mainly noroviruses and hepatitis A viruses cause illnesses in consumers through bivalve molluscs, especially oysters and mussels. While this route is also plausible for rotavirus, there is scientific debate about its contribution to the burden of foodborne diseases via the fish supply chain.

In addition to the main infection route mentioned above, i.e. the accumulation of viruses in bivalves in particular, handling of fish and fish products by (previously) infected persons also plays a role in the preparation and processing stages of the supply chain. This can lead to cross-contamination of other batches of fish, crustaceans and molluscs. This contamination route is not specific to fish products and is comparable to potential contamination of other foods. It mainly involves contamination with norovirus and hepatitis A virus, and possibly also rotavirus. Post-contamination occurs during product preparation when, symptomatic or asymptomatic, food handlers do not follow proper personal hygiene. Symptomatic means an infection with symptoms, while asymptomatic means an infection without any symptoms. The contamination can occur while opening oysters, peeling crustaceans or preparing sushi, sandwiches, salads or other ready-to-eat meals that contain fish, crustaceans or molluscs.

Norovirus
Norovirus is not specific to fish or fish products. An estimated 14% of the disease burden attributed to fish-borne infections is caused by norovirus. However, in only a part of infections the source could be traced; person-to-person transmission soon follows, and these secondary infections are often attributed to other routes. Moreover, some infections attributed to fish and fish products are probably caused by infected, symptomatic or asymptomatic, food handlers. Norovirus mainly poses a risk through the consumption of molluscs, especially oysters that are eaten raw. Primary contamination of crustaceans (crabs and lobsters) with norovirus is possible, but it is not known to what extent this transmission route contributes to contamination. Fish are almost never naturally contaminated with norovirus, but contamination can occur during preparation and processing. Due to their filtering properties, oysters are frequently simultaneously infected with different types of noroviruses, thus increasing the probability of virus recombination in humans.

Hepatitis A virus
In a non-endemic country such as the Netherlands, the population vulnerable to hepatitis A virus is relatively large due to the lack of immunity built up in childhood and a first infection later in life with a more severe clinical picture. Hepatitis A virus, which is spread through human faeces, forms a particular risk through consumption of filter-feeding bivalve molluscs that can also be imported from hepatitis A virus-endemic countries. Contamination of crustaceans with hepatitis A virus is also possible, especially in endemic countries, although it is not known to what extent this exposure route contributes to food contamination. Fish are almost never naturally contaminated with hepatitis A virus. The risk of contamination with hepatitis A virus later in the fish supply chain increases when food preparation takes place in endemic countries. Asymptomatic infection of hepatitis A virus is less frequent in the Netherlands, and hence this transmission route is less important for fish products prepared in the Netherlands.

The genome of hepatitis A virus is stable, which allows to trace its geographical origin. This increases the chances of finding a link between human disease and food source. On several occasions, specific hepatitis A viruses from certain regions were linked to international food-related outbreaks, including outbreaks caused by molluscs consumption. This risk does not seem to be high in the Netherlands (Figure 3).

Hepatitis E virus
Different genotypes of hepatitis E virus are known. The contamination of fish, crustaceans and molluscs with hepatitis E virus occurs via different routes and differs between genotypes. Genotypes 1 and 2 are spread by water contaminated with human faeces in endemic areas (genotype 1: Asia and Africa, and genotype 2: Mexico and West Africa). The extent to which dishes with fish, crustaceans or molluscs become contaminated with hepatitis E virus later in the fish supply chain, e.g. by infected food handlers, is unknown. Infections with these genotypes of hepatitis E virus are only found in people who travelled to endemic areas. Exposure to genotypes 3 and 4 mainly happens through faeces from pigs or wild animals contaminating the water. Whereas genotype 3 is found worldwide, genotype 4 mostly occurs in Southeast Asia.

Rotavirus
Rotavirus is best known as a water-related virus rather than a foodborne one. For further information, see the report WHO/FAO Viruses in Food: Scientific Advice to Support Risk level Management Activities. Fish are almost never naturally contaminated with rotavirus. At present, there is insufficient insight into whether rotavirus poses a relevant hazard and subsequent risk via molluscs farmed or harvested in the Netherlands. This risk profile may be, however, different for imported fish, crustaceans and molluscs. Since water quality is a vital aspect in the fish supply chain, rotavirus can be considered a relevant hazard to food safety.

Other viruses
Enterovirus and adenovirus in particular, but also astrovirus, Aichi virus and sapovirus can be found in crustaceans and molluscs. A limited number of studies showed, however, a great variation in the prevalence of adenovirus (6-67%) and enterovirus (37-46%) in shrimps, oysters, cockles and mussels from India, Spain, Greece, Denmark, Chile and New Zealand. In the Netherlands, monitoring of enterovirus in Dutch oyster production farms revealed its presence in 22%, 86% and 5% of flat oysters, Pacific oysters and molluscs, respectively. Enterovirus is present in shrimp originating from India and in bivalve molluscs in the Netherlands and hence poses a relevant hazard. However, there is a scarcity of case reports in which crustaceans or molluscs were identified as the sources of human illness. Therefore, it is at present difficult to determine whether the health risk is negligible.

3.2.4.3 Specific health risks caused by parasites

The main cause of human parasitic infections related to the fish supply chain is the consumption of raw or undercooked fish, crustaceans or molluscs. In the Netherlands, the most common cause of adverse health effects is the exposure to the herring worm (*Anisakis*) through consumption of raw herring. In other parts of the world, parasites cause health damage ranging from mild discomfort, as in fish tapeworm infections, to chronic and severe illness, as in massive liver-bone infections. Thorough heating is the most effective method to eliminate the risk of parasitic infection from fish, crustaceans and molluscs. However, if raw consumption is preferred, freezing is also an acceptable method to kill parasites. Provisions on cold treatment of fishery products in hygiene rules for food products of animal origin have been also included in the European legislation. Regulation (EC) No 853/2004 stipulates that fish or cephalopods intended to be consumed raw must undergo a freezing treatment of at least -20 °C for not less than 24 hours or at least -35 °C for not less than 15 hours in all parts of the product. The legal obligation for food business operators also applies to fish intended to undergo a treatment that is not sufficient to kill parasites with certainty. Dutch consumers can mainly be exposed to parasites by consuming local dishes based on raw fish while travelling in endemic areas or by eating raw fish imported from endemic areas. As with bacteria and viruses, contamination later in the fish supply chain can occur via single-cell intestinal parasites, originating from an infected food handler. Parasites do not reproduce in dead fish, crustaceans and molluscs after capture or harvest.

Worms

Diversity of parasitic worms, which are known by the term helminths, is found in fish. It includes round worms that inhabit salt and fresh water, tapeworms in freshwater and anadromous (marine fish that spawn in freshwater rivers) fish species, and flukes in freshwater and to a lesser extent brackish habitats. Marine fish usually harbour few parasite species that can infect humans. The greatest variety of parasitic worms hazardous to humans is found in freshwater fish in parts of South America and East and Southeast Asia. The majority of parasitic worms that cause the highest burden of disease worldwide - flukes - are adapted to tropical climates and do not occur in Dutch waters. Moreover, many flukes depend on the presence of specific intermediate hosts, needed to maintain their infectious life cycles.

The extent of freshwater fish imports from areas endemic to flukes in East and Southeast Asia, with the highest burden of disease caused by these worms worldwide, is limited. It accounts for about 0.1% of total Dutch imports of freshwater fish. Moreover, these freshwater fish species often do not form a good basis for making sushi; high-quality marine fish species are typically used for this purpose.

In farming systems, management measures can be taken to reduce the diversity and presence of parasites in fish. For farmed Atlantic salmon, if reared in floating cages in sea or onshore tanks and fed with commercial compound feeds, the risk of infection with *Anisakis* is negligible. However, insufficient data are available for all other farmed fish species to determine which of them present a health hazard with regard to the presence of parasites.

Incidental cases of disease are attributed to worms in the Netherlands. However, underdiagnosis and underreporting of helminth infections originating from the fish supply chain is presumed. The known worm-related parasitic hazards pose a limited risk in the Dutch situation because of various mandatory control measures.

Single-celled intestinal parasites

Cryptosporidium and *Giardia* are regularly found in molluscs, but human infections are rarely, if ever, related to molluscs consumption although they are often consumed raw or lightly cooked. It is not known whether this is because transmission via molluscs is actually rare, medics and epidemiologists rarely consider molluscs as vectors of these parasites, or a combination of both.

RIVM attributes limited disease burden of *Cryptosporidium* and *Giardia* to fish and molluscs; approximately 2% of the burden of disease is attributed to the fish supply chain.

Toxoplasma
In 2017, RIVM attributed the toxoplasma burden of disease of 39 DALYs to the consumption of fish and molluscs, which corresponds to approximately 13% of the burden of disease caused by fish. The protozoan *Toxoplasma* can be prevalent in fish and molluscs, but its exact transmission to humans remains understudied.

3.2.4.4 Specific health risks caused by bacteria
A wide variety of bacteria is found in fish, crustaceans and molluscs, and products made from them. Worldwide, the most relevant bacterial pathogens that cause disease through consumption of fish, crustaceans and molluscs are *Salmonella*, *Listeria monocytogenes*, *Vibrio* spp. and *Clostridium botulinum.*
Growth of bacteria can often be prevented by refrigerated storage. Some pathogenic bacteria can, however, grow at temperatures below 5 °C. In these cases an additional preservation method or shortened shelf life are required.
As in the case of viruses and parasites, products that have been thoroughly heated and for which post-contamination has been prevented do not pose a health risk. Fishery products that are eaten raw, including sushi, pose the greatest risk, especially molluscs (bivalves) and fish (herring). The risk of consuming raw bivalve molluscs may be limited by various germicidal treatments.

Salmonella
Fish, crustaceans and molluscs get contaminated with *Salmonella* through faecal contamination of the aquatic environment. An exception is the *Salmonella* Weltevreden (*S.* Weltevreden), which is associated with farmed fish from Southeast Asia. *Salmonella* is found in all stages of the fish supply chain, but cases of illness are mainly caused by the consumption of (raw) fish. Fish, crustaceans and molluscs are vectors of *Salmonella* but do not act as zoonotic reservoirs. *Salmonella* causes relatively many cases of illness compared to other microorganisms in the fish supply chain. Compared to other routes of foodborne salmonellosis, outbreaks and cases of illness caused by consumption of fish, crustaceans and molluscs account for only 1-2% of all cases. The outlier in these statistics was the large outbreak of *Salmonella* Thompson on smoked salmon that occurred in the Netherlands in 2012. Although the hazard - *Salmonella* - originated from the fish supply chain (i.e. the processing environment), the public health risk was determined by an error introduced in the production process. Such errors are not specific to the fish supply chain.
Salmonella cannot grow at the prescribed storage temperature in the fish supply chain and is killed by thorough heating. Cases of foodborne disease mostly occur when products are consumed raw or are not properly heated, or through contamination of heated products later in the fish supply chain.

Listeria
Chilled ready-to-eat food products are a major source for contracting a *Listeria monocytogenes* infection. Cases of foodborne disease that have been proved to originate from the fish supply chain are primarily caused by smoked fish. In the Netherlands, herring could also play a role in the observed disease cases. The main entry route of this pathogen in the fish supply chain is the contamination of ready-to-eat fishery products during the production process. *L. monocytogenes,* due to its ability to form biofilms, survives well in the production environment. A biofilm is a layer of microorganisms encased in a layer of their own mucus that is attached to a surface. The biofilms are difficult to remove, and hence *L. monocytogenes* growing within the biofilms may contaminate the food products.
Food products with a high concentration of *L. monocytogenes* lead to most of the disease cases. As one of the few pathogens, *L. monocytogenes* can grow at refrigerator temperature and is

thus not overgrown by natural microbial spoilage. To limit its growth, proper refrigeration at all stages of the fish supply chain in combination with suitable shelf life (determined based on food safety) and a limited storage time in the consumer’s home, are necessary.

Vibrio

The main food-related *Vibrio* species are *V. vulnificus*, *V. parahaemolyticus* and non-toxigenic *V. cholerae*. Fish, crustaceans and molluscs are the only sources associated with cases of foodborne disease caused by *Vibrio* spp. The main reservoir (source of contamination) of *Vibrio* spp. is the relatively warm, preferably saline or brackish, water. Molluscs are frequently contaminated, although *Vibrio* spp. are also found in crustaceans and fish. Molluscs, raw oysters in particular, are sometimes associated with cases of disease. Contamination of fish, crustaceans and molluscs with *Vibrio* spp. almost always occurs in the aquatic environment.
Neither in the Netherlands nor in Europe are data available on the incidence of foodborne cases of vibriosis. However, cases of disease are described in the literature. It is estimated that the incidence rate in the Netherlands is low. This may change with an increase of seawater temperature. As a result, the probability of contamination, both in terms of frequency and concentration, of fish, crustaceans and molluscs may increase and thus the probability of infection.
Due to the lack of insight into incidence data, it is not possible to determine the burden of disease caused by *Vibrio* spp. in the Netherlands.

Campylobacter

It is not clear whether *Campylobacter* spp. contributes to the public health risk resulting from the consumption of fish, crustaceans and molluscs. *Campylobacter* spp. mainly cause sporadic cases of disease and, to a much lesser extent, outbreaks. It is generally difficult to determine the source of *Campylobacter* infection as well as to assign bivalve molluscs as an infection source with the help of source attribution studies. Nevertheless, based on observed outbreaks, it has been estimated that ‘fishery products other than fish’ play a relevant role in the cases of disease caused by *Campylobacte*r spp. in the United States. This mainly involves consumption of raw bivalve molluscs. Bivalve molluscs could become contaminated with *Campylobacter* via faecal contamination in the aquatic environment.

Clostridium botulinum

Clostridium botulinum is naturally present in fish (as part of their microbiota). *C. botulinum* causes proven cases of disease, which are mainly linked to homemade products such as traditionally fermented fish (Alaska) or canned/preserved fish. Disease cases are rare in the Netherlands, although fish is sometimes referred to as a source of infection.

Other bacteria

There are also other bacteria found in fish, crustaceans and molluscs with attributed burden of disease. According to the risk assessment, they do not pose a public health risk linked to the fish supply chain, and it is also unclear whether they can cause foodborne illnesses. These bacteria include *Aeromonas* spp., *Plesiomonas shigelloides*, *Arcobacter* spp., *Bacillus cereus*, *Clostridium perfringens*, *Staphylococcus aureus,* pathogenic *Escherichia coli* (STEC) and *Yersinia enterocolitica*.

3.2.5 *Chemical public health risks in the fish supply chain*

This risk assessment identifies substances found in the fish supply chain worldwide that may pose an increased risk to public health. Many of the substances in this risk assessment are found not only in the fish supply chain but also in other food products. Moreover, people may also come in contact with the same substances through other exposure routes, as for example inhalation or dermal contact. In a number of cases, the risk assessment will therefore focus on the contribution of fish consumption to the total intake of a substance. The burden of disease from exposure to substances through fish consumption cannot be determined with accuracy; the (often) long period of time between exposure and effect and the simultaneous exposure to multiple substances make it impossible to estimate the effect caused by exposure to a particular substance. Commonly, the risks of substances are assessed by the extent to which exposure exceeds the health-based guidance value. These values are expressed in terms of either exposure per day and per kg of body weight or per week and per kg of body weight, depending on the type of substance. Whether, and to what extent, consumers experience potentially harmful effects after ingestion of the chemical substances depends largely on their susceptibility.

A number of important chemical hazards are introduced into the aquatic environment of fish, crustaceans and molluscs. These may include both natural substances and environmental contaminants, in particular persistent organic pollutants and heavy metals that may enter fish and produce a health risk for consumers. In addition, some chemical substances are introduced during preparation and processing of fish, crustaceans and molluscs (Figure 5).

3.2.5.1 Introduction of chemical substances in the fish supply chain

Some fish species occupy a large area and are reasonably insensitive to local contaminations. Other fish species, and especially crustaceans and molluscs, inhabit a small area during (a certain phase of) their lives. Therefore, the concentrations of chemical contaminations in those animals depend heavily on local concentrations of substances in the water and soil. Predatory fish are at the top of the food chain and hence may accumulate higher concentrations of heavy metals and persistent environmental contaminants compared to fish, crustaceans and molluscs lower down the food chain. Moreover, older fish have had more time to accumulate persistent substances than fish species with a shorter lifespan, while in fast-growing (young) fish accumulated persistent substances can be diluted to some extent by their growth.

The protein content of fish and its composition are fairly constant, while the fat content and fat composition can vary widely. 'Oily fish' that is mentioned in dietary recommendations refers to the fat content of the fish and not to the oil or fat in which the fish is prepared for consumption. Periods of food abundance or scarcity can cause extra fat tissue to be produced or lost, which can affect the concentrations of (in particular persistent) fat-soluble substances in fish.

Heavy metals and also radioactive materials are naturally present in water. They can be absorbed by fish, which leads to their accumulation in fish tissues. Moreover, different heavy metals widely used in industry and household appliances are discharged into water. Consequently, concentrations of, for example, mercury, arsenic, cadmium and lead can be regionally significantly elevated in water.
Toxic substances can be produced in the aquatic environment by (micro)organisms, and they can be later absorbed by fish, crustaceans and molluscs. Some of these biotoxins can accumulate (bioaccumulate) up to concentrations that pose a significant risk to consumer health.

In addition to natural substances, many non-natural substances also occur in the aquatic environment. In particular, persistent organic pollutants such as PCBs, dioxins, polybrominated and polyfluorinated compounds (especially PFAS, PFOA and PFOS) are found in waters around the world. Even though concentrations of these substances are low in water due to their strong fat-solubility, they may increase in fish, and hence pose a significant risk to fish consumers. In the Netherlands, areas with heavily contaminated sediments are considered high-risk areas for both ecosystem effects and food safety due to high concentrations of environmental contaminants in fish, crustaceans and molluscs. A number of areas with high concentrations of dioxins or dioxin-like PCBs are closed for fishing for eel and Chinese mitten crab. More information can be found in the fisheries implementing regulation (Article 23b and Article 28b). Little is known about concentrations of environmental contaminations in commercially caught and traded fish from heavily polluted areas. Given the large share of imported fish products in Dutch food consumption, it is important that contamination levels are also known from fishing and farming areas outside of the Netherlands. However, the lack of systematically collected data on the presence of contaminants in fish prevents an adequate risk assessment of imported fish. Occasional studies show that the level of contamination is of great importance for consumer risks. For example, shrimp caught in different parts of the Western Scheldt contain considerably different levels of perfluorinated compounds (Zwartsen A, Boon PE, 2022. Consumption of products contaminated with PFAS from the Western Scheldt). More information is available in the RIVM letter report Consumption of products contaminated with PFAS from the Western Scheldt.

Other – less persistent – substances, such as (residues of) plant protection products, can also locally and regionally lead to high exposure of fish, crustaceans and molluscs, e.g. through runoff from land into rivers and coastal waters. For example, local industry, wastewater treatment or sewage discharges can cause elevated concentrations of drugs, medicines and substances from cosmetics in the water. In addition, especially in farmed fish, the use of some substances may be deliberate. This includes not only potentially risky substances from animal feed (e.g. mycotoxins) but also veterinary medicines, including antibiotics.

link	**introduction of different types of chemical substances**
Living environment	Environmental contaminants in water, soil and food: dioxins and PCBs, PAHs, plant protection products, brominated flame retardants, perfluorinated compounds, metals and metal compounds, pharmaceuticals/hormones/drugs, substances from personal care products/chemicals/food contact materials, radioactive substances, biotoxins, veterinary medicines, detergents/biocides, mycotoxins
Capture, Landing/import Transport/storage	Food contact materials, detergents/biocides, hydraulic oils/refrigerants
Processing	PAHs, food contact materials, detergents/biocides, hydraulic oils/refrigerants, treatments, additives
Distribution	Food contact materials, allergens, biogenic amines, plastics.

Figure 7 Different links in the fish, crustacean and molluscs supply chain (on the left), in which different types of chemical substances (on the right) may be introduced.

3.2.5.2 Specific chemical risks from the living environment of fish

Heavy metals:

- *Methylmercury*

Mercury occurs naturally in the habitat of fish, crustaceans and molluscs. In addition, mercury is still widely used in industry. Inorganic mercury (metal) is partly converted in the environment to the much more toxic methylmercury (organometallic). The main sources of methylmercury in the diet are fish and fish products. Concentrations of mercury (total and methylmercury) in fish are particularly high in predatory fish; concentrations in other (farmed) fish species, crustaceans and molluscs are significantly lower. People with high fish consumption or people who eat a relatively high proportion of predatory fish may exceed the tolerable weekly intake (TWI) for methylmercury, which may then lead to adverse health effects. Eating predatory fish by pregnant women poses an increased risk to the healthy development of the unborn child. The contribution of crustaceans and molluscs to the total mercury intake is small and hardly contributes to potential health risks from mercury. Reported concentrations of mercury in farmed fish also tend to be lower than those in wild-caught fish. Most data on mercury concentrations concern the total mercury, although information about methylmercury is far more essential due to its higher toxicity.

- *Organic and inorganic arsenic*

Most concentration data available for the fish supply chain concern total arsenic, even though information about inorganic arsenic, a more toxic form of arsenic, is more important.

With the estimated intake of inorganic arsenic by European consumers at moderate and high exposure levels the health risks cannot be excluded. In general, consumption of (farmed) fish, crustaceans and molluscs can contribute substantially to total arsenic intake. It is, however, unknown whether farmed fish contains more or less inorganic arsenic than wild-caught fish.

- *Cadmium*

The average fish consumption of the European population results in a cadmium intake that is close to, or slightly exceeds, the tolerable weekly intake (TWI). The average fish consumption in the Netherlands is below the European average fish consumption. In the Netherlands, therefore, (farmed) fish, crustaceans, molluscs and their products contribute only to a limited extent to the maximum tolerable intake of cadmium. Moreover, fish consumption in line with the advice of the Health Council of the Netherlands would also hardly contribute to potential health risks from cadmium. Chemical analyses indicate that particularly squids occasionally contain large quantities of cadmium.

- *Lead*

The average intake of lead by European consumers is at a level at which health risks cannot be excluded. However, the contribution of (farmed) fish, crustaceans and molluscs to the total lead intake is limited and hardly contributes to potential health risks from lead. Therefore, lead in fish poses a negligible public health risk.

Radioactive substances
The concentrations of radioactive materials in (farmed) fish, crustaceans and molluscs do not pose a health risk to Dutch consumers.

Biotoxins/marine toxins
Biotoxins is a collective term for several substances that can cause adverse effects in humans after exposure. These substances are mainly produced by marine algae (phytoplankton) and sometimes also by bacteria. Most biotoxins can accumulate in marine organisms such as bivalves and fish. There are approximately 70-80 species of marine microorganisms that can produce toxins. Only a small part of these microorganisms are found in Dutch waters, but the import of fish from other areas could also lead to introduction of fish containing biotoxins. The toxins are classified according to the effects they cause: paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), diarrhetic shellfish poisoning (DSP) and amnesic shellfish poisoning (ASP). The frequency of poisoning with these toxins is low in the Netherlands, however, a poisoning is followed by severe consequences for the consumer. The severity depends on the type of toxin and the quantity that has been ingested.
In the Netherlands, health problems are occasionally caused by an ingestion of diarrhetic shellfish poisoning (DSP) toxins. The occurrence of blooms of toxin-producing algae is, however, difficult to predict. Changes in water temperature and other environmental parameters affect algal blooms and toxin production. These changes may also lead to the introduction of new toxins. Climate change and increasing globalisation are expected to trigger an increase in algal bloom outbreaks and biotoxin production.

Ciguatoxins are endemic in tropical and subtropical regions of the Pacific and Indian Oceans, and the Caribbean Sea. These toxins are also found in European waters; especially in large fish such as sea bass. In the Netherlands, the probability to become poisoned with ciguatoxins is currently small. Farmed fish from open systems could become contaminated with ciguatoxins, although little is known about it.

Certain marine toxins, such as tetrodotoxin (also known as TTX), are most likely produced mainly by microorganisms. They subsequently accumulate in molluscs. These toxins in mussels and oysters, for example, may lead to severe intoxications in humans. The Netherlands applies the tolerable concentration of 44 µg/kg recommended by the EFSA CONTAM Panel as a standard

for TTX. This standard has also been included in 2022 in the Policy rule under the Dutch Commodities Act on TTX in living bivalve molluscs.
No maximum permitted levels have been set for several biotoxins. Moreover, there is sometimes a discrepancy between the current maximum permitted levels for biotoxins in molluscs and the Acute Reference Doses (ARfD) established by EFSA. These are areas of concern for adequate risk management. This applies in particular to the biotoxins: cyclic imines, palytoxins, brevetoxins and tetrodotoxin.

Cyanobacteria, also known as blue-green algae, are found in salt, brackish and fresh water. They can produce toxins, including microcystins, nodularins, cylindrospermopsins, anatoxins and saxitoxins (PSPs). Microcystins are hepatotoxic and can also affect other organs and the nervous system. They are a cause for concern in freshwater fisheries. Anatoxins and saxitoxins are neurotoxic. The probability of these toxins to be found in the water and to contaminate fish, crustaceans and molluscs is increasing due to the global warming. It is unclear how high is the risk in the Netherlands.

Persistent organic pollutants

- *Dioxins and polychlorinated biphenyls (PCBs)*

With the current consumption of (farmed) fish, crustaceans and molluscs and the levels of dioxins and dioxin-like PCBs, the TWI (tolerable weekly intake, EFSA 2018) may be exceeded as a health-based guidance value. Consequently, an increased risk to consumer health cannot be excluded. Fish, especially predatory fish, is a significant contributor (56%) to the intake of dioxins and dioxin-like PCBs. The maximum permitted levels of dioxins and dioxin-like PCBs in fish are occasionally exceeded; these are regularly observed in fish liver.
Concentrations of dioxins and PCBs in crustaceans and molluscs are generally below the maximum statutory levels. However, brown meat of the Chinese mitten crab contains high levels of dioxins and dioxin-like PCBs and its consumption poses risk of adverse health effects for consumers. The concentrations of dioxins and dioxin-like PCBs in farmed salmon and trout are higher than in wild salmon, but they remain below the maximum levels. The higher concentrations in farmed salmon and trout are presumably related to contamination of fish feed with these substances. In particular, fish feed based on fish oil and fishmeal may contain dioxins and dioxin-like PCBs.

- *Brominated flame retardants*

There are no or limited data on the occurrence and effects of many new brominated flame retardants such as polybrominated diphenyl ethers (PDBE) and hexabromocyclododecans (HBCDD). Based on the available data, oily fish contain higher concentrations of brominated flame retardants than lean fish. Consumption of crustaceans and molluscs hardly contributes to the intake of brominated flame retardants. The concentrations of PDBEs in farmed salmon are higher than in wild salmon. Furthermore, the concentrations of PBDEs in farmed salmon from Europe are higher than those of the farmed salmon from North America and Chile. These differences are most likely related to concentrations of PBDEs in animal feed that show the same pattern. No adverse health effects are expected from the intake of the brominated flame retardants (HBCDDs and PBDEs) from (farmed) fish, crustaceans, molluscs, or fish products, although there may be risks posed by the specific PBDE congener, BDE-99.

- *Perfluorinated substances (PFAS)*

Perfluorooctane sulphonate (PFOS) and perfluorooctanoic acid (PFOA) are the most known and regulated perfluorinated substances (PFAS). Based on the TWI derived by EFSA in 2020, it can be concluded that the intake of PFOS and PFOA from fish may pose a risk to consumer health. The highest contribution to PFOS intake from food comes from the consumption of (predatory) fish. Crustaceans and molluscs also contribute to the intake of PFOA. There is limited information on the concentrations of PFOS and PFOA in crustaceans and molluscs in the Netherlands, although initial studies into concentrations of perfluorinated substances in fish and fish products from Dutch waters showed that shrimp may contain extremely high concentrations in highly

polluted habitats such as the Western Scheldt. More information is available in the RIVM letter report Consumption of products contaminated with PFAS from the Western Scheldt.
There is limited information on the concentrations of PFOS and PFOA in farmed fish, but it has been indicated that the concentrations of PFAS in farmed fish may be lower than in wild-caught fish.
The information on exposure and toxicity of other perfluorinated substances is too limited to assess any potential risks. There seems to be a shift towards the use of shorter-chain PFAS and perfluoroalkylethercarboxylic acids (including GenX).

Other environmental contaminants

- *Plant protection products*

Health risk from the consumption of fish and shrimp from the North Sea can be assessed for a small number of organochlorine pesticides (DDT, dieldrin, endosulfan) that are no longer permitted. The presence of residues of these products in fish and shrimp from the North Sea do not pose a risk to consumer health. There are indications that the levels of organochlorine pesticides (OCPs, plant protection products) in farmed fish may be higher than in wild-caught fish. However, the health risks to humans from the intake of organochlorine plant protection products in farmed fish, as far as they can be assessed, are negligible.
There is little information on the prevention and effects of other plant protection products in (farmed) fish, crustaceans and molluscs.
A large number of plant protection products in water exceed the ecological standards. Therefore, the effects on aquatic organisms cannot be excluded. It is also not known which effects can be expected higher up in the food chain.

- *Medicines, hormones and drugs*

Medicines for humans and veterinary medicines, hormones, drugs, or their metabolites have been detected in surface water. Medicines and their metabolites in surface water are mostly found near municipal wastewater treatment plants where effluents are discharged to surface water. Recreational fishermen who always catch fish near such sites for their own consumption may be exposed to higher levels of these substances than advisable. However, it is not known whether professional fishermen also catch fish near such sites. Different medicines have been analysed in fish, crustaceans and molluscs, especially in bivalve molluscs (mussels), but the concentrations are generally below the LOQ (limit of quantification) or LOD (limit of detection). This means that the concentrations of these substances cannot be properly determined.
Most drugs are water-soluble and are unlikely to accumulate in (farmed) fish, crustaceans and molluscs. The same applies to water-soluble medicines. There is, however, insufficient knowledge about other medicines and hormones in fish, crustaceans and molluscs.
Farmed fish may be treated with hormones; for example, to facilitate growth rate or to achieve a single sex (monosex) population. Some hormones, for example steroids such as testosterone and progesterone, bioaccumulate in fish tissue. The risk to consumer health after consumption of fish contaminated with steroids is generally considered to be low or negligible.
17α-Ethynylestradiol (EE2) is a synthetic hormone derived from the natural hormone oestradiol (E2). EE2 is an oral bioactive oestrogen and one of the most commonly used medicines in humans and animals. EE2 is not easily degraded and can accumulate in sediment and in biota. It is toxic for many organisms. Water and aquaculture products (i.e. farmed fish) contaminated with this hormone may be possibly linked to human health risks, as for example decreased fertility and possibly cancer. Likewise, adverse effects of hormones on aquatic organisms often cannot be excluded.

- *Veterinary medicines and animal feed*

The use of veterinary medicines does not apply to wild-caught fish, crustaceans and molluscs. The application of veterinary medicines in European farms is regulated in legislation. If waiting periods are introduced for killing of the animals, there will, in principle, be no risks to consumer health. There is, however, little insight into the types and amounts of antibiotics that are used

for fish, crustaceans and molluscs in farms outside Europe. Shrimp farming, especially in Southeast Asia, is an example of intensive farming with the use of animal feed, such as manure, and veterinary medicines. These tropical shrimps are imported to the Netherlands and are frequently eaten.
Most of the water in closed recirculation systems is reused repeatedly and continuously purified and oxygenated. Unlike for wild-caught fish, crustaceans and molluscs, intensive aquaculture systems may involve the use of veterinary medicines and biocides (e.g. against sea lice), and contaminated fish feed. Furthermore, contamination may result from cleaning the culture systems with detergents.
There is also little insight into the type and amounts of antibiotics and antiparasitic agents used in farms outside Europe. There are indications that concentrations of antibiotics may be high; it is, however, unclear whether this poses a health risk to consumers.
The KAP database contains a small number of samples for the period of 2007-2017 in which antibiotics were found. This concerns nitrofurans in shrimp and farmed fish. KAP is the Quality Programme for Agricultural Products and contains data on residues in agricultural products in the Netherlands.

Malachite green and leucomalachite green are not permitted by the EU to be used in fish intended for human consumption. RASFF reports and other (fraud) investigations show that these substances are nevertheless found in fish, crustaceans and molluscs intended for consumption in the European market. The health risks to consumers cannot be, however, excluded if the maximum intake of 2 µg/kg for the sum of both substances is exceeded.
Moreover, in countries outside the EU, other veterinary medicines (antibiotics) may be used for farmed fish and shrimp that are not covered by European standards. Further research is required to verify whether their consumption leads to public health risks.
Little is known about the intake of mycotoxins in farmed fish from animal feed. There are strict maximum permitted levels of mycotoxins in animal feed. However, these were not established for fish and fish products. Given the likely limited transfer of mycotoxins from fish feed to edible parts of fish, no health risks to consumers are expected.

- *Chemical substances from personal care products, consumer products, household chemicals and food contact materials*

Lack of information on substances and their concentrations from personal care products, consumer products and household chemicals, makes it impossible to reliably assess human health risks. Residues of these substances in surface water are mostly found near wastewater treatment plants where effluents are discharged to surface water. Fish present at these sites or farmed in their vicinity may be contaminated. Recreational fishermen who always catch fish near such sites for their own consumption may be exposed to higher levels of these substances than advisable. It is not known whether commercial fishermen catch fish near such sites. Two polycyclic, hydrophobic musks (AHTN and HHCB) are regularly found in crustaceans and molluscs.

3.2.5.3 Specific risks of chemical risk by the preparation and processing of fish

This risk assessment has not included the unauthorised/fraudulent use of substances. No information is available on detergents that are being used on board, at the fish auction and during preparation and processing.

On a number of vessels, i.e. freezer trawlers and shrimp trawlers, treatments may be carried out and additives added to fish and/or crustaceans. Whether this constitutes a consumer health risk is unclear. Within the crustaceans and molluscs supply chain, as in case of the common shrimp (*Crangon crangon*), a number of additives occasionally play a role, including benzoic acid/benzoates (E210-213) in crustaceans. Sulphiting agents (E220-228) are used as preservatives in fresh, frozen, deep-frozen and cooked crustaceans and cephalopods. No risk assessment can be carried out for crustaceans and molluscs due to insufficient knowledge about the frequency and quantities of (un)authorised treatments and additives.

Polycyclic Aromatic Hydrocarbons (PAHs)
PAHs are formed during the smoking of (farmed) fish, crustaceans and molluscs. The concentrations of PAHs are, however, much lower when indirect smoking methods are used compared to direct smoking. Smoking can be a major source of PAH contamination in (farmed) fish, crustaceans and molluscs. The intake of PAHs from foods does not pose a health risk to consumers with an average consumption. However, regular intake of smoked (farmed) fish, crustaceans, molluscs and their products with high concentrations of PAHs may lead to consumer health risks. There is not enough information on the effects and intake of oxygen- and nitrogen-containing PAH derivatives to carry out a risk assessment.

Chemical substances from food contact materials
Migration of bisphenol A from packaging materials does not appear to lead to concentrations in (farmed) fish, crustaceans and molluscs that pose a risk to consumer health. However, EFSA did propose a new health-based guidance value for bisphenol A in 2022 that is a factor of 100,000 lower than the current maximum permitted levels. Should this new maximum permitted level be adopted, it will have an impact on the present fish supply chain risk assessment.

Cleaning preparations and biocides (including from the environment)
The intake of organotin compounds from fish is well below the tolerable daily intake (TDI) and does not pose a health concern for consumers. The health risks of the possible presence of other residues in (farmed) fish, crustaceans and molluscs cannot be assessed due to the lack of information on both the use of these compounds and the presence of residues in (farmed) fish, crustaceans, molluscs and fish products.

Treatments and additives
The use of excessive amounts of antioxidants, such as vegetable extracts, and the treatment with carbon monoxide, may mask organoleptic changes and discolouration of fish that result from, for example, unrefrigerated storage. In order to retain its fresh colour, some fish species, such as tuna, are dyed with beetroot juice. However, this does not lead to reduced microbial growth or histamine production. As a result, consumers may have problems to assess the freshness of a fish, and hence microbial growth or histamine formation may become a possible risk for consumers.
Sometimes (unauthorized) additives are used in the preparation and processing of fish and fish products. Whether this constitutes a consumer health risk is unclear. Within the crustaceans and molluscs supply chain, a number of additives play a role, including the unauthorised hydrogen peroxide in canned molluscs and benzoic acid/benzoates (E210-213). These methods are known to be used as preservatives for cooked crustaceans and molluscs; for example, for the transport of shrimp to Morocco where they are peeled. Sulphiting agents (E220-228) are also sometimes used as preservatives in fresh, frozen, deep-frozen and cooked crustaceans and cephalopods. No risk assessment can be carried out for crustaceans and molluscs due to insufficient knowledge about the frequency and quantities of (un)authorised treatments and additives.

3.2.6 Physical public health risks in the fish supply chain
Swallowing of sharp objects such as fishbones and pieces of shell that are naturally present in fish, crustaceans and molluscs, may cause injury to the throat, oesophagus and gastrointestinal tract of consumers.

In 2016, there were an estimated 1,500 emergency care incidents related to suffocating and/or intestinal damage due to the ingestion of food, drinks or liquid foods. Averaged over the period from 2012 to 2016, choking/suffocation incidents with ‘foreign material’ involved fishbone in more than half of all cases. One quarter of the cases involved choking or suffocation with a bone from farm animals. Fishbones therefore represent an important category in these incidents, even though the absolute number of annually reported cases is small (roughly 150 cases) and the health effects are limited. Occasionally (a few times per year) foreign non-natural materials are found in fish products, such as pieces of metal, glass or plastic. The health risks are estimated to be low.

Plastics, micro- and nanoplastics
Plastics can accumulate in plants and animals and thus enter the human food chain. Larger pieces of plastic can end up in the gastrointestinal tract with severe effects for the animals involved. As far as known, larger pieces of plastic (i.e. visible to the naked eye, in order of magnitude of millimetres or larger) are hardly a food safety issue. Micro- and nanoplastics cannot be seen with the naked eye. Intake and accumulation of microplastics is shown in different fish and molluscs (i.e. bivalves such as mussels, clams and oysters). This also applies to farmed fish kept in open and flow-through culture systems. No risk assessment can be carried out at this stage due to the lack of sufficient information about intake, concentrations and effects of plastic particles. Microplastics and presumably also nanoplastics can absorb chemical substances. It is unclear, however, which substances can be absorbed and what risks are involved. Little is also known about the intake of nanoplastics. The analytical methods for measuring microplastics need to be improved and those for nanoplastics need to be (further) developed. The same applies to the accurate measurement of micro- and nanoplastics in other foods. The substantiation of these risks can be found in Appendix 3.2 on chemical risks in the fish supply chain.

3.3 Risks to animal welfare and animal health in the fish supply chain

3.3.1 Introduction
There are animal welfare risks associated with the wild capture and farming of fish and crustaceans. This risk assessment uses EFSA's definition of animal welfare, which, in turn, is derived from Broom's definition: 'The welfare of an individual is its state as regards its attempts to cope with its environment.' For farmed animals, EFSA adds to this that 'the welfare of an animal is good if, as indicated by scientific evidence, it is healthy, comfortable, well-nourished, safe, able to express key aspects of behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress'.

For the risk assessment of animal welfare, it is important to determine whether animals are sentient and capable of experiencing pain. There are more knowledge gaps on this topic for fish, crustaceans and molluscs than for farm animals. Still, there is good evidence – supported by EFSA and other organisations – that fish are sentient animals and experience pain. There is also some evidence that the same can be said about certain crustacean species, although as of 2022 there is still a limited scientific basis for this. EFSA has concluded that at least the largest crustaceans (lobsters, crabs, langoustines, and large shrimp) are to some extent sentient and capable of experiencing pain. BuRO follows the scientific line that argues in favour of the existence of a form of animal sentience in fish and crustaceans. For fish and crustaceans, this is also – albeit very limited - within the scope of EU and Dutch legislation. Due to a limited knowledge on bivalve molluscs, it is not possible to make any far-reaching statements in this risk assessment.
Although it is not always clear how severe are the impacts on animal welfare, it is evident that the hundreds of thousands of tonnes of fish produced each year involve billions of organisms. This makes the probability of impairing the welfare of an individual organism well beyond the animal welfare issues of the red meat sector or the poultry sector. *For more information on animal welfare and animal health, please see IKA Vis: particularly the information sheets on supervision of production companies in aquaculture in the Netherlands, and on supervision of animal welfare of killing eels.*

The assessment of risks to animal welfare in the fish supply chain involves not only feeding and housing but also, for example, injuries due to mutilations and animal diseases that affect animal welfare. A distinction is made between endemic infectious animal diseases, which may cause a more or less continuous impact on animal welfare in farming systems, and epidemic animal diseases that in general do not occur in the Netherlands but may lead to serious health and welfare consequences during disease outbreaks. Unlike endemic diseases, epidemic diseases are governed by a specific legal framework, the European Animal Health Law.
Standard guidelines and experimental data are lacking for the risk assessment of animal welfare and animal health as well as for the assessment of risks to nature caused by fisheries. Moreover, the risks to animal welfare, animal health and nature are characterised by a high degree of uncertainty. In spite of these limitations, BuRO conducted a risk classification and, insofar as possible, applied the conventional scientific approach for the risk assessment of physical, chemical and microbiological hazards.

3.3.2 Risks to animal welfare in the fish supply chain

Animal welfare risks to wild-caught fish and crustaceans

All fishing activities assessed here lead to a serious welfare impairment for the example species relevant to Dutch fisheries and Dutch consumption (Appendix 3.4). Regardless of capture technique, catching and collecting fish (e.g. herring, plaice and sole), is a highly stressful phase, especially when combined with killing without stunning after capture. Despite the differences in the fishing techniques, fish suffer from severe levels of distress that may be followed by death. The stress starts already during capture, when the fish swim out in front of the cod-end or, in case of demersal fish, when they are startled by tickler chains or previously by pulses.
Dutch consumption of tuna and cod is high, but these are rarely fished by Dutch fishermen and are therefore excluded from this animal welfare risk assessment. For crustaceans and bycatch (i.e. quoted undersized fish and unquoted species), there is still an incomplete picture of welfare risks based on the available data.

3.3.2.1 Specific risks to animal welfare in demersal fisheries

Demersal fishery involves a fishing technique that is used to catch fish living in, on or near the seabed. In demersal fisheries, the welfare of fish is considerably affected during capture and retrieval of the fish on board. Fishing activities cause a considerable amount of stress, crushing and injuries. So-called tickler chains used by beam trawlers may for example cause injuries in flatfish.

There are high welfare risks on board due to exposure to sunlight and air. This leads to (heat)stress and hypoxia. Animal welfare is seriously impacted, both in terms of effect and number of fish, when fish is placed in ice after being killed by viscera removal (i.e. gutting) or when it is placed in ice alive.

The welfare risks for crustaceans are generally expected to be smaller compared to the risks for fish; crustaceans have a protective exoskeleton and are more resistant to air exposure. This group of animals does face significant animal welfare risks by the removal of crab claws (which is prohibited) or, if stored alive, by cooling during the storage. There is insufficient knowledge about the risks to the welfare of crustaceans associated with the subsequent stages: the transportation, storage and killing of live crustaceans. It is unclear how long they remain alive after capture, what is the effect of (prolonged) feed deprivation during that period and to what extent exposure to potential hazards takes place. Killing of crustaceans causes a significant impact on animal welfare due to the lack of appropriate stunning methods.

3.3.2.2 Specific animal welfare risks in pelagic fisheries

Pelagic fishery involves a fishing technique, for example with trawl nets, that is used to catch fish species that live in the middle of the water column and swim together in large schools. Pelagic fisheries have a much larger volume (number of individuals) than demersal and passive fisheries (beam trawl and gill netting).

Also in pelagic fisheries, the welfare of fish is considerably affected during capture and retrieval of fish on board. Both activities cause considerable stress. Moreover, specifically in the case of herring (compared to sole, plaice and crustaceans), the difference in pressure can cause the swim bladder to burst when being lifted.
The most stressful stage, specifically for herring, is the period when they are stored in large numbers in Refrigerated Sea Water (RSW) tanks. These RSW tanks cause hypoxia and food deprivation that lead to severe stress in fish. For example, it is estimated that the majority of herring die before they are frozen in the plate freezers. The herring that is frozen alive (and intact) is likely to experience serious welfare impairment. RSW tanks where the herring are pumped to the tank have the advantage that fish are less likely to be damaged during loading as they are not lifted above the water.

3.3.2.3 Specific animal welfare risks in passive gear fisheries

For sole and lobster that are caught by standing rigging (gill nets), being trapped in the net and animal’s consequent struggle are the major welfare risks due to severe stress and exhaustion. Animals trapped in the nets can also be predated by birds and other animals. However, the greatest risk to animal welfare arises when the sole is killed without stunning. The methods used – placing in ice after gutting or placing live fish in ice – are all a serious breach of welfare. Since fish are caught in higher numbers than lobsters, placing them intact in ice is of higher relevance with respect to the animal welfare. Similar to crustaceans caught by demersal (cutter) fisheries, also for lobsters little research is conducted with respect to welfare risks present during the period of storage, transportation and stunning/killing.

3.3.2.4 Specific animal welfare risks in farmed fish

There are generic animal welfare risks in both (Dutch) closed and (international) open fish farming systems. For the assessment of welfare risks of farmed fish, a number of example species relevant to the Netherlands were chosen in the context of farming and/or consumption in the Netherlands. Many of the potential risks to the welfare of farmed fish are related to health and housing. One important consideration is that nutrition (e.g. an approach based on specific nutrients) and natural behaviour (e.g. hazards such as high or low animal densities, but also more fundamentally, knowledge about possible emotions) in relation to welfare in farmed fish are still relatively unexplored areas compared to health and housing of farm animals and might have therefore received little attention and recognition.

Animal welfare impacts are estimated to be high for many of the identified hazards; the combination of severity and duration leads to a very high welfare impact for individual animals. At the same time, the prevalence of animal welfare consequences is also often estimated to be high to very high if animals are actually exposed to the identified hazards, i.e. if the largest part of the population is affected when hazards actually occur. These are expert estimates because actual prevalence is unknown. In this advice only those risks are presented that have a high estimated effect on animal welfare (i.e. combination of animal welfare impact and theoretical prevalence of animal welfare consequences) and a large estimated exposure (i.e. a large proportion of the farmed fish is exposed to hazards).

Major generic animal welfare risks include inadequate
fixed’ housing characteristics (i.e. lack of hiding or resting places) and ‘variable’ housing characteristics (i.e. water quality, water temperature and an inadequate composition of feed). In

the latter case, the feed is not adapted to the farmed fish species or the production phase of the fish. The aforementioned risks have welfare consequences for fish. These include acute or chronic stress, physical deformations, tissue damage, and weakened immune system that may result in diseases and early death.
Many farmed fish are exposed to these risks for longer periods of time. The most significant risk period (the duration of the exposure) for most farmed fish is the rearing phase to the marketable size (3 months – 2 years).

Fish kept in farms are usually transported to the rearing location at the end of the fry stage. They continue to grow there until they are suitable for consumption (i.e. of marketable size). The transports prior to slaughter, compared to an entire fish life, are relatively short. However, this concerns the entire population of farmed fish, and hence the relative importance of transport for animal welfare risks is high. Major animal welfare risks that are specific to transport include inadequate feed deprivation prior to transport, water quality and water temperature during transport, too high fish densities, and vibration and noise pressure. These risks to animal welfare entail following consequences: stress, skin and/or gill irritation, tissue damage, fatigue and early death.

For parent stock, the data used give an incomplete picture of animal welfare risks especially around housing. A major animal welfare risk for this group, irrespective of the culture system, is the lack of an effective stunning/killing technique for animals that are not sent for slaughter.

Killing and processing of fish poses a welfare risk to animals from both closed and open systems. This results in animal welfare consequences such as stress, detachment of the mucus layer on the skin, tissue damage and severe suffering. However, the way in which animals are stunned or killed varies per system and fish species. On a global scale, 96-97% of all farmed fish are killed without stunning.

Specific animal welfare risks for farmed fish in closed systems
Recirculating Aquaculture Systems (RAS) are mainly used in the Dutch aquaculture of farmed fish. In these systems mostly African catfish (*Clarias gariepinus*) and Claresse catfish (*Clarias gariepinus* x *Heterobranchus longifilis*) (i.e. most in terms of weight) and eel (i.e. most in terms of numbers) are reared.

- *Catfish*

Catfish have a relatively limited exposure to pathogens because they are reared in an environment isolated from the outside world (RAS). In addition, catfish are generally considered to be relatively robust fish that are less susceptible to diseases. Nevertheless, the following bacteria pose a welfare risk to catfish if they enter a RAS system: *Aeromonas hydrophila, Flavobacterium columnare and Mycobacterium marinum (fortuitum)*. These pathogens cause animal welfare consequences such as frayed fins, itching, tissue damage, emaciation and early death.

Other animal welfare risks specifically related to catfish concern the marketable fish at the slaughter location. Catfish are kept in large numbers (in high densities) in storage tanks, therefore, water quality (acidity, oxygen, carbonic acid, ammonia) and water temperature continue to be essential for their good welfare until slaughter. If these parameters are not optimal, the consequences for fish welfare include stress, irritation of skin and gills, increased gill beat rate and early death. However, it is unclear how often poor water quality (mainly caused by pollution) occurs at the slaughter locations.

In the Netherlands, about half (~40-60%) of the catfish are killed without stunning by placing them in ice or ice water. This method of killing without stunning leads to detachment of the mucus layer on the skin and severe stress.

- *Eel*

At the moment, it is not possible to fully assess animal welfare risks for Dutch eel. Important animal welfare risks currently in focus concern diseases and slaughter, and also potentially the wild capture and transport of glass eels (i.e. post-larval stage of eels).

For the eel reared in RAS systems, the pathogens with a high welfare risk include the parasitic gill worm (*Pseudo*)*dactylogyrus*, virus *Herpesvirus anguillae*, and bacteria *Vibrio vulnificus* and *Aeromonas* spp. Consequences for animal welfare include reduced feed intake, bleeding, injuries and early death.

Wild-caught glass eels are needed to rear eels to a marketable fish. It is unknown how the wild capture of glass eels, their transport and subsequent placement in artificial controlled RAS environment affect animal welfare.
As of 1 July 2018, stunning is required for slaughter of marketable eel. A stunning device was present at around 75% of companies where eels are killed that were inspected in 2018 and 2019. If stunning is omitted or not carefully done, welfare risk may arise due to the subsequent use of a so-called salt bath, which, if the fish are not stunned, leads to severe pain and stress. The extent of this animal welfare risk was not adequately assessed in the 2018-2019 period; the inspections only checked the presence of the device and not its actual use.

Specific animal welfare risks for farmed fish in open systems
Fish destined for consumption that is farmed abroad is mainly (i.e. most of the imports) kept in open systems connected to environmental water (natural source or through a water supply system) and often also exposed to open air. The open nature of these systems poses major welfare risks for the farmed fish due to the potentially suboptimal water quality and temperature caused by limited control over these parameters. Furthermore, there may also be a continuous threat of predation, by birds in particular. The limited possibilities to escape of fish kept in open systems lead to chronic stress and possibly also tissue damage and early death. Animal welfare risks for the African catfish farmed in a more controlled closed RAS systems or the Nile tilapia farmed in a flow-through system are estimated to be lower.

- *Pangasius*

Parasites, bacteria and viruses pose the greatest and most common animal welfare risks for pangasius farmed in flow-through ponds. It should be noted here that vaccines are now applied in practice (personal communication WLR), however, as of 2019 detailed information was not available for BuRO. If vaccines are not applied, the main hazards for pangasius constitute: the parasites *Icthyophthirius multifiliis* and *Hexamita*, the bacteria *Flavobacterium columnare, Aeromonas hydrophila* and *Vibrio anguillarum* and the channel catfish virus (CCV). Furthermore, several other identified pathogens also lead to major animal welfare risks for pangasius. Consequences for welfare range from getting pale and minor injuries to chronic tissue damage and early death. In particular, the juvenile pangasius (i.e. fry) is less robust compared to adult pangasius and other farmed fish; their welfare impact is therefore estimated to be higher.

The marketable pangasius is killed by bleeding without stunning. This causes a major animal welfare risk and results in detachment of the mucus layer on the skin and severe suffering.

- *Nile tilapia*

Major animal welfare risks for the Nile tilapia are the parasite *Hexamita* and the bacteria *Mycobacterium marinum* (*fortuitum*) and *Francisella noatunensis*. These pathogens have welfare consequences such as reduced feed intake, bleeding, diarrhoea, injuries, exhaustion and early death. For Nile tilapia, it appears that particularly the juvenile fish (fry) suffer the most in terms of animal welfare; the older fish seem to be more robust.

The removal of upper jaws of male Nile tilapia for reproductive purposes is considered a serious welfare impact. It leads to impairment of the natural behaviour and chronic stress. It is not clear how many male individuals have their upper jaw removed, either in the Netherlands or abroad. Consequently, it is difficult to estimate how high is the welfare risk for the entire (male) population. As of 2019, Nile tilapia is only kept for spawning in the Netherlands, while rearing takes place abroad.

The marketable Nile tilapia is killed by placing them intact in ice or ice water without stunning. The temperature shock leads to detachment of the mucus layer on the skin and severe stress.

- Atlantic salmon (*Salmo salar*)

It is a frequently eaten fish by the Dutch population that is mainly produced in Norway. Atlantic salmon kept in Norway has received particularly a lot of attention in research, also with respect to animal welfare. Nevertheless, it is still difficult to estimate its exposure to various hazards.

Animal welfare risks for salmon from viruses are expected to be high due to the absence of effective vaccines. These viruses include: the salmon gill poxvirus (SGPV) (exposure is unclear, but the mortality rates are high), the infectious pancreatic necrosis (IPN) virus (while decreasing in terms of exposure, it induces high mortality rates) and the salmonid alphavirus (SAV/SPDV/PD). The infectious salmon anaemia virus (ISAV) and the piscine orthoreovirus (PRV) are important viruses that can harm welfare of this fish species. As of 2019, the exposure of Atlantic salmon to these viruses is possibly increasing or is already high. The viruses described above have no human pathogenic effect, but they result in various animal welfare consequences for salmon such as problems with gills (breathing), anaemia, reduced appetite and mortality.

In addition, salmon suffers from major animal welfare risks due to the pseudo-fungal (oomycete) *Saprolegnia* spp. (infectious to the freshwater stage of Atlantic salmon), the parasitic sea louse, the bacteria *Yersinia ruckeri* and *Flavobacterium psychrophilum* as well as bacteria that cause winter ulcer of which *Moritella viscosa* is the most important. In recent years, much effort has been made to control the infestation (i.e. prolonged presence of animal ectoparasites on and in the surface of organisms, while not penetrating deeper tissues) of sea louse. The welfare risk has not been, however, completely eliminated due to the resistance of the sea louse to the applied pesticides. Consequently, biological control through the 'cleaner fish' is nowadays more common. No proper treatment is possible for *Saprolegnia* spp. due to the ban on malachite green. Both *Saprolegnia* spp. and parasitic sea louse cause, among other things, tissue damage, reduced immunity to diseases, suffocation and death. The bacteria cause blood poisoning, ulcers and can also result in mortality.

It is a common practice that Atlantic salmon is first stunned and then killed. This practice is mandatory in Norway but also applied elsewhere.

3.3.3 *Animal health risks (contagious animal diseases) in the fish supply chain*

The Netherlands does not have an active fish disease monitoring system; there is no systematic overview of fish diseases. The current knowledge of the presence of fish diseases in inland waters, including fish farming, is therefore limited and based on submissions for diagnostics to the fish and shellfish diseases laboratory of Wageningen Bioveterinary Research (WBVR). Twice a year, in spring and autumn, WBVR carries out monitoring for mandatory notifiable molluscs diseases in Grevelingen and Eastern Scheldt.

Below is an overview of the current animal health status of fish intended for consumption in the Dutch waters, including fish farming, and an overview of emerging diseases in fish, crustaceans and molluscs.

3.3.3.1 Routes of introduction

More than land-based livestock farming, aquaculture is susceptible to the introduction of infectious diseases. High stocking rates in fish, crustaceans or molluscs farming, if accompanied by poor management, can lead to stress in the animals that results in impaired immune

function. This increases the risk of the introduction and spread of infections. Some farming systems are also in open contact with natural waters, and compared to terrestrial habitats, aquatic habitats are also characterised by higher connectivity.
Pathogens can be introduced to new regions and come into contact with immunologically naïve populations through transport and trade of infected live aquatic animals and their products (fish roe), contaminated fishery products or materials, and the presence of reservoirs in the environment. For example, the swim bladder nematode (*Anguillicola crassus*), introduced to Europe with the import of live Japanese eel, now infects the native European eel population. Evolution of pathogens may lead to increased pathogenicity, as possibly happened with the infectious salmon anaemia (ISA) virus that evolved at least twice from a non-pathogenic wild precursor.

3.3.3.2 Dutch situation

Several fish diseases occur naturally in the Netherlands (Appendix 3.4).

Of the infectious diseases in fish, crustaceans and molluscs listed in the European Animal Health Act, infectious salmon anaemia (ISA) has never been found in the Netherlands in fish species that are susceptible to it, such as sea trout (*Salmo trutta trutta*). Viral haemorrhagic septicaemia (VHS) and infectious haematopoietic necrosis (IHN) have sporadically led to outbreaks in Dutch trout farms. In 2009, Koi herpes virus (KHV) led to mortalities of carp in Dutch open waters, probably due to the escape of the virus from private koi ponds.

Bonamia ostreae, a parasite of bivalves in the Grevelingen and Eastern Scheldt estuaries, was first detected in Dutch waters in 1980. Since then, part of the Dutch flat oyster (*Ostrea edulis*) population has been infected with the parasite. *Marteilia refringens* has not been observed in the Netherlands since the 1970s.

The stone moroko, also known as the topmouth gudgeon (*Pseudorasbora parva*) is a fish belonging to the Cyprinid family that was first described in the Netherlands in 1992. Since then, it steadily expands its range. The stone moroko is an asymptomatic carrier of *Sphaerothecum destruens*, a fungal parasite of fish. Introduction of this parasite into populations of salmon and carp can lead to significant mortality and decreases in population sizes.

Since 2008, a new genotype of the oyster herpesvirus (OsHV-1), the OsHV-1 μVar (read: micro variant) has been causing problems in Pacific oysters (*Crassostrea gigas*). In 2012, OsHV-1 μVar was also detected in juvenile Pacific oysters on oyster beds in the Dutch Wadden Sea.

3.4 Risks to nature in the fish supply chain

3.4.1 Introduction

The wild capture and farming of fish, crustaceans and molluscs pose risks to nature (Appendix 3.5). On the one hand, this involves adverse effects on the natural habitat in which these animals live; the ecological value of nature can be threatened by fisheries. On the other hand, nature contributes to human wellbeing and quality of life through ecosystem services, which include provision of food by fisheries. In this case, the natural value for ecosystem services is primarily aimed at ensuring the sustainable continuation of fisheries.

Both the ecological and natural values of ecosystem services are under pressure from fishing activities, for example due to overfishing, underwater noise pollution or the introduction of alien species. The Netherlands Environmental Assessment Agency refers to ‘pressure factors’ that affect the state of nature: if changes impose strong pressure in a certain direction, this can lead to loss of natural values. Diversity of fishing methods and techniques is used in the fish supply chain. They are applied in different aquatic ecosystems and aquacultures, each bearing their own risks. Marine fisheries cause major pressures through overfishing, bycatch and seabed disturbance. Coastal fisheries, which take place in Delta waters and the Wadden Sea, also cause these pressures, but on a smaller scale. In inland fisheries, overfishing has traditionally led to an unsustainable situation. The biggest risks in molluscs fisheries arise from seabed disturbance and the introduction of invasive alien species. Crustacean fishery causes risks in several ways. The aquaculture contributes to overfishing through production of fishmeal for farmed fish from the wild-caught fish. In all sub-supply chains, the introduction and spread of potentially invasive alien species is a risk that requires more research. Finally, there are diverse topics with only partial of anecdotal data available for which the assessment of the effects of fishing on nature is not possible.

Table 1 Summary of risk assessment on sub-supply chains in terms of different pressure factors

pressure factor	**marine fisheries**	**coastal fisheries**	**inland fisheries**	**molluscs**	**crusta-ceans**	**aqua-cultur e**	**recrea-tional fisheries**
Overfishing	pr	nr	pr	nr/ido	pr/ido	pr	pr/nr
Bycatch and discards	pr	nr/ido	pr/ido	nr	pr	n/a	n/a
Bottom trawling	pr	nr	n/a	pr	pr	n/a	n/a
Pulse trawling	nr/ido	n/a	n/a	n/a	n/a	n/a	n/a
Underwater sounds/sonar	ido	ido	ido	ido	n/a	n/a	n/a
Disturbance	pr/nr	nr	nr	nr	pr	n/a	n/a
Exotic species	pr/ido	pr/ido	pr/ido	pr	pr/ido	pr/ido	pr/ido

Key:
pr = potential risks
nr = negligible risks
ido = insufficient data for an opinion
n/a = not applicable

Information on the supervision of risks associated with nature can be obtained from the integrated supply chain analysis on fish (IKA Vis) and especially from the information sheets on supervision of coastal and inland fisheries, on supervision of catches in marine fisheries, on supervision of IUU fisheries, on fishing areas with special status, on supervision of ('*schubvis*')fisheries on IJsselmeer, Markermeer and IJmeer, on supervision of professional eel fisheries in Dutch waters in closed areas, on supervision of landing and tracing of fish at auction and trade, on supervision of fish landings in Dutch ports, on landing and sale of fish in ports, on landing obligation and quantity of discarded fish, and on supervision of engine power of Dutch fishing vessels.

3.4.2 Risks to nature in the fish supply chain

3.4.2.1 Specific risks of overfishing

If more is harvested than the natural system produces, it leads to the exploitation of nature: overfishing. In the last century, overfishing both at sea and in inland waters led to the disappearance of species that were commercially fished. European fisheries policy has imposed restrictions on fisheries to ensure sustainable fishing in the future. The estimates of quoted fish stocks by the International Committee for Exploration of the Seas (ICES) play here a pivotal role.

Overfishing can manifest itself in the disappearance of populations or in the changes in their composition and structure (e.g. age class), leading to reduction in their ability to recover; for example, when large fish are caught and only the small ones remain. Effects on one species can trigger effects on other species through interactions in aquatic ecosystems. Minor changes in an ecosystem can lead to a cascade of effects such as a disappearance of predators or an increase in prey or competitors. It may also result in an incomplete recovery of a temporarily overfished population. It is difficult to assess how sustainable marine fisheries have become. Different model calculations by, for example, ICES and Wageningen Marine Research (WMR) reach different conclusions within different reference frameworks. Despite the ambiguity of these models, it appears that while some fish stocks have recovered, the other stocks have either not yet reached the full recovery or are for a long time on the verge of recovery and further decline. Consequently, the threat of overfishing by marine fisheries continues to be as up to date as ever. This pose risks to both the fisheries as ecosystem service and the ecological value of nature.

Coastal fishery have already been restricted in the past due to overfishing and the resulting reduction in fish numbers. BuRO estimates that in the current situation, the additional risk of overfishing by coastal fisheries is negligible.

Inland fisheries have a long history of overfishing and shifting to new species. Other factors that besides fisheries put pressure on fish populations are the design of water systems, barriers to fish migration and changing water quality. The stocking of fish also affects fish populations. At present, commercial fish stocks, including bream, perch, zander, roach and eel, are under great pressure. Despite the measures already taken, such as reduced capture of certain fish species and the implementation of the eel management plan, the fishery cannot be yet considered sustainable.

Catch management in shrimp fishery to maintain Marine Stewardship Council (MSC) sustainability certification is also vital to prevent overfishing of common shrimp. However, the data available from research studies are not yet sufficient to draw conclusions about overfishing. There are also indications that the Norway lobster may be subject to overfishing. Similarly, there are indications of a decrease of the European lobster (*Homarus gammarus*) population in Eastern Scheldt for which other factors, in addition to overfishing, are likely to play a role.

3.4.2.2 Specific risks of bycatch and discards

Animals other than the target species are also captured during fishing, including marine mammals and non-target fish species. In addition, undersized fish are considered as bycatch. In marine fisheries, bycatch and discards add to the effect of overfishing. This involves very large numbers of animals in bycatch or discards that die after capture or experience long-term animal welfare problems. Long-lived species with low reproductive capacity such as sharks and rays are particularly at risk. Bycatch of porpoises occurs regularly in Dutch waters but is below the policy target set for it. The standard is: the bycatch of porpoises is below 1% of the population estimated by ICES. This means an average of about 23 porpoises per year.

Under European fisheries policy, a landing obligation has been established for bycatch in marine fisheries of most quoted fish species. The role of this obligation is to stimulate the development of more selective fishing techniques and net innovations. In coastal fisheries, non-target organisms are mainly found in fixed fishing gear, e.g. traps, standing rigging/gill nets. Migratory fish, birds and marine mammals are at risk. High mortality rates have been estimated for migratory fish in particular. For birds, the extent is limited. There are no structural research data available. Given the measures taken in, among other things, management plans, and the limited size of the sector, the risk to the ecological value of nature is estimated to be low.

In inland fisheries, many undersized fish form bycatch. This results in risks for nature, especially for migratory fish and diving birds. There is, however, no up-to-date quantitative data to provide an accurate risk assessment on these risks.
In molluscs fishery and farming, bycatch does not play a significance role. In crustacean fishery, bycatch of undersized shrimp and non-target species poses a risk for nature as an ecosystem

service. There is policy aimed at reducing bycatch. The solution is mostly sought in technical developments of the fishing gear, and for shrimp fisheries also in closing certain areas.

Bycatch is of no significance in fish farming in the Netherlands.

3.4.2.3 Specific risks caused by bottom trawling

In parts of the North Sea, the seabed is disturbed by fishing gear more than once a year. Bottom trawling poses a major risk to the ecological value of nature and to the ecosystem services. The risks of seabed disturbance particularly apply to long-lived benthic animals and to species that deposit eggs on the seabed, such as sharks and rays.

The effect on benthic communities varies greatly by gear type and location. Lighter fishing systems with less seabed disturbance have been developed as an alternative to the heavy beam trawl with tickler chains. For example, fishing with flyshoot (seine fishing), sumwing, boards and electric pulses, among other things, seems to be less harmful to benthic communities than traditional beam trawling with tickler chains. Although the assessment of pulse fishing and the system chosen for it are a subject of debate. Pulse fishing was banned by the European Parliament in April 2019, and it remains to be used only on a limited scale for scientific research purposes on economic and environmental advantages and disadvantages of this fishing method. For more information, please see WUR’s dossier on Pulse fishing. ICES concludes that fishing for sole (a flatfish species) with the pulse trawl fishing in the North Sea scores better on relevant sustainability aspects than fishing with the traditional beam trawl. It involves namely less seabed disturbance, less bycatch of undersized fish and lower fuel consumption.

In areas subjected to frequent bottom trawling, most of the sensitive and potentially long-lived benthic species are often absent or rarely found. The species still present in those areas are to a certain extent resistant to bottom trawling. This effect can be seen, among other things, in the relative increase in short-lived, younger and smaller species and a difference between areas targeted for fishing and closed to fishing. Currents and tides create high dynamics with changing seabed in the coastal zone of the North Sea and Wadden Sea. When fishing takes place in these areas, its effects on the seabed (structure and type) will be less prominent. Restrictions on bottom trawling have been and are being imposed in protected areas. Fishing in protected areas is subject to certain licensing conditions that seem to control the potential risks to nature. Bottom trawling is also limited in coastal fisheries, i.e. in the Delta waters and Wadden Sea.

Mechanical fishing for cockles, surf clams (*Spisula*) and razor clams (*Ensis*) poses significant risks to nature due to the considerable seabed disturbance. Mechanical cockle-dredging is banned in the Wadden Sea. Mechanical fishing on molluscs is allowed in other parts of the coastal zone of the North Sea and the Delta waters. There is an immediate major effect on benthic communities, although the current benthic species seem to be adapted to severe disturbances.
Shrimp fisheries take place, among other places, in protected Natura 2000 areas, such as in the Voordelta, North Sea coastal zone and the Wadden Sea. Research data indicate that seabed disturbance through shrimp fisheries affects nature in the marine Natura2000 areas and the Wadden Sea. It is likely that it also pose a risk to natural values.

Seabed disturbance does not play a role in Dutch fish farming or inland fisheries.

3.4.2.4 Specific risks caused by underwater sounds

Noise from human activities can be disruptive to marine mammals and other animals, affecting the ecological value of nature. Among other things, fisheries produce noise through the use of sonar, the sailing of vessels, the use of fishing gear and the jacking of poles to attach fixed fishing gear. Studies indicate that the use of sonar in particular and the generally high underwater noise levels may pose risks to seals and porpoises. More research is, however, required to make a more substantiated statement.

3.4.2.5 Specific risks caused by disturbance

Overall, the effects caused by disturbance appear to pose negligible risk to nature. One exception is the disturbance of seabirds foraging behaviour caused by shrimp fisheries in the North Sea coastal zone. In particular, the common scoter (*Melanitta nigra*) and common eider (*Somateria mollissima*) are negatively affected.

3.4.2.6 Specific risks caused by alien species

Marine alien species may be introduced and spread by detached fishing gear and waste, and possibly also by the use of uncleaned vessels and equipment and the disposal of discards and fish waste. The extent of these risks in the North Sea cannot be accurately assessed due to a lack of data.

There are invasive colony-forming alien species in the Delta waters and Wadden Sea, which can be spread by bottom trawling. Again, the extent of these risks cannot be accurately assessed due to a lack of data.

In the past, alien species have been released for inland and recreational fishing in the Netherlands. Fish stocking is, however, no longer allowed under the Dutch Nature Conservation Act. There is an exception for stock management and farming of already resident alien fish species listed in the Fisheries Implementation Regulation of the Fisheries Act 1963. These species may still be stocked, with potential risks for Dutch nature because: i) the species released may alter species communities, ii) other non-native species may unintentionally be released, and iii) parasites and disease may be introduced with these alien species. There is no central registration of fish stocking, which makes it impossible to quantify these effects.

Inland fisheries and recreational fishing can also contribute to the introduction and spread of alien species through stocking of native fish. In recreational fishing, storage facilities for live fish and bait are used. The use of these facilities could contribute to the spread of alien zooplankton, e.g. water fleas. Moreover, there is an international trade in live bait for recreational fishing, e.g. in alien bristle worms. These live bait species and other hitchhiking organisms can be introduced through this pathway. Although the risk seems limited given that predominantly native worms are used in the Netherlands, the recreational fishermen also regularly pursue their hobby in other countries. Data on the extent of possible introductions are, however, lacking. Improper cleaning of fishing gear and vessels can also lead to the spread of alien species. Furthermore, the use of dead bait such as shrimp enables the spread of pathogens, for example viruses.

The farming of molluscs involves storage and transport, both from abroad and within the Netherlands. This can result in the accidental introduction of new alien species, parasites and pathogens, which pose risks to nature. The Shellfish Movements Policy Rule (i.e. *Beleidsregel schelpdierverplaatsingen*) prescribes measures (not applying to pathogens) for a limited number of movements. However, this policy rule does not apply to all movements, as for example from the Wadden Sea to the Eastern Scheldt or between Grevelingen and the Eastern Scheldt.

In crustacean fisheries, imports of the American lobsters (*Homarus americanus*) lead to potential risks for the European lobsters.

Several alien crayfish species have been introduced into Dutch inland waters. The crayfish plague (*Aphanomyces astaci*) has been brought along with its crayfish hosts and caused the disappearance of all but one population of the European crayfish species (*Astacus astacus*) in the Netherlands. The numbers of alien crayfish have increased dramatically in the recent years, especially in peatland areas. Their spread poses ecological and safety risks through predation, consumption of underwater vegetation and burrowing activities.

In the Netherlands, native and alien fish species are imported to set up or enhance farming systems. This is a potential introduction pathway for species that are accidentally imported with them, such as pathogens and parasites. The extent to which live non-native feed is used in aquaculture is unknown.

There are European regulations governing open and closed aquaculture systems, which include the prevention of introductions of alien species and the prevention and control of aquatic animal diseases. In the Netherlands mainly closed farming systems are used, with the exception of trout ponds that often have a flow-through system. The probability of the alien species introduction into nature from closed farming systems is low. Escapes of trout from farming facilities have been reported, but these are expected to have a limited effect on local ecosystems.