CHAPTER 1
Fishery sector

1.1 Characterization of seafood

1.1.1 Classification

The term ‘seafood’ used throughout this book represents three categories of organisms – fish, crustaceans, and mollusks – each of them belonging to a different phylum within the kingdom Animalia.

Identification of fish from different species by nonproperly trained people can be very challenging and even impossible most of the times. The use of local or common names can also originate misunderstandings; the same species may have distinct names in different regions or the same name may be attributed to different species. The best way to avoid such mistakes is the use of the scientific name (in Latin) to clearly identify seafood species all over the world. This clarification is also of great importance since the economic value of seafood can be dependent on the species.

In taxonomic terms, the majority of commercially relevant fish species category belong to the phylum Chordata (subphylum Vertebrata), which is divided into different classes among which stands out the class of ray-finned fish Actinopterygii (superclass Osteichthyes, also called bony fish) (Nelson 2006; Auerbach 2011). By the fact that their skeleton is entirely composed of cartilage, sharks, rays, and skates belong to the class of cartilaginous fish Chondrichtyes (Huss 1988; Auerbach 2011).

Crustaceans belong to the phylum Arthropoda and to the subphylum Crustacea. Within this subphylum, the class Malacostraca stands out for being the class that has the largest number of known species by far (Saxena 2005; Auerbach 2011). This class includes shrimps, prawns, crabs, and lobsters which, in turn, constitute the order Decapoda (Saxena 2005).

Food Safety in the Seafood Industry: A Practical Guide for ISO 22000 and FSSC 22000 Implementation,
First Edition. Nuno F. Soares, Cristina M. A. Martins and António A. Vicente.

Finally, mollusks belong to the phylum Mollusca, which is divided into several classes. Bivalve mollusks, such as mussels, oysters, scallops, and clams, belong to the class Bivalvia (also known as Lamellibranchia or Pelecypoda), and cephalopod mollusks (e.g., squids, octopuses, and cuttlefishes) belong to the class Cephalopoda or Siphonopoda (Haszprunar 2001; Helm *et al.* 2004; Auerbach 2011).

1.1.2 Anatomy

Bony fish

The skeleton of bony fish, as the name suggests, is totally made of bones. Wheeler & Jones (1989) suggested that the skeletal structure of bony fish could be divided into two parts: head skeleton and axial skeleton. The head skeleton is composed of three systems: (1) neurocranium, which surrounds and protects the brain and the sense organs; (2) bones system, that is related to feeding; and (3) combined hyal and branchial systems, which form gill arches and gill covers. The axial skeleton is formed of a set of articulated vertebrae that range from head to tail forming the vertebral column or backbone (Huss 1988; Wheeler & Jones 1989).

According to Schultz (2004), the body of bony fish has three types of muscles: smooth, cardiac, and striated (edible part). Although most fish muscle tissue is white, certain species (e.g., pelagic fish, such as herring and mackerel) have a portion of reddish- or brown-colored tissue. The so-called dark muscle is located under the skin or near the spine (Huss 1988, 1995). According to Love (1970), fish activity causes variations on the proportion of dark to white muscle. For instance, the dark muscle of pelagic fish (i.e., species which swim more or less continuously) could represent up to 48% of the body weight. The chemical composition of dark muscle differs from that of white muscle since it contains higher amounts of lipids, myoglobin, alkali soluble proteins, stroma, and glucogen (Chaijan *et al.* 2004; Bae *et al.* 2011). These differences, especially the high lipid content found in the dark muscle, are directly responsible for problems related to rancidity (Huss 1988). Moreover, muscle composition is relevant in terms of ability to cause an allergic reaction. A glycoprotein named parvalbumin, which is responsible for triggering the immune response leading to allergy symptoms, has been demonstrated to be 4–8 times higher in white muscle compared to dark muscle (Kobayashi *et al.* 2006).

Bony fish have a skin which is commonly covered by scales and they use the gills for breathing underwater, as seen in Figure 1.1. There are different organs within the fish body which form part of the digestive system including stomach, intestine, and liver, which are commonly known as guts (Johnston *et al.* 1994). Because many pathogenic bacteria are commonly present in the normal gut microflora, evisceration is the first critical step to control contamination of fish flesh after handling and before freezing.

Crustaceans

Crustaceans are classified as arthropods and are characterized by the presence of a hard exoskeleton made of chitin and a segmented body with appendages on each segment (Adachi & Hirata 2011).

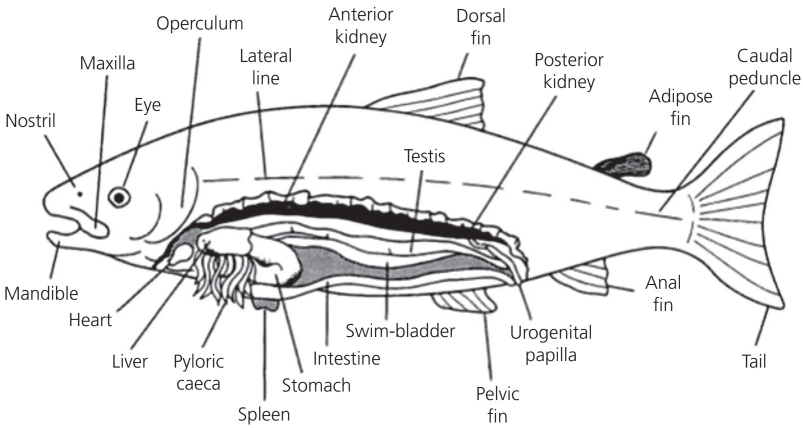

Figure 1.1 Diagram of the basic anatomy of a salmonid fish. Source: Roberts (2012). Reproduced with permission from John Wiley & Sons.

According to Raven & Johnson (2002), most species belonging to the Subphylum *Crustaceae* have two pairs of antennae, three types of chewing appendages, and a different number of legs, as presented in Figure 1.2. Shrimps, prawns, crabs, and lobsters, which are a very important fishery resource, have ten legs in the form of thoracic appendages. This characteristic reflects the origin of the name *Decapoda*, a word that derives from the Greek words for ten (*deka*) and feet (*pous*) (Ng 1998). The carapace of decapod crustaceans is reinforced with calcium carbonate and their head and thoracic segments are fused, forming a structure called cephalothorax. These animals can have a telson (or tail spin) in the terminal region of the body (Raven & Johnson 2002).

Allergies to crustaceans are common and usually more publicized than allergies to other seafood products. Tropomyosin, a water soluble and heat-stable muscle protein, has been identified as the major allergen of shrimp (Shanti *et al.* 1993; Daul *et al.* 1994). Tropomyosin can also be responsible for allergic reactions in other products such as mollusks, but it has not been demonstrated that this allergen cross-reacts with fish allergens (Lopata *et al.* 2010).

Bivalve mollusks

Bivalve mollusks such as mussels, oysters, scallops, and clams are invertebrates characterized by the presence of a shell. According to Gosling (2003), the shells of bivalve mollusks are mainly formed of calcium carbonate in three different layers: first, an inner calcareous (nacreous) layer; second, an intermediate layer of aragonite or calcite; and finally a thin outer periostracum of horny conchiolin. Depending on the species, shells can have a variety of shapes, colors and markings. For that reason, the characteristics of shells are commonly used in the identification of diverse species of bivalves (Poutiers 1998; Gosling 2003).

The shells of mollusks shells are formed of two valves, which laterally compress their soft body, and are dorsally hinged by an elastic and poorly calcified structure,

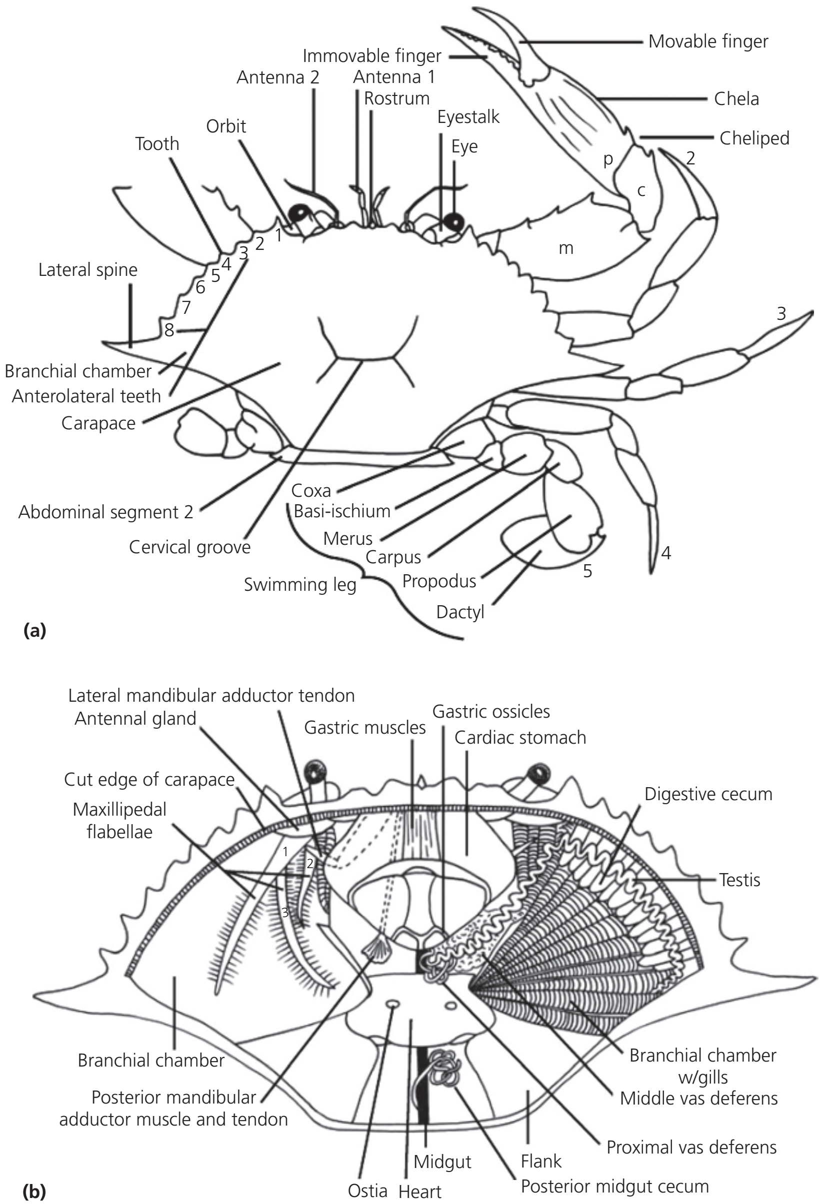

Figure 1.2 Schematic drawing of a male blue crab. (a) Dorsal view of external anatomical features. (b) Dorsal view of internal anatomy. Source: Lewbart (2011). Reproduced with permission from John Wiley & Sons.

the ligament (Poutiers 1998; Helm *et al.* 2004). This ligament is also involved in the system that controls the opening and closing of both valves. Shells are closed due to the contraction of the adductor muscle(s), which causes a reaction of stretching within the ligament. When the muscle relaxes, the ligament tends to contract and releases the created tension. As the ligament returns to its initial position the valves depart from one another, hence opening the shell (Ray 2008).

According to Helm *et al.* (2004), when one of the valves is removed it is possible to see the internal organs of the mollusks. All the organs are covered by a mantle, shown in Figure 1.3, among which the gills or ctenidia stand out. This organ is

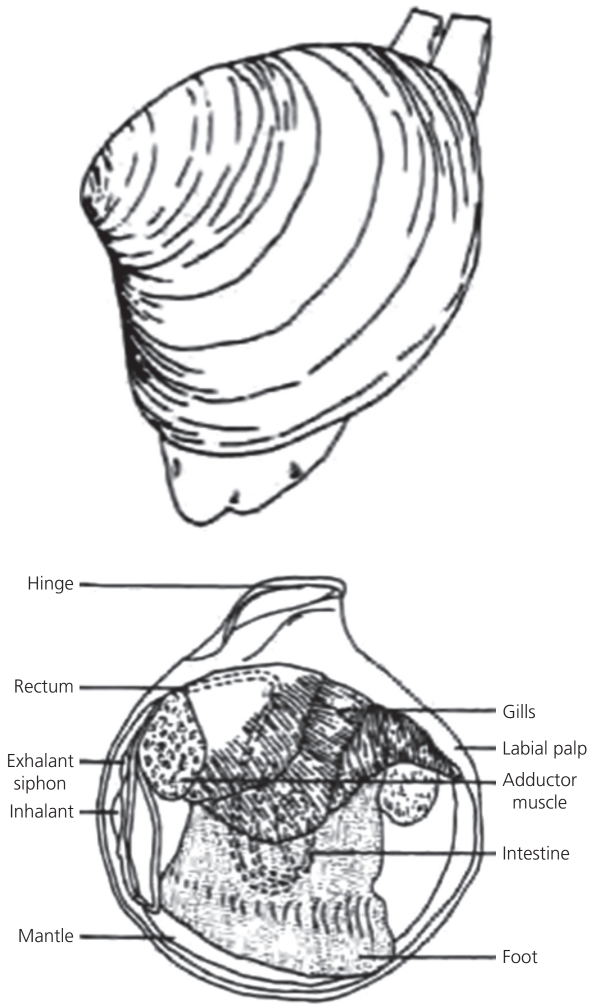

Figure 1.3 Internal features of a Quahog clam. Source: Granata *et al.* (2012). Reproduced with permission from John Wiley & Sons.

used to filter food from water and to breathe (Coan & Valentich-Scott 2006). However, some contaminants present in the environment, such as pathogenic bacteria, viruses, and chemicals, are commonly retained inside.

Cephalopod mollusks

As mentioned above, cephalopod mollusks, which include squid, octopus, cuttlefish, and nautilus, belong to the class Cephalopoda, one of the major and most complex classes of the phylum Mollusca (Jereb & Roper 2005; Ray 2008).

The name *Cephalopoda* derives from the combination of two Greek works: *kefale* and *pous* which mean head and feet, respectively. This is related to the fact that the members of this class have a head that supports a set of arms or both arms and tentacles, placed in a circle around its mouth. These appendages (arms or tentacles) are provided with many suckers or hooks, helping them to capture and hold prey (Jereb & Roper 2005). Like other mollusks (e.g., bivalves and gastropods), cephalopods have an external shell. However, according to several authors (Boyle & Rodhouse 2005; Jereb & Roper 2005), the greater part of the living forms of these animals lost their shell or it was reduced. For instance, in squids and cuttlefish the external exoskeleton was reduced; they presently possess an internal shell called gladius, pen, or cuttlebone. An outer shell for protection is only present in the living cephalopods from the Family *Nautilidae* (Dunning & Wadley 1998). Jereb & Roper (2005) concluded that the loss of the external shell allowed the development of a muscular mantle which covers the internal organs (Jereb & Roper 2005). Figure 1.4 depicts the basic features of a squid.

1.1.3 Chemical composition

When the subject is food safety, it is fundamental to know the chemical composition of seafood. With this knowledge, professionals are able to foresee what kind of microorganisms can develop in seafood and which changes may occur in the product after harvesting and during shelf life.

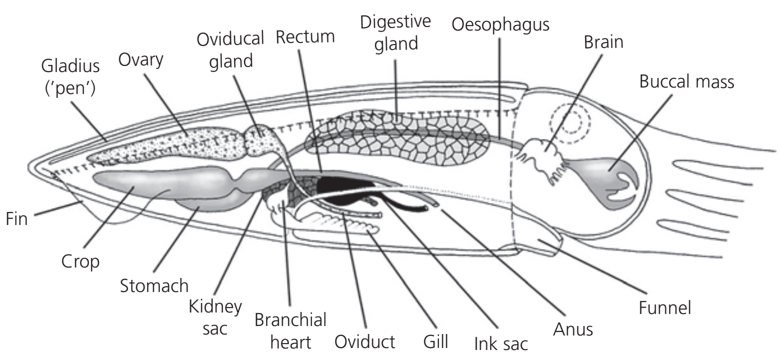

Figure 1.4 Generalized anatomy of a loliginid squid. Source: Boyle & Rodhouse (2007). Reproduced with permission from John Wiley & Sons.

According to Murray & Burt (2001), the chemical constituents of fish flesh can be divided into two groups: the major and minor components. The former comprises water, protein, and fat, whereas the latter includes carbohydrates, minerals, and vitamins. The amount of each constituent can be influenced by extrinsic factors (e.g., the environment/season) or by intrinsic factors of the fish (e.g., species, age, sex, or spawning/migration period) (Huss 1988, 1995).

Water

Water is well known as a fundamental substance to maintain life on Earth and is the main constituent of all living organisms. According to Murray & Burt (2001), water typically comprises up to 80% of a lean fish fillet weight and about 70% of a fatty fish flesh weight. However, these values may vary between 30% and 90% in certain species. Several authors (Feeley *et al.* 1972; Love 1980, 1988; Huss 1988; Osman *et al.* 2001; EFSA 2005; Pirestani *et al.* 2009) reported that water content in fish varies inversely to the fat percentage, that is, water content is higher in low-fat species than in fatty fish. Regarding the three categories described in Section 1.1.1, mollusks have more water than fish and crustaceans.

The absolute content of water present in food usually takes two forms: (1) free or available water; and (2) bound or unavailable water. Water that is not linked to any component, such as proteins or carbohydrates, is available for growth of microorganisms including pathogenic bacteria (Dauthy 1995). According to Jay *et al.* (2005), the amount of water available for microbial growth is described in terms of water activity (a_w) and can vary between 0 and 1 (Neumeyer *et al.* 1997; Aberoumand 2010). Jay *et al.* (2005) reported that the value of this parameter exceeds 0.99 in the majority of fresh foods and, according to Martin *et al.* (2000), fresh fish has a water activity close to 1, making it vulnerable to contamination.

Each microorganism has a different water activity range: pathogenic and spoilage bacteria require a high amount of water and do not grow in foods with a water activity of less than 0.85, whereas many yeasts and moulds can grow at water activity values as low as 0.60 as shown in Table 1.1 (Jay *et al.* 2005; FDA 2011). In order to prevent microbial growth, there are a number of strategies that can be applied, namely freezing, drying, and addition of solutes or ions.

Proteins

Proteins are chains of small units called amino acids linked to one another to make a long molecule. There are 20 different naturally occurring amino acids, most of them essential for the maintenance of good health, making their presence in the human diet very important. A healthy human diet should include the ingestion of amino acids in balanced proportions. A proper combination of amino acids to meet the nutritional needs of man can be provided by fish protein equally as supplied by meat, milk, and eggs (Murray & Burt 2001).

Fish protein is easily digested and has a high biological value (Bohl *et al.* 1999; EFSA 2005). Among species, the amino acid content of fish meat is similar. The protein content of their edible parts is similar to the muscle meat

Table 1.1 Approximate minimum a_w values for growth of microorganisms important in foods

Microorganism	Minimum a_w (using salt) (FDA 2011)	Minimum a_w (using salt) (Jay *et al.* 2005)
Bacillus cereus	0.92	–
Campylobacter jejuni	0.987	–
Clostridium botulinum (type A)	0.935	0.94
Clostridium botulinum (type E)	0.97	0.97
Clostridium perfringens	0.93	–
Escherichia coli	0.95	0.96
Listeria monocytogenes	0.92	–
Salmonella spp.	0.94	–
Shigella spp.	0.96	–
Staphylococcus aureus (toxin production)	0.83	0.86
Vibrio cholerae	0.97	–
V. parahaemolyticus	0.94	0.94
V. vulnificus	0.96	–
Yersinia enterocolitica	0.945	–

of animals but, in contrast to cuts from many animals, the uniformity/homogeneity of fish is higher (EFSA 2005).

The amount of protein present in fish muscle is around 15–20%; however, values as high as 28% can be found in some species of fish (Murray & Burt 2001). According to EFSA (2005), the protein content decreases somewhat with age-related increases in the lipid content, despite the fact of being similar in fish on a weight basis (15–20 g/100 g).

Lipids

Often referred to as fats, lipids include fats, oils, waxes, and other compounds of fatty acids (Murray & Burt 2001). Commonly, fish is divided according to the fat percentage of body weight. Fatty fish (5–20%) accumulates fat in muscle tissue and lean fish (1–2%) accumulates fat predominantly in the liver (EFSA 2005). The lipid content of fish varies not only between different species but also within the same species according to season and feeding. Lipids are unevenly distributed even within a particular individual; in salmon for example, near the head the lipid content is double that in tail muscle (Murray & Burt 2001).

Similarly to most vertebrates, in most fish species fat depots are composed of triglycerides. However, fish lipids are different from mammalian lipids since they are composed of long-chain polyunsaturated fatty acids (LC-PUFAs) containing many fatty acids with five or six double bonds (Stansby & Hall 1967; Huss 1988). These LC-PUFAs, especially eicosapentaenoic and docosahexaenoic acids, are very important in human nutrition since they cannot be synthesized (due to the absence of the enzyme that synthesizes alpha-linoleic acid). They are conventionally known as ω-3, indicating that the first double bound is located after the third carbon atom from the methyl end of the chain. LC-PUFAs are associated with important functions such as brain development in children, in the last trimester of pregnancy, and disease prevention such as sudden cardiac death, coronary heart disease, and atherosclerosis. Another benefit of seafood is that its consumption can produce effects very rapidly, within weeks or months, as in the case of lowering blood pressure or anti-thrombotic actions (FAO 2013). Most of these benefits have been known of since the middle 1970s and early 1980s when Danish scientists acknowledged that Greenland Eskimos, despite the large presence of fat and cholesterol from marine foods in their diet, rarely suffer from ischemic heart disease and have lower low-density lipoprotein (LPL), cholesterol, and triglyceride levels than Denmark Eskimos (typically on a western European diet). Although there is convincing evidence of fish LC-PUFAs benefits, it is a great challenge to define a dose–response relationship; not only does the concentration of these constituents differ among distinct products, but the benefits obtained may not be linearly dependent on the amount consumed (Mozaffarian & Rimm 2006).

Carbohydrates

Carbohydrates are substances containing only elements of carbon, hydrogen, and oxygen that, when combusted, produce carbon dioxide and water. This group of substances includes sugars, starches, gums, and celluloses. Fish is a poor source of carbohydrates. Generally, the amount of carbohydrates in fish muscle is less than 1%, although other tissues such as liver can provide higher values. In the dark muscle of some fatty species and in some mollusks carbohydrate content can increase up to 2% or 5%, respectively (Aitken *et al.* 2001; Murray & Burt 2001).

Minerals and vitamins

Seafood is a good source of minerals and vitamins for a healthy diet. Usually reported in compositional tables as ashes, because of their quantification method, minerals are inorganic compounds that typically represent less than 2% of the edible portion (Aitken *et al.* 2001) of fish. For example, iodine and selenium are almost exclusively found in foods from the aquatic environment and are important for the development of brain and neural systems of children (Toppe 2012). Iodine deficiency is estimated to affect about one-third of the global human population and can lead to brain damage and mental retardation (de Benoist *et al.* 2008). According to EFSA (2005) the amount of iodine present in fish has been reported to range from 5 μg to 1210 μg iodine per 100 g fresh weight of edible parts. According to the same report, it is also possible to observe that all species of fish contain considerable amounts of selenium. This element presents a high binding affinity for mercury and can therefore reduce mercury toxicity (Ralston *et al.* 2008).

Vitamins can be divided into two groups, namely: those that are soluble in fat, such as vitamins A, D, E, and K; and those that are soluble in water, such as vitamins B and C. One of the main characteristics of the vitamin content in fish muscle is that it varies significantly between different fish species and even between some parts of the same fish. The vitamin content of fish muscle is comparable to that of mammals and in general is a great source of fat-soluble vitamins A, D, and E (Huss 1988). Vitamin D is particularly important since it is not found in many foods and is important to bone health and type-2 diabetes reduction, among other benefits. Despite the fact that vitamin D can be produced from skin exposure to sunlight, some populations can suffer from its deficiency due to long winters or the use of clothes that cover the entire body. Water-soluble vitamins, such as B and C, tend to be more uniformly distributed through the flesh (Murray & Burt 2001). Vitamin B has an important role in energy production in the cells. Since vitamins can be sensitive to factors such as light, heat, temperature, and storage time, processing and storage conditions are important to preserve the natural vitamin content of fish.

1.1.4 Marine ecosystem

The management of fisheries and marine ecosystems is critical to reduce the increasing degradation and loss of marine habitats, to improve research and define policies for marine science, and to manage conflicts in the use of marine resources. The need to exercise some control over the various uses of a maritime area became evident in the late twentieth century as a result of concern for the health of oceans and the need to regulate human activities, which were generating an increasing occurrence of conflicts.

The proper functioning of an ecosystem results from the capacity of a community to adapt to the physical environment and its relationships with other communities, consisting of populations of species that have their own dynamics in terms of abundance, survival, growth, production, reproduction, and other strategies.

The geographic boundaries of ecosystems are often difficult to define, since the extent, location, and structure of an ecosystem, as well as species composition and functioning, may vary seasonally or change every year under certain climatic conditions.

The ocean as an ecosystem is not a uniform and constant environment. Weather phenomena such as *El Niño* alter the oceans, both physically and biologically, and also affect the distribution of fish. In addition to these changes in oceanographic features, other changes occur as a result of events such as *El Niño* such as in sea surface temperature, vertical thermal structure of the ocean (particularly in coastal regions), coastal and upwelling currents, and patterns of migration. All these changes directly affect species composition and abundance of fish, while fish that remain in the affected regions experience a reduction in growth, reproduction, and survival. Fluctuations in fish stocks are therefore not exclusively caused by fishing, but also by environmental conditions. *El Niño*-induced weather changes are felt worldwide, with important implications in the dynamics of aquatic ecosystems. According to Tudhope *et al.* (2001) and Garcia *et al.* (2004), *El Niño*-like conditions are becoming more frequent and more intense, making a deeper understanding of the impact of those events in the ecosystems extremely important (Garcia *et al.* 2004).

An extensive knowledge of the characteristics of ecosystems, namely complexity, structure, functioning, natural variability, and boundaries, as well as the implementation of better management techniques are essential for maintaining the productivity of ecosystems for present and future generations. To achieve that goal, it is imperative to maintain habitats, reduce pollution and degradation, minimize waste, and protect threatened and endangered species.

The closer ecosystems are to human intervention, the greater the impact of pollution on them. In inland or coastal waters, which are more susceptible, direct intervention with the habitat can minimize environmental problems, while in marine ecosystems, due to the fact that direct intervention is limited, the focus is mainly on the control of certain human activities (namely fishing).

The complexity of the interactions between different marine species, either in the predator/prey relationship or between species of the same trophic level, makes the prediction of the consequences of perturbations introduced in the ecosystem very difficult. For example, diseases or contaminants that are introduced in a trophic level will be transmitted to their predators by feeding. The fishing of certain species and consequent reduction of its abundance in the ecosystem also has consequences not only on their predators but also on their prey and other species that compete for the same food sources.

Because we cannot fully understand the ecosystem structure and functioning and as it is extremely difficult to distinguish between natural and human-induced changes, most of the consequences of human interventions are not always perfectly predictable and/or reversible. However, it is well known that fishing affects the ecological processes on a large scale and that overfishing can transform an originally stable, mature, and efficient ecosystem into an immature and stressed ecosystem (Garcia *et al.* 2003).

1.2 Characterization of the seafood industry

1.2.1 Development of the fish industry

The fish industry has evolved significantly over the last few decades. This development was driven by several factors such as population growth, expansion of production and processing of fish, greater concern of consumers with a healthy diet, and increasing efficiency of distribution channels. The combination of all these factors with a growing interest in food safety and quality has forced the adoption of increasingly stringent hygiene actions to protect the health of consumers. Given the high perishability of fish, all steps of handling, processing, preservation, packaging, and storage become essential to improve its shelf life, ensure safety, maintain quality and nutritional attributes, and avoid waste and losses.

Currently, the fish industry processes seafood in a large variety of products and uses different packaging materials and conditions. This transformation was largely due to technological developments in recent decades related to food processing and packaging and to an increasing importance given to product differentiation. For instance, innovations in refrigeration, ice making, packing, and shipping allowed product integrity to be ensured and fish distribution to be expanded in different forms such as fresh, chilled, and frozen.

In developing countries, such advances in processing have not yet occurred and sophisticated methods of processing, such as filleting, salting, canning, drying, and fermentation, are still not used or are used to a lesser extent due to a lack of infrastructure and services (including hygienic landing centers, electricity, drinking water, roads, ice, cold rooms, and appropriate refrigerated transport). However, a few signs of evolution have been observed. For instance, frozen fish production for human consumption has increased from 13% to 24% between 1992 and 2012 (FAO 2014).

1.2.2 Fish consumption and international trade

Fish utilization can be categorized as 'nonfood' or 'food' use. Since the beginning of 1990, the proportion of fish production used directly for human consumption has increased. In fact, in the 1980s about 71% of fish produced was intended for human consumption, increasing up to 73% in 1990 and 81% in the 2000s. In 2012, 136 million tons of world fish production accounted for 86% utilization for direct human consumption, while the remaining 14% were for nonfood purposes including reduction to fishmeal and fish oil, ornamental purposes, pharmaceutical uses, or animal feed.

Live forms of fish, fresh or chilled, are usually preferred and comprise the higher-priced products in many markets; the proportion of live fish marketed for edible purposes in 2012 reached about 46% (63 million tons). Other forms of fish, such as dried, salted and smoked, accounted for 12% (16 million tons), 13% (17 million tons) were prepared and preserved forms, and the remaining 29% (40 million tons) were frozen products (FAO 2014).

From 1976 to 2012, the trade of fish and fishery products increased by about 8.3% per year in nominal terms and 4.1% in real terms. The international financial crisis which began in 2008 and its subsequent economic contraction in several economies created a pressure in the market, leading to reduced demand from key markets. Pressure to reduce prices in some fishery products, especially in farmed species, has also been noticed. The combination of these factors can explain the stall at international trade from the 2011 peak at US$ 129.8 billion (which was an 17% increase over 2010), to US$ 129.2 billion in 2012. In 2012, 90% of trade in fish and fishery products consisted of processed products in terms of quantity (live weight equivalent[1] excluding live and fresh whole fish), and only the remaining 10% were of live fish (fresh and chilled). Nevertheless, it is clear that in the last decades there was an improvement in logistics and a growing demand for unprocessed fish, since it doubled the 5% value of 1976.

[1]Mass or weight, when removed from the water.

Preliminary statistics indicate an increase in world per capita fish consumption of 9.9 kg in 1960 to 19.2 kg in 2012. The presence of fish in a healthy diet is so important that, in 2010, its consumption was responsible for 16.7% of the global population's intake of animal protein and 6.5% of all protein consumed. Fish proteins therefore represent an essential nutritional component in countries with high population density, where the total level of protein intake may be low (FAO 2014).

1.2.3 Fish production

The last five decades have seen a growing world fish production, increasing the supply of fish food at an average annual rate of 3.2%, outpacing population growth worldwide at 1.6%. World food fish aquaculture production grew at an average annual rate of 6.2% between 2000 and 2012, more than doubling its value from 32.4 million tons in 2000 to 66.6 million tons in 2012.

The global capture fishery production, in both marine waters and inland waters, has remained stable over the last 5 years, reaching the second highest global capture fishery production of 93.7 million tons in 2011 and 91.7 million tons in 2012. Comparing capture production with aquaculture production, capture production stabilized in the 1990s while aquaculture production continued to grow. In fact, the global aquaculture production (for human consumption and other uses) reached a new high of 90.4 million tons (live weight equivalent) in 2012, and FAO estimates that aquaculture production for human consumption will increase 5.4% to 70.2 million tons in 2013. In fact, in Asia the aquaculture production has surpassed the capture production since 2008 (FAO 2014).

1.2.4 Fish as a source of income

Employment in the fisheries sector grew at a faster rate than employment in the traditional agriculture sector during the period between 1990 and 2012. Approximately 58.3 million people were estimated to be involved in the primary sector of capture fisheries and aquaculture in 2012, representing about 4.4% of the 1.3 billion people economically active in the agriculture sector; these figures are well above the 2.7 and 3.8% registered in 1990 and 2000, respectively.

The growing importance of aquaculture in the fisheries sector can also be observed in the employment. In the last decade, the average annual percentage growth rate of fish farmers was 3.7% and 4.1% during 2000–2005 and 2005–2010, respectively, while in capture fishers it was only of 1.2% and 1.5% in the same periods. As well as fish farmers and catchers, this sector also provides jobs in the secondary sector; overall, the fisheries sector provides employment to 10–12% of world's population (FAO 2012).

1.2.5 World fleet

The total number of fishing vessels in the world was estimated at 4.72 million in 2012. The distribution of the global fleet by region designates Asia as the biggest player in the world with 3.23 million of vessels (68%). In second place comes Africa with 16% (mostly due to inland, nonmotorized small vessels), followed by

Latin America and the Caribbean, North America, and Europe, with 8%, 2.5%, and 2.3%, respectively. Although the inland fleet is significant, representing 32% of the world fleet in 2012, its proportion relative to marine vessels operating in inland waters varied substantially by region, being the highest in Africa (64%), followed by Asia (30%), and Latin America and the Caribbean (18%) (FAO 2014).

1.2.6 The status of fishery resources

Since 1996 when marine fisheries reached a maximum production of 86.4 million tons, the total capture of fish has been steadily declining, dropping to 79.7 million tons in 2012.

In 2011, the stocks of fish captured within biologically sustainable levels were 71.2%; this means that 28.8% was fished at levels where the abundance is lower than the level that can produce the maximum sustainable yield, being almost 3 times higher than in 1974 when it was about 10%.

There is in fact no perspective that in the near future this scenario will change; it is actually expected that this trend in reducing marine fisheries resources will continue since, in 2011, only 10% of such resources were underfished (FAO 2014).

1.2.7 Unveiling the future

According to the World Bank, five years after the global financial crisis, the world economy shows signs of regression in 2014. However, thanks to general signs of growth, preliminary estimates for 2013 indicate a further increase of fish trade and fishery products. It is expected that the long-term slow but steady economic recovery will continue to show a positive trend for fish trade in the future, despite the instability in stocks during the last couple of years (FAO 2014).

Aquaculture is at a historical turning point since it is estimated to surpass capture as the main source of fish for human consumption in 2015 (OECD & FAO 2013). Nevertheless, it will face some challenges that are responsible for the estimated reduction in its growth from the 5.6% per annum in the last decade to 2.5% per annum until 2023 (OECD & FAO 2014). The main restrictions are:

- *regulation and competition for space*: especially in coastal areas, competition with other users will increase and licensing may become more difficult to obtain;
- *investment in research*: an increasing investment in research will be necessary to increase productivity, find substitutes for fishmeal and fish oil, increase animal health and avoid diseases, and reduce environmental impact;
- *production costs*: expected increase in fishmeal, fish oil, and energy prices; and
- *climate change*: offshore aquaculture will be affected by the rising temperatures of the oceans.

The reduction in the aquaculture growth trend, together with an almost stable capture production, means that only an increase of 2.5% is estimated for the period of 2014–2023 (OECD & FAO 2014). This will lead to a rise in prices (Figure 1.5) since demand will increase at the same time not only by world population growth, but also by *per capita* consumption increase (from the 19.2 kg in 2011–2013 to 20.9 kg in 2023). Demand pressure has a tendency to be reduced

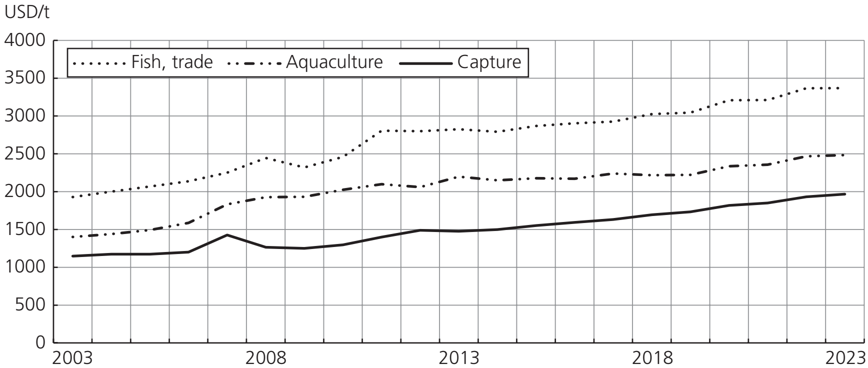

Figure 1.5 World fish price development in nominal terms between 2003 and 2023.
Source: OECD.

in the future because, even with the greater awareness of the general population towards the importance and great benefits of fish protein on human diet, the higher price of fish will lead to its substitution by other cheaper sources. Moreover, although the population rate is growing, that growth will tend to become slower (in the last 10 years the growth rate has fallen from 1.24% to 1.18%), which will also contribute to the deceleration of the demand pressure (UN 2015).

The world total fisheries production is projected to reach 181 million tons in 2022. In 2013, exports reached a new record of over US$ 136 billion, larger than the previous year by more than 5%. Despite the decline in the average growth rate projected for the 2013–2022 period, fish products will still be one of the most highly traded goods in the word with exports reaching 36% of total fishery production in 2022 (FAO 2014).

1.3 Hazard assessment in seafood

Hazards can be classified as one of three distinct categories: biological, chemical, and physical hazards. In the particular case of fish, biological hazards include pathogenic bacteria, viruses, and parasites. Chemical hazards refer to pesticides, polychlorinated biphenyls (PCBs), heavy metals, veterinary medicines, dioxins, polycyclic aromatic hydrocarbons, marine biotoxins and biogenic amines (including histamine; note that these are sometimes classified as biological hazards as in CAC 2003), allergens, chemical from materials in contact with foodstuffs, waste products, and cleaning compounds. Finally, physical hazards such as hooks, fishing nets, plastic, pieces of glass, wood, personal ornaments, and constituent pieces of equipment are commonly identified. These are all described in more detail in Sections 1.3.1–1.3.3 below.

In order to prevent foodborne illnesses caused by ingestion of food contaminated by pathogenic bacteria, both the WHO and the FDA advise cooking foods until they reach temperatures above 70°C (140°F) at the thermal center of the product (WHO 2006; FDA 2014).

1.3.1 Biological hazards

Pathogenic bacteria

Pathogenic bacteria are the main agents responsible for cases of infections/food poisoning. Food infections are characterized by ingestion of viable bacteria, which multiply inside the human body. On the other hand, food poisoning is caused by the ingestion of food previously contaminated with toxins produced by pathogenic bacteria, which are present in high numbers in food (Huss *et al.* 2004).

According to Huss *et al.* (2004), pathogenic bacteria associated with diseases caused by the ingestion of fish can be divided into three major groups:

- indigenous pathogenic bacteria of the aquatic environment: *Clostridium botulinum* (nonproteolytic type B, E, and F), *Vibrio* (*V. cholerae*, *V. parahaemolyticus*, and *V. vulnificus*), and *Plesiomonas shigelloides*;
- indigenous pathogenic bacteria of the general environment: *Listeria monocytogenes*, *Clostridium botulinum* (proteolytic type A and B), *Clostridium perfringens*, and *Bacillus spp.*; and
- indigenous pathogenic bacteria of humans and animals: *Salmonella spp.*, *Shigella spp.*, *Escherichia coli*, *Campylobacter jejuni*, *Yersinia enterocolitica*, and *Staphylococcus aureus*.

Although several factors can influence the growth rate of microorganisms, temperature is undoubtedly one of the most relevant. For that reason, the minimal growth temperatures of pathogenic bacteria associated with diseases caused by contaminated fish ingestion are listed in Table 1.2. It is clear from this set of data that there is no consensus regarding the minimum temperature needed for the growth of certain pathogenic bacteria; the lowest temperature should therefore be considered for the hazard analysis.

Escherichia coli

The genus *Escherichia* is a group of Gram-negative bacteria which are facultative anaerobics, mesophilic, rod-shaped organisms with an optimum growth temperature of 37°C (98.6°F) (Delgado 2006).

Escherichia coli belong to the family *Enterobacteriaceae*, and are one of the most predominant species in the intestinal tract of humans and warm-blooded animals as part of natural intestinal flora. In addition to being harmless to the host, this species provides multiple benefits such as prevention of gut colonization by various pathogenic bacteria (FDA 2012a). However, there is a small group of bacteria within the *E.coli* species that are pathogenic for humans. According to Huss *et al.* (2004), the main groups of *E. coli* responsible for cases of food poisoning are:

- enterotoxigenic *E. coli* (ETEC);
- enteropathogenic *E. coli* (EPEC);
- enterohemorrhagic *E. coli* (EHEC);

Table 1.2 Minimal growth temperatures of pathogenic bacteria associated with seafood

	Temperature (°C/°F)		
Microorganism	**FDA (2011)**	**Jay *et al.* (2005)**	**Huss *et al.* (2004)**
Clostridium botulinum (proteolytic, types A and B)	10/50	–	10/50
Clostridium botulinum (nonproteolytic, types B, E and F)	3.3/37.4	—	3.3/37.4
Clostridium perfringens	10/50	—	–
Vibrio cholerae	10/50	—	10/50
V. parahaemolyticus	5/41	5/41	5/41
V. vulnificus	8/46.4	–	8/46.4
Vibrio spp.	–	– 5/23	–
Plesiomonas shigelloides	–	–	8/46.4
Listeria monocytogenes	– 0.4/31.28	1/33.8	0–2/32–35.6
Salmonella spp.	5.2/41.36	7/44.6	5/41
Shigella spp.	6.1/42.98	–	6
Escherichia coli	6.5/43.7	–	7/44.6
Staphylococcus aureus	7/44.6	6.7/44.06	7/44.6
(toxin production)	10/50	–	10/50
Yersinia enterocolitica	– 1.3/29.66	– 2/28.4	– 1.3/29.66
Bacillus cereus	4/39.2	7/44.6	–

- enteroinvasive *E. coli* (EIEC);
- enteroaggregative *E. coli* (EAEC); and
- diffusely adherent *E. coli* (DAEC).

Of those groups, ETEC, EPEC, EIEC, and EHEC *E. coli* can be transmitted to humans through contaminated food and water. EHEC *E. coli*, more specifically *E. coli* serotype O157:H7, is more dangerous due to its ability to produce verotoxin (FDA 2012a). The most common symptoms associated with this serotype are hemorrhagic colitis and hemolytic uremic syndrome (FDA 2011).

When microbiological analyses of food products are performed, *E. coli* is commonly used as an indicator of fecal contamination with the possible presence of enteric pathogens.

Staphylococcus aureus

Bacteria of the genus *Staphylococcus* are generally Gram-positive, are of spherical shape (coconut), are immobile, and group themselves in the form of aggregates. *Staphylococcus aureus* belong to the family *Micrococcaceae* and have an optimum growth temperature between 35°C (95°F) and 37°C (98.6°F) (Delgado 2006). *S. aureus* are often found in soil, water, air, skin, and mucous glands of humans and warm-blooded animals, as well as in all surfaces that come into contact with them (Huss *et al.* 2004). Many *Staphylococcus* species, including coagulase-positive and coagulase-negative strains, have the ability to produce extremely heat-stable enterotoxins (FDA 2012a); however, according to Huss *et al.* (2004), this only occurs when bacterial concentrations exceed 10^6 CFU/g. The main symptoms of poisoning caused by *S. aureus* are abdominal pain, diarrhea, vomiting, nausea, weakness and, in some cases, death (FDA 2011).

Salmonella spp.

Bacteria belonging to the genus *Salmonella* are mesophilic, Gram-negative, movable, rod-shaped, non-spore-forming organisms that have their optimum growth temperature at about 37°C (98.6°F) (Delgado 2006). *Salmonella* belong to the family *Enterobacteriaceae* and can be found in the intestinal tract of humans and animals in general. This genus can be divided into two species that are pathogenic to humans: *Salmonella enterica* and *Salmonella bongori*. The first species constitutes a greater public health concern and is subdivided into six subspecies (FDA 2012a):

- *S. enterica* subsp. *enterica* (I);
- *S. enterica* subsp. *salamae* (II);
- *S. enterica* subsp. *arizonae* (IIIa);
- *S. enterica* subsp. *diarizonae* (IIIb);
- *S. enterica* subsp. *houtenae* (IV); and
- *S. enterica* subsp. *indica* (VI).

These can be further subdivided into more than 2500 known serotypes, such as *S. enterica* sp. *enterica* serotype Typhimurium (*S.* typhimurium). Depending on the serotype, *Salmonella* can cause two types of disease – nontyphoid and typhoid Salmonellosis – with the latter leading to a higher mortality rate (FDA 2012a). The main symptoms are high typhoid fever, headache, diarrhea or constipation and, in some cases, may lead to death (FDA 2011).

Listeria monocytogenes

Listeria monocytogenes are Gram-positive, facultative anaerobic bacteria, which occur in rod-shaped mobile cells (bacillus) due to the presence of flagella. *L. monocytogenes* belong to the family *Listeriaceae* and are ubiquitously distributed in nature (Huss *et al.* 2004; FDA 2012a). They can grow at 37°C (98.6°F) and are halotolerant and psychrotolerant (Huss *et al.* 2004). Seven species of *Listeria* are known; however, only *L. monocytogenes* is pathogenic to humans, which is the main cause of death from foodborne diseases. This species can be divided into 13 serotypes (1/2a, 1/2b, 1/2c, 3a, 3b, 3c, 4a, 4ab, 4b, 4c, 4d, 4e, and 7), with the majority of food infections associated with serotypes 1/2a, 1/2b, and 4b (FDA 2012a).

The main symptoms of infection by *L. monocytogenes* are flu syndrome, meningitis, septicemia, encephalitis, spontaneous abortion, and fetal death in the uterus. Pregnant women, newborns, and people with weak immune system are more susceptible to this type of bacteria (FDA 2011).

Vibrio parahaemolyticus

Bacteria of the genus *Vibrio* belong to the family *Vibrionaceae*, are generally found in marine environments and/or estuaries, and the majority of them require the presence of sodium chloride to grow (FDA 2012a). *V. parahaemolyticus* are

Gram-negative, rod-shaped (bacilli), facultative anaerobic, mesophilic bacteria. Not all pathogenic strains are characterized by the production of hemolysins (e.g., Thermostable Direct Hemolysin (TDH) and/or Thermo Stable Related Hemolysin (TRH)), responsible for the lysis of red blood cells (FDA 2012a). The most common symptoms are diarrhea, abdominal cramps, fever, headache, vomiting, chills, nausea, and primary septicemia (FDA 2011).

Of the 34 known *Vibrio* species, 13 are pathogenic to humans and *V. parahaemolyticus*, *V. cholerae,* and *V. vilnificus* are the main species associated with cases of foodborne illnesses caused by eating fish. It should be noted that all cases related to the presence of *V. parahaemolyticus* were caused by the consumption of fish (Huss *et al.* 2004).

Viruses

Viruses are small microorganisms (25–70 nm) that can only reproduce within a host; the number of viral particles in the food therefore remains constant. It is estimated that in the aquatic ecosystem there are approximately 10 thousand million viruses per liter of water, but none are pathogenic to humans.

Viruses associated with foodborne illness are called enteric viruses (originated in the gastrointestinal tract of humans) and their presence in fish is mainly due to poor hygienic conditions of food handlers or poor water quality (pollution of the aquatic environment with waste water) (Huss *et al.* 2004).

According to the FDA (2011), the main viruses associated with diseases caused by fish consumption are:

- *Norwalk* virus, which causes symptoms such as diarrhea, nausea, vomiting, abdominal cramps, headache, and a low-fever painful body; and
- Hepatitis A, for which symptoms include nausea, malaise, abdominal discomfort, anorexia, and jaundice.

When compared to pathogenic bacteria, these viruses exhibit a higher resistance to low temperatures; they are stable at refrigeration temperatures, and freezing temperatures only lead to a small increase in the rate of inactivation. Consumption of raw or undercooked bivalve mollusks, especially oysters, is the main source of viral contamination associated with fish (FAO & WHO 2010).

Parasites

Parasites are often found in seafood (with the exception of bivalve mollusks) and, according to the FDA (2011), these can be divided into three groups as follows.

- Nematodes (including *Anisakis spp*. and *Pseudoterranova spp.*): the *Anisakis simplex* and *Pseudoterranova decipiens* species are commonly found in fish. These parasites cause nausea, vomiting, diarrhea, severe abdominal pain, and may also penetrate the gut.
- Cestodes (e.g., *Diphyllobothrium spp.*): these cause symptoms such as abdominal pain, weight loss, and anemia.
- Trematodes (*Heterophyes spp.* and *Nanophyetes salmincola*): these cause abdominal pain and diarrhea.

Parasites are transmitted to humans through the consumption of raw or undercooked fish. Usually, heat treatment (60°C/140°F for 1 minute) is effective in the elimination of parasites present in food. Freezing can also be used for parasite elimination although its effectiveness depends on several factors, such as (FDA 2011):

- type of fish;
- type of parasite;
- temperature of freezing;
- time needed to freeze the fish; or
- the period of time during which the fish remains frozen.

According to Regulation (EU) No. 1276/2011, in order to eliminate the parasitic tapeworms and roundworms the fish should be submitted to a freezing treatment which consists of lowering the temperature in all parts of the fish to –20°C (–4°F) for at least 24 hours, or to –35°C (–31°F) for at least 15 hours. On the other hand, the FDA states that freezing and storing at an ambient temperature of –20°C (–4°F) or below for a total of 7 days, freezing at an ambient temperature of –35°C (–31°F) or below until solid and storing at an ambient temperature of –35°C (–31°F) or below for 15 hours, or freezing at an ambient temperature of –35°C (–31°F) or below until solid and storing at an ambient temperature of –20°C (–4°F) or below for 24 hours are sufficient to kill parasites (FDA 2011).

1.3.2 Chemical hazards

According to Huss *et al.* (2004), chemical compounds may or may not be toxic to human health, depending on their concentration. The most severe effects, such as neurological damage, birth defects, and/or oncological diseases, occur when the organism is exposed to low concentrations for a long period of time.

Environmental contamination with chemical compounds such as pesticides is a direct result of human activity. These compounds are present in low levels in lakes, rivers, seas, or oceans and accumulate particularly in fish by biomagnification (the concentration increases along the food chain from one trophic level to the next) or by bioaccumulation (concentration increases throughout the fish life by exposure to contaminated environments). The risk of contamination is relatively low in wild fish captured offshore, but increases in coastal locations or in fish originating from aquaculture as a result of human activity.

Pesticides

Pesticides are chemicals used in horticultural and agricultural soils to combat pests (e.g., insects) and pathogenic microorganisms and in aquaculture systems to eliminate weeds, algae, and invertebrates. These substances accumulate in fish and can be transmitted to humans through its ingestion (FDA 2011; WHO 2010d).

Pesticides can affect the nervous, cardiovascular, reproductive, and endocrine systems, the gastrointestinal tract, liver, and kidneys, and some may be carcinogenic (FDA 2011).

Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls are fat-soluble environmental contaminants which are able to produce persistent organic pollutants due to their chemical and physical properties, such as nonflammability, stability, high boiling point, low heat conductivity, and a high dielectric constant. These products are used as flame-retardants in paints, heat transfer systems, hydraulic fluids, lubricants, and dielectric fluids in capacitors and transformers, and are stored in adipose tissues of the body since their absorption occurs through the respiratory system, gastrointestinal tract, or skin. In order to reduce the levels of these products, the skin and trimming fat of fish exposed to them must be removed before cooking. Certain cooking procedures, such as using grills, can also minimize PCB exposure. This exposition causes neurobehavioral alterations, including abnormal reflexes, motor immaturity, slowed mental development, alteration in memory function, and decreased immunocompetence. In order to avoid the risk of PCB contamination, two professional groups – Physicians for Social Responsibility and The Association of Reproductive Health Professionals (ARHP) – recommend limiting the intake of fatty fish to one or two times per month (Sidhu 2003; Dovydaitis 2008).

Heavy metals

According to Huss *et al.* (2004), of the several heavy metals in the environment those exhibiting a greater concern to human health include arsenic, cadmium, lead, and mercury, as discussed in the following sections.

Arsenic

Arsenic is naturally distributed in the Earth's surface, usually as arsenic sulfides or arsenates and metal arsenides. This pollutant is released into the atmosphere as a result of natural activities (e.g., volcanic activity) and anthropogenic activities (e.g., burning of fossil fuels). Processes involving high temperatures mainly generate arsenic trioxide, an inorganic compound adsorbed by particles dispersed in the air. These particles are carried by wind and may be deposited in terrestrial and aquatic ecosystems (WHO 2010a).

Of the various arsenic compounds present in the environment, organic compounds (e.g., arsenobetaine) have lower toxicity to living organisms. In fish there is a predominance of arsenobetaine. However, there are no current studies that prove the absence of inorganic compounds in the foodstuff as well as the possible conversion of arsenobetaine into toxic compounds by the human body (Ahmed 1991).

Cadmium

Cadmium is a metal present in low concentrations in the environment and results from various human activities, such as the burning of fossil fuels and incineration of municipal waste, as well as natural activities (e.g., volcanic activity, weathering, runoff). The emergence of the industrial era increased the load of this and other metals used in industrial processes in the environment, resulting in higher levels of pollution from improper disposal of wastes after use in industry (James 2013).

This compound can be atmospherically transported over long distances and/or deposited in the soil and/or groundwater, accumulating rapidly in living organisms including mollusks and crustaceans. In fact, cadmium accumulates in different levels in mammalian kidneys, hepatopancreas and muscles of some mollusks, large swordfish, marlin, and tuna (James 2013). When accumulated in the kidneys, this metal can cause renal tubular dysfunction. Apart from the kidneys, this metal has toxic effects in the respiratory system and skeleton (James 2013). It is also considered carcinogenic, causing throat, kidney, and prostate cancer (WHO 2010b).

Lead

Lead is a heavy metal found in low concentrations on the Earth's surface mainly in the form of lead sulfide. This compound has a similar behavior to cadmium in terms of transport and accumulation.

This metal is responsible for neurological disorders, anemia, headache, irritability, lethargy, convulsions, muscle weakness, ataxia, tremors, and paralysis. In men, it affects the quality and quantity of sperm, whereas in pregnant women it can cause miscarriage, fetal death, pre-term birth (low birth weight), and birth defects. Lead is also considered carcinogenic (WHO 2010e).

Mercury

Mercury is a reactive heavy metal emitted from natural sources (e.g., volcanoes, forest fires) and human sources (e.g., coal-fired electric power plants, gold mining, industrial boilers, chlorine production, waste incineration). It is present in nature in various forms, including elemental, organic compounds (e.g., methyl mercury and ethyl mercury), and inorganic compounds (e.g., mercuric chloride). Elemental mercury is present in a liquid state at room temperature; however, due to its high volatility, it easily passes to the gas phase. This gas remains in the atmosphere and can be deposited in the aquatic environment (e.g., rivers, lakes), where it is transformed into methyl mercury.

Mercury in the Earth's crust is mostly in the inorganic form, but once in the aquatic environment it can change to methyl mercury. This form is soluble, mobile, and quickly enters the aquatic food chain, accumulating in a greater extent in biological tissues than inorganic forms of mercury, and constitutes over 90% of the total mercury detected in fish (James 2013). Methyl mercury is absorbed by phytoplankton and accumulates in fish, primarily in the predatory species that have a longer lifetime, such as shark and swordfish. Methyl mercury follows the food chain passing through bacteria, plankton, macro invertebrates, herbivorous fish, piscivorous fish, and finally humans (Dovydaitis 2008). Worldwide emissions, natural sources, and the environmental half-life of the compound preclude short-term reductions, although it may be possible to reduce global average methyl mercury concentrations in fish in the long term (James 2013).

Increased levels of fish consumption during pregnancy and lactation have been linked to a significant reduction in incidences of pre-term labor and delivery, the risk of intrauterine growth restriction, and pregnancy-induced hypertension, and are also associated with increases in a child's intelligence quotient (IQ) (Sidhu 2003). Nevertheless, both elemental mercury and methyl mercury exhibit high toxicity to the central and peripheral nervous systems because mercuric ions concentrate in the brain. All forms of mercury can cause neurological and behavioral disorders, among which memory loss and cognitive and motor dysfunction stand out, particularly in children. It can also cause seizure disorders, blindness and choreoathetosis (Dovydaitis 2008). When pregnant women ingest food contaminated with methyl mercury, this metal can lead to the development of neurological disorders in the fetus including mental retardation, seizures, vision and hearing loss, developmental delay, speech disturbances, and memory loss (WHO 2007).

Veterinary medicines

In recent years there has been a significant increase in the use of veterinary drugs in the aquaculture system. These accumulate in the edible parts of fish and are transmitted to humans through the ingestion of food (Huss *et al.* 2004). In aquaculture systems, the use of veterinary medicines has the following main objectives (Huss *et al.* 2004; FDA 2011):

- prevention and treatment of diseases in fish caused by a wide variety of pathogenic bacteria, such as *Aeromonas hydrophila*, *A. salmonicida*, *Edwardsiella tarda*, *Pasteurella piscicida*, *Vibrio anguillarum*, *V. salmonicida*, and *Yersinia ruckeri*;
- control of the growth and reproduction of fish; and
- control of parasites.

The use of pharmacologically active substances in veterinary medicines is commonly controlled and regulated by authorities. Even when their use is allowed, there are maximum levels of its presence in various foodstuffs that must be complied with. In the European Union for example, pharmacologically active substances are regulated by Regulation (EU) No. 37/2010 (EC 2010).

Veterinary drugs may cause allergies and intestinal flora modifications, and reduce the efficacy of antibiotics in the treatment of infections due to acquired resistance (Huss *et al.* 2004).

Dioxins

Dioxins are toxic chemical compounds formed during the combustion of organic compounds in the presence of chlorine. The term dioxin includes 75 polychlorinated dibenzo-para-dioxins (PCDDs), 135 polychlorinated dibenzofurans (PCDFs), and 12 polychlorinated biphenyls (PCBs) in the form of dioxins, all presenting a similar mechanism of action and toxicological properties (EFSA 2010; WHO 2010c).

Using several routes such as air, soil, and water, dioxins and dioxin-like PCBs cause environmental contamination to reach the food chain (Sidhu 2003). The main source of contamination of the environment and foodstuffs results from dioxin release from industrial plants, where food consumption is the main form of exposure of humans. According to Sidhu (2003) about 95–98% of human exposure comes from the food supply, mostly from products of animal origin (e.g., dairy products, seafood, meat). These compounds remain for long periods of time in the atmosphere, soil, and aquatic ecosystems, therefore considered persistent organic compounds (POPs), and accumulate in food with high fat content (such as fish) due to their low solubility in water (WHO 2010c).

Dioxins can affect the developing nervous system, thyroid, and reproductive functions (WHO 2010c).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are compounds formed during incomplete combustion, pyrolysis of organic matter, or even as a result of thermal processing. PAHs have a high persistence in the environment and can contaminate aquatic ecosystems and accumulate in living organisms, particularly in fish. PAHs are considered carcinogenic and genotoxic compounds (EFSA 2008).

Benzo(a)pyrene (BaP) is the most-studied aromatic hydrocarbon and, when limits are defined, it can be used as a marker regarding the occurrence of carcinogenic PAHs in food.

Marine biotoxins

Marine biotoxins are toxic substances produced by certain marine algae (phytoplankton), indigenous bacteria from the aquatic environment such as *Vibrio alginolyticus*, *Bacillus* spp., and *Pseudomonas* spp., and species of fish. In the first case, it is estimated that of the 4000 known species of seaweeds, only 70–80 species produce biotoxins. These toxins accumulate mainly in bivalve mollusks by filtration or may accumulate in certain species of fish when they ingest toxic algae or other previously contaminated species. Thermal processing, even at high temperatures such as frying, is usually not sufficient to eliminate biotoxins (Huss *et al.* 2004).

A description of the most common marine biotoxins in bivalve mollusks is provided in the following. The maximum legal limits for their presence can be found, for example, in Regulation (EC) No. 853/2004 and in the FDA's Fish and Fishery Products Hazards and Controls Guidance (EC & EP 2004; FDA 2011).

- Saxitoxins cause poisoning of the type Paralytic Shellfish Poison (PSP). Main symptoms of PSP are drowsiness, tingling, numbness, burning sensation on the lips and tongue extending to the face and hands, and lack of coordination of the hands, legs, and chest. In most severe cases, PSP can lead to respiratory arrest and death (FDA 2011).
- Domoic acid causes poisoning of the type Amnesic Shellfish Poison (ASP). This type of poisoning is responsible for symptoms such as nausea, vomiting, diarrhea, abdominal cramps, headache, and some neurological effects (e.g., loss of short-term memory, disorientation, dizziness, confusion). In more severe cases, seizures, coma, and death may occur (FDA 2011).

- Okadaic acid and dinophysistoxins cause poisoning of the type Diarrhoeic Shellfish Poisoning (DSP). This disorder is essentially responsible for gastrointestinal disorders, abdominal pain, nausea, vomiting, diarrhea, headache, and fever (FDA 2011).
- Azaspiracids cause poisoning of the type Azaspiracid Shellfish Poisoning (AZP). The main symptoms of AZP are abdominal pain, nausea, vomiting, and diarrhea (FDA 2011).

Apart from the marine biotoxins described above, the FDA also mentions other biotoxins including ciguatoxin, brevetoxin, and tetrodotoxin (FDA 2011). In the case of the EU, to prevent and control the occurrence of disease incidences related to the ingestion of shellfish contaminated with marine biotoxins, Regulation (EC) No. 853/2004 states that fish farmers can only harvest in production areas with locations and boundaries fixed by competent authorities (EC & EP 2004). Given the level of fecal contamination of bivalve mollusks, competent authorities classify the production areas as one of three categories (A, B, and C). Mollusks from Class A production areas can be placed directly into the market, whereas mollusks from Class B and Class C areas may only be marketed after decontamination in purification centers or relaying areas to reduce and/or eliminate contaminants (EC & EP 2004). According to the Regulation (EC) No. 854/2004, production and relaying areas should be regularly monitored by authorities that monitor, among others, the microbiological quality of live bivalve mollusks, the presence of toxin-producing plankton in the waters, and the presence of biotoxins in bivalve mollusks.

Histamine

Histamine is a biogenic amine called scombrotoxin produced in the *post-mortem* period of fish. This amine results from the decarboxylation of histidine (an amino acid present in high and variable amounts in fish) into histamine by the enzyme histidine decarboxylase. Once present in fish, this enzyme is responsible for the ongoing formation of histamine even at refrigeration temperatures. Its inactivation occurs at freezing temperatures, but it can be reactivated rapidly after thawing. It should be noted that histamine is not removed by thermal processing such as cooking (FDA 2011).

Histidine decarboxylase is produced by bacteria found in saltwater environments (e.g., *Vibrio* spp.) and can therefore be present on the surface or inside the fish body (gills, liver, and/or intestine) (FDA 2011). This enzyme may also be produced by bacteria that contaminate fish after being caught, such as *Clostridium perfringens* (Huss *et al.* 2004). The bacteria responsible for the production of the histidine decarboxylase are able to multiply over a wide temperature range, although a more rapid formation of histamine is achieved at higher temperatures (21.1°C/69.98°F or higher) than at moderate temperatures (7.2°C/44.96°F). In order to inactivate some of these bacteria, fish should be maintained at freezing temperatures. Bacteria and histidine decarboxylase enzymes are efficiently inactivated by thermal processing such as cooking (FDA 2011).

High levels of histamine are commonly found in fish species of the families *Scombridae*, *Clupeidae*, *Engraulidae*, *Coryfenidae*, *Pomatomidae*, and *Scombresosidae* (EC 2007). The consumption of fish contaminated with histamine causes tingling or burning around the mouth or throat, skin rash or hives, low blood pressure, headache, dizziness, itchy skin, nausea, vomiting, diarrhea, asthma, heart palpitations, and breathing problems (FDA 2011).

Allergens

There are certain components present in food which are capable of inducing an immune response. In the United States of America, the Food Allergen Labeling and Consumer Protection Act (FALCPA) (Public Law 107-282) that took effect on 1 January 2006 lists eight foods that are considered ‘major food allergens’ and should therefore be declared on food labels. The ‘Big Eight’ are: milk, eggs, fish, crustacean shellfish, tree nuts, peanuts, wheat, and soybeans (Helm & Burks 2009). The *Codex Alimentarius* Commission issued general standards for the labeling of packaged food and listed the same eight substance categories (CAC 2010).

Due to the fact that the prevalence of food allergy varies in different countries, some governments have added additional foods to the list of ingredients that must be declared on food labels (Helm & Burks 2009). For example, the European Union has a list of 14 allergenic substances, which can be found in Regulation (EU) No. 1169/2011. The list includes (EC & EP 2011):

- cereals containing gluten and products based on these cereals;
- crustaceans and crustacean-based products;
- eggs and egg-based products;
- fish and fish-based products;
- peanuts and peanut-based products;
- soybeans and soybean-based products;
- milk and milk-based products (including lactose);
- nuts and nut-based products;
- celery and celery-based products;
- mustard and mustard-based products;
- sesame seeds and sesame-seed-based products;
- sulfur dioxide and sulfites in concentrations higher than 10 mg/kg or 10 mg/L expressed as total SO_2;
- lupin and lupin-based products;
- mollusks and mollusk-based products.

Allergens cause tingling in the mouth, swelling of the tongue and throat, difficulty in breathing, hives, vomiting, abdominal cramps, diarrhea, low blood pressure, loss of consciousness and, in the most severe cases, death (FDA 2011).

Food additives

In accordance with the General Standard for Food Additives (FAO & WHO 2014), a food additive can be defined as:

> 'any substance not normally consumed as a food by itself and not normally used as a typical ingredient of the food, whether or not it has a nutritive value, the intentional addition of which to food for a technological (including organoleptic) purpose in the manufacture, processing, preparation, treatment, packing, packaging, transport or holding of such food results, or may be reasonably expected to result (directly or indirectly), in its by-products becoming a component of or otherwise affecting the characteristics of such foods'.[2]

Food additives can be used as preservatives, antioxidants, acidity regulators, and acidifiers. Those that represent minimum toxicological concerns, such as calcium carbonate or lactic acid, can be added to the vast majority of processed food, while the use of those which pose a greater risk for the health of consumers should be limited (EC 2011).

In the General Standard for Food Additives, a list of food additives that can be used in foods, which product category they may be used in, and their maximum concentration in the product is provided. The Australian New Zealand Food Standards Code (Standard 1.3.1 Food Additives, Volume 2) also has a list of products in which food additives can be used and which food additives are allowed to be used in each of the products. In the European Union the safe food additives list is provided in Regulation No. 1333/2008 and respective amendments (in particular Regulation (EU) No. 1129/2011). In this regulation a list of additives that are allowed in fish and fishery products can be found, for example sulfur dioxide (sulfites in crustaceans are used as a way to prevent the formation of 'black spot') (FDA 2011). Regular consultation of these lists is recommended as they are frequently updated.

When an overdose of both authorized and unauthorized food additives occurs, foods become unsafe for human consumption. Additives can cause hypersensitivity reactions or food intolerance, tingling sensation in the mouth, swelling of the tongue and throat, breathing problems, hives, vomiting, abdominal cramps, and diarrhea. Some additives may also be carcinogenic (FDA 2011).

Plastic materials and objects in contact with foodstuffs

Chemical compounds from plastic materials and objects that can migrate to food are considered chemical hazards. In this sense, it is important not to use substances that can constitute a hazard to human health as a constituent of plastic materials that are in contact with food products.

There are several published standards that identify those substances. For example, in 2008 the Chinese Ministry of Health (MOH) published the GB 9685-2008 *Hygienic Standard for Use of Additives in Food Containers and Packaging Materials*, which contains over 1500 substances approved to be used in China.

The European Union has also published a list of authorized substances in the manufacture of plastic layers in plastic materials and articles in Regulation (EU) No. 10/2011 and respective amendments (in particular, Regulation (EU) 2015/174).

[2] According to the standard, this definition does not include contaminants or substances added to food for maintaining or improving nutritional qualities.

According to this Regulation, packaging materials contain plastic additives and monomers, especially vinyl chloride (a substance considered carcinogenic that, by polymerization, yields polyvinyl chloride). It should also be taken into account that the plastic can be printed, coated or held together by adhesives.

Waste products from chemical cleaning agents and equipment

Among all products for cleaning and disinfection, biocidal products used in the fight against pests stand out. Only active substances authorized for the purpose should be present in their composition (in the case of the EU, these substances are regulated by (EC) No. 528/2012).

In case of errors in the dosage of biocidal products or poor elimination, surfaces that come into contact with food can become contaminated with residues of these products, constituting a source of food contamination.

Chemical components of some equipment, such as lubricating oils, are also considered chemical hazards. The presence or prohibition of some constituents is currently not internationally consensual, but it is possible to find a reference in the published FDA Code of Federal Regulations Title 21, Sec. 178.3570 (FDA 2013) list. Excessive use of lubricants or lubricants manufactured with the use of unauthorized substances poses a danger to public health.

1.3.3 Physical hazards

Any foreign material not normally found in food and which is potentially dangerous to consumers is considered a physical hazard. There are many physical dangers that can be present in the raw materials such as hooks, fishing nets, plastic pieces, or pieces of glass and wood, or may originate from processing such as pieces of equipment and personal adornments.

The consumption of food adulterated by the presence of foreign bodies can result in serious injuries such as cuts in the mouth, throat, stomach, and intestines and broken teeth. In some situations, the outcome can be suffocation and death (FDA 2011).

1.4 Risks and benefits of seafood consumption

Although seafood is widely considered by the general population as a nutritional and healthy product – especially since brands started to emphasize the presence of ω-3 and its benefits – knowledge of most of the risks associated with seafood is not so common. Another interesting aspect of seafood, and even less known, is its contribution to the evolution of the human brain.

1.4.1 Seafood at the beginning of modern human brain

Before exploring the balance between the most common/measurable benefits and the risks associated with seafood, it is important to discuss what could be referred to as ‘The Original Benefit’. It is known that *Australopithecus* spp. evolved over 3 million years, but despite that it had a brain volume of about 500 cm^3 and almost no increase in the encephalization quotient (EQ), that is, the quotient between brain and body size. Conversely, *Homo sapiens* had an estimated brain volume of 1250 cm^3 and in just 1 million years, between *Homo erectus* and *Homo sapiens*, the EQ doubled (Crawford *et al.* 1999). How can this sudden increase be explained? In fact, the evolution of the brain was not vital for survival, and actually made it dependent on energy and some minerals. Even today there is still a large percentage of the population that do not consume sufficient vital nutrients for brain development. What factor could be responsible for a nonlinear Darwinistic evolution where natural selection acts to preserve and accumulate small advantages?

The fact that the earliest *Homo sapiens* individuals found in Africa are associated with lake and marine environments, and the fact that they exploited those shorelines as an accessible food source, could be involved in the genesis of the encephalization sudden growth. It is now known that the human brain is dependent on docosahexaenoic acid and requires high energy consumption, especially in infants when, at the term of birth, 74% of the energy intake is used by the growing brain (Cunnane & Crawford 2003). A diet where seafood was included could not only provide the energy and nutrients necessary for brain growth but also reduce the obligation of hunting or making of complex tools, benefiting those less fit to perform these tasks. This way, the early hominids could divert more energy from travelling in search of food to brain and other activities such as social interaction, making tools, or developing strategies to kill prey (also made possible by the increasing sophistication of the brain).

1.4.2 Benefits and risks

The main constituents of fish, the health benefits that consumers can enjoy by its consumption, and the risks that they are exposed to were discussed in Sections 1.1 and 1.3. The exposure to these risks/benefits is widely dependent not only on the amount consumed, but also on the particular species and size of the fish and even on the production method (harvest/aquaculture). In recent years, several research articles have been published based on risk or benefit assessment of seafood consumption in order to support or contradict the recommendations of national food safety agencies, generally encouraging seafood consumption (Sidhu 2003; Cohen *et al.* 2005; Mozaffarian & Rimm 2006; Torpy 2006; Dovydaitis 2008; FAO & WHO 2011; James 2013).

In most studies the balance was between the benefits of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), and the risks of methyl mercury and/or dioxins. The challenge in performing quantitative analyses is to define how much each benefit/risk affects the human health; when both negative and positive effects are balanced, an overall positive or negative result can therefore be defined. For instance, Cohen *et al.* (2005) expressed the effects in terms of quality-adjusted life year (QALY), a measure of health damage that takes into account changes in longevity and quality of life. A set of five scenarios was considered, and in only

Table 1.3 Number of fish servings per week recommended by different food safety agencies

Food Safety Agency	Country	Servings/week	Year recommendation made
SACN/COT	UK	General population: 4. Women in reproductive age, pregnant women and children under 16: 2 (1 serving/1 oily fish)	2004
EFSA	EU	General population: 1–2 up to 3–4 during pregnancy. Pregnant women: avoid some species with high mercury levels	2014
FDA/US EPA; AHA	USA	2–3	2014
Health Canada	Canada	2	2007
FSANZ; AHF	Australia; New Zealand	2–3 of most types of fish. Exception for some types of fish with high levels of mercury, especially for pregnant women.	2011
MHLW	Japan	Limit consumption of some species, especially for pregnant women and children	2005
WHO/FAO	–	1–2	2008

one there was a recommendation to reduce seafood consumption during the years of child-bearing age.

More recently, the FAO Globefish Research Programme (James 2013) released the Risks and Benefits of Seafood Consumption report, which concludes that proven benefits of seafood consumption far outweigh the possible risks. Once again, the benefit of DHA+EPA *versus* the risk of methyl mercury and dioxins was compared. A methodology was developed using numerical indices that quantified the intelligence quotient points gained/lost by children from the effect of DHA+EPA/methyl mercury, respectively. In the case of dioxins, the effect in the increase of cancer risk associated with contaminated seafood intake was quantified and compared with the benefits of DHA+EPA in mortality reduction from coronary heart disease. In both cases, seafood was classified according to its content of EPA+DHA, methyl mercury, and dioxins, and for each possible combination the positive and negative effects were compared. Only in cases of excessive consumption of a few species did the risks exceed the benefits.

Overall, none of the food safety agencies discourage fish consumption. For the biggest international organizations in the world, the total number of fish portions recommended varies from one to four portions per week with two portions per week being the most consensual number. The number of fish portions/week recommended by the principal food safety agencies are listed in Table 1.3.