

FOOD SAFETY ISSUES ASSOCIATED WITH PRODUCTS FROM AQUACULTURE

Report of a
Joint FAO/NACA/WHO Study Group



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The past decade has seen rapid expansion in aquaculture production. In the fisheries sector, as in animal production, farming is replacing hunting as the primary food production strategy. In future, farmed fish will be an even more important source of protein foods than they are today, and the safety for human consumption of products from aquaculture is of public health significance.

This is the report of a Study Group that considered food safety issues associated with farmed finfish and crustaceans. The principal conclusion was that an integrated approach — involving close collaboration between the aquaculture, agriculture, food safety, health and education sectors — is needed to identify and control hazards associated with products from aquaculture. Food safety assurance should be included in fish farm management and form an integral part of the farm-to-table food safety continuum. Where appropriate, measures should be based on Hazard Analysis and Critical Control Point (HACCP) methods; however, difficulties in applying HACCP principles to small-scale farming systems were recognized. Food safety hazards associated with products from aquaculture differ according to region, habitat and environmental conditions, as well as methods of production and management. Lack of awareness of hazards can hinder risk assessment and the application of risk management strategies to aquaculture production, and education is therefore needed.

Chemical and biological hazards that should to be taken into account in public health policies concerning products from aquaculture are discussed in this report, which should be of use to policy-makers and public health officials. The report will also assist fish farmers to identify hazards and develop appropriate hazard-control strategies.

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Bangkok, 22–26 July 1997

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1. Introduction

A Joint FAO/NACA/WHO Study Group on Food Safety Issues associated with Products from Aquaculture met at the headquarters of the Network of Aquaculture Centres in Asia-Pacific (NACA) in Bangkok, Thailand, from 22 to 26 July 1997. The meeting was opened by Mr Dhammarong Prakobboon, Director-General of Fisheries, Thailand, and was also addressed by Mr Dong Qingsong, Deputy Regional Representative of FAO, Dr Kitjar Jaiyen, Chairman of the NACA Governing Council, and Dr E.B. Doberstyn, WHO Representative in Thailand.

The address by Mr Prakobboon emphasized the significance of the fisheries sector to Thailand and the growing importance of aquaculture as a source of nutritious foods and high-quality export products. In Thailand, the aquaculture of fish, shrimp, molluscs and other marine and freshwater animals is a very important rural activity accorded a high level of priority by the government with respect to both food security and international trade. Thailand is very active in international efforts to ensure the quality of food, including products from aquaculture, and the meeting was timely in further strengthening such efforts to enhance product quality for domestic consumers and increase international competitiveness. He confirmed his continued support of NACA and its efforts to provide guidelines to governments and farmers in sustainable aquaculture, thanked FAO and WHO for supporting the Study Group and looked forward to further cooperation in this field.

Dr Jaiyen described the Study Group as one of the priority activities of the five-year work programme of NACA, covering the period 1996–2000. He welcomed the Study Group as an opportunity to develop practical recommendations to help governments and farmers in the NACA region increase the production of high-quality products and enhance international trade opportunities. He urged the Study Group to develop a stepwise programme for assisting farmers and governments. The NACA work programme is intended as a cooperative programme within which concerned agencies and institutions can work as partners to assist the region's aquaculture development. The NACA Chairman looked forward to a continuing cooperation with WHO and FAO for the benefit of the peoples in the Asian-Pacific region.

Dr Doberstyn explained that foodborne diseases are a major public health problem that cause considerable morbidity and mortality worldwide. The 1992 FAO/WHO International Conference on Nutrition recognized that hundreds of millions of people worldwide suffer

from communicable and noncommunicable diseases caused by contaminated food. These diseases take a heavy toll in human life and cause much suffering, particularly among infants and children, the elderly and other susceptible individuals. They also place an enormous social, cultural and economic burden on communities and their health systems. Low-income food-deficit countries,¹ where poverty and malnutrition are common, bear the brunt of these diseases.

Mr Dong Qingsong noted the increasing contribution of products from aquaculture to world food security. FAO, together with WHO, has promoted the application of the Hazard Analysis Critical Control Point (HACCP) system for controlling foodborne safety hazards. FAO has undertaken many training and research projects for the global adoption of the HACCP system, particularly in developing HACCP-based fish inspection systems.

1.1 Background

Aquaculture is currently one of the fastest growing food production sectors in the world. Its increasing global importance is directly related to the contribution it makes to reducing the gap between supply and demand for fish products. With over-exploitation in the fisheries sector in some regions, initiatives to strengthen environmentally sound and sustainable aquaculture development, particularly among small-scale producers, need to be pursued to ensure a maximum contribution to world food security, as recognized by FAO (1). Approximately 90% of global aquaculture production is in Asia, where it provides an important source of dietary protein as well as income for many small-scale farmers. Commercial aquaculture contributes significantly to the economies of many countries, since high-value species are a major source of foreign exchange.

Fish and crustaceans are generally regarded as safe and nutritious foods, but products from aquaculture have sometimes been associated with certain food safety issues, as the risk of contamination by chemical and biological agents is greater in freshwater and coastal ecosystems than in open seas. There are many different methods of farming fish, ranging from intensive commercial operations to extensive small-scale or subsistence systems, and food safety hazards vary

¹ For a country to be classified by FAO as a low-income food-deficit country, it should have a per-capita annual income below the ceiling used by the World Bank to determine eligibility for certain forms of assistance (set at US\$ 1505 for 1996). Second, its food-trade position (i.e. food exports minus food imports) should be negative when averaged over the preceding three years. Finally, a country meeting both of the above criteria should not have specifically requested to be excluded from the low-income food-deficit category.

according to system, management practices and environment. Foodborne trematode infections and foodborne disease associated with pathogenic bacteria, residues of agrochemicals and veterinary drugs, and heavy-metal contamination have all been identified as hazards. The origins of such food safety concerns are diverse, ranging from inappropriate aquacultural practices to environmental pollution and cultural habits of food preparation and consumption. Thus, as aquaculture makes its transition to a major food-producing sector, proper assessment and control of any food safety concerns are becoming increasingly important.

1.2 **International initiatives related to food safety and aquaculture**

In 1993, WHO convened a Study Group on the Control of Foodborne Trematode Infections (2). The Study Group concluded that fish farming was continuing to grow rapidly in economic importance worldwide and that the consumption of raw or inadequately processed products from aquaculture was not without health risks. Fish ponds could be an excellent habitat for parasites and pathogenic bacteria originating from contamination with human and animal excreta or their use as fertilizers in aquaculture. In view of the lack of public-health guidelines or food safety advice related to aquaculture, WHO, in collaboration with FAO and NACA, decided to convene a Study Group exclusively devoted to food safety issues associated with products from aquaculture.

In 1995, the FAO Conference adopted the Code of Conduct for Responsible Fisheries, which advocates food safety and high quality for products from aquaculture. Article 9, “Aquaculture Development”, and in particular the provisions for “Responsible Aquaculture at the Production Level”, addresses the need for safe and effective use of feeds, feed additives, fertilizers, manure, chemotherapeutants and other chemicals. Governments are called upon to ensure the safety of products from aquaculture and to promote efforts to maintain product quality.

1.3 **Scope of the Study Group**

The Study Group considered food safety issues associated with farmed finfish and crustaceans, particularly biological and chemical contamination that may occur during production. It considered the quantification of hazards and measures for the control of potential food safety hazards, including current national and international programmes. The Study Group did not address occupational hazards or food safety issues associated with farmed molluscan shellfish.

1.4 Objectives of the Study Group

The objectives of the Study Group were:

- to review available information on food safety hazards associated with finfish and crustacean products from aquaculture;
- to determine geographical and temporal changes in aquaculture production practices and determine the significance and severity of risks posed by the identified hazards in relation to specific aquaculture systems and post-harvest handling and consumption patterns;
- to evaluate options for implementing risk management strategies to reduce or eliminate risks associated with products from aquaculture systems in coastal, brackish-water and inland-freshwater habitats;
- to recommend follow-up actions to address the needs identified by the Study Group, including any specific requirements for capacity building and financial and technical assistance to implement and monitor food safety measures.

2. Global aquaculture production and food supply

2.1 Definition of aquaculture

The current FAO definition of aquaculture is the “farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, and protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licences, are the harvest of fisheries.” (3).

2.2 Global production

FAO has compiled detailed statistics for aquaculture production for the period 1984–1993 and provisional statistics for 1994–1996 (3). These data show that aquaculture production of fish and shellfish increased from 6.94 million tonnes in 1984 to 22.8 million tonnes in 1996, a threefold increase amounting to an average increase of 1.24 million tonnes/year. The average increase in the quantity of fish destined for human consumption caught from wild stocks during this

period was 0.65 million tonnes/year. In 1996 aquaculture accounted for 26% of the total quantity of fish and shellfish destined for human consumption. The rate of increase in aquaculture production is rising, and in the period from 1990 to 1996 the average increase was 1.81 million tonnes/year. This rapid growth in the aquaculture sector contrasts with near stagnation in the growth of supplies from wild stocks, and indications are that aquaculture will continue to make increasing contributions to fish supplies over at least the next few years.

According to the same FAO publication, of production in 1993, 68% was finfish, 7% crustaceans (mostly shrimp raised in brackish water) and 25% molluscs, predominantly marine bivalves. Of the finfish, approximately 90% were raised in fresh water. Asia, which has the longest tradition in aquaculture, currently accounts for around 90% of total aquaculture production, mostly extensive cultivation in freshwater systems, followed by Europe (5%), North America (2%), South America (1.5%), the countries of the former USSR (0.6%), Oceania (0.35%) and Africa (0.3%). Table 1 summarizes the production of the principal producers in 1995. The importance of Asia as a region of production, and, within Asia, of freshwater finfish as a product, has a significant bearing on the global incidence of the human health problems associated with products from aquaculture. Approximately 87.1% of total aquaculture production was from developing countries and 76.8% from low-income food-deficit countries. The latter group produced 83% of total farmed finfish, 79% of total farmed aquatic plants, 61% of total farmed molluscs, and 58% of total farmed crustaceans.

Table 1
Global aquaculture production by principal producers, 1995

Rank	Producer	Production (million tonnes)	% of global production
1	China	17.6	63.4
2	India	1.61	5.8
3	Japan	1.40	5.1
4	Republic of Korea	1.02	3.7
5	Philippines	0.81	2.9
6	Indonesia	0.72	2.6
7	Thailand	0.46	1.7
8	USA	0.41	1.5
9	Bangladesh	0.32	1.2
10	Taiwan, China	0.29	1.0
11	Norway	0.28	1.0
12	France	0.28	1.0

Source: reference (3)

2.3 Farming systems and feeding practices

At present about 70–80% of the total global production of farmed finfish and crustaceans takes place within extensive and semi-intensive farming systems. In such systems, fish are raised in earthen ponds, pens and cages, rice fields or small water bodies at low (extensive) to moderate (semi-intensive) densities and farming input levels. Tables 2 and 3 show the principal inland and coastal farming systems currently employed for the production of finfish and crustaceans. There are no comprehensive global statistics on the production of the major species groups within the farming systems listed in these tables.

The systems listed in Tables 2 and 3 generally fall into one of the following categories with respect to the supply of exogenous inputs:

- No exogenous input use (i.e. extensive feed management).
- The application of fertilizers to augment or stimulate the natural production of food organisms for consumption by the cultured

Table 2
Principal inland aquaculture systems for finfish and crustaceans

Physical environment	Type of management/ input	Climate	Fish
Rice fields and swamps	Extensive or semi-intensive	Tropical	Tilapia, cyprinids, crayfish
Ponds	Extensive	Tropical	Cyprinids
	Semi-intensive mono- or polyculture	Tropical, temperate	Cyprinids, catfish, tilapia, prawns
	Semi-intensive small-scale integrated/nightsoil, agricultural by-products and livestock manure	Tropical	Cyprinids, tilapia
	Semi-intensive/livestock manure and fish	Tropical	Cyprinids, tilapia
	Semi-intensive/wastewater	Tropical	Cyprinids, tilapia
	Semi-intensive/nightsoil	Tropical	Cyprinids, tilapia
	Intensive	Tropical, temperate	Cyprinids, tilapia salmonids
Tanks and raceways	Intensive/formulated feed	Tropical, temperate	Cyprinids, catfish, tilapia, salmonids, prawns, shrimp
	Intensive	Tropical, temperate	Salmonids, catfish, cyprinids, tilapia
Cages	Semi-intensive	Tropical	Tilapia, cyprinids
	Intensive	Tropical, temperate	Tilapia, cyprinids, salmonids
	Intensive/formulated feed	Tropical, temperate	Salmonids, tilapia
Pens	Extensive or semi-intensive	Tropical (Philippines)	Milkfish, tilapia

Table 3

Principal coastal aquaculture systems for finfish and crustaceans

Physical environment	Type of management/ input	Climate	Fish
Ponds	Extensive	Tropical	Shrimp
	Semi-intensive mono- or polyculture	Tropical	Shrimp, milkfish, mullets, tilapia
	Intensive/formulated feed	Tropical	Shrimp, milkfish, eels
Tanks and raceways	Intensive/formulated feed	Tropical, temperate	Salmonids, bass, eels, flatfish
Cages	Intensive/trash fish	Tropical, temperate	Bass, groupers
	Intensive/formulated feed	Temperate	Salmonids, mullets, bass

species (i.e. semi-intensive feed management). Such fertilizers range from inorganic and organic chemical fertilizers to fresh or processed animal manure, composted plant material, nightsoil and wastewater.

- The supply of supplementary feed for direct consumption by the cultured species, ranging from simple agricultural by-products (e.g. rice bran) to a combination of ingredients in the form of a mash or pellet. Supplementary feeds are generally used with fertilizers (i.e. semi-intensive feed management).
- The provision of a nutritionally complete feed, in the form of either a compound fish feed or trash fish (i.e. intensive feed management).

The most common method of producing low-value freshwater fish in developing countries, especially low-income food-deficit countries, is to use a combination of fertilizer application and supplementary feed. Moreover, polyculture of species with complementary feeding habits is general practice, in order to optimize feed utilization within the pond ecosystem. Polyculture is common in farming of the Chinese and Indian major carps.

The patterns of aquaculture production are changing rapidly. Recent years have seen increased use of traditional semi-intensive farming systems, particularly in rural Asia. Although still largely based on integrated¹ and wastewater-fed systems,² improvements in sanitary practices are leading to a reduction in the use of nightsoil as fertilizer.

¹ Integrated farming systems use the waste of one process as an input for another: e.g. the placement of chicken pens above fish ponds so that the bird manure fertilizes the pond.

² Wastewater refers to domestic sewage and municipal wastewater that does not contain substantial quantities of industrial effluents.

The expansion of wastewater-fed systems in periurban areas is also increasingly constrained by urban development. Although it is estimated that less than 20% of the total finfish and crustacean production in developing countries is from intensive farming systems, there is a trend towards intensification, with increasing reliance on formulated feeds. Production in developing countries is divided between low-value staple-food species for domestic markets and high-value cash-crop species for export. More intensive animal production practices have led to an expansion of integrated animal/fish production systems in east and south-east Asia.

In contrast, over 65% of the total finfish production in developed countries is based on the intensive monoculture of high-value diadromous finfish. Such finfish (e.g. salmon) are raised in ponds, tanks or cages at high stocking densities and fed on manufactured complete diets (Tables 2 and 3).

3. **Food safety risk analysis**

Inherent in all human activities, including activities related to food production, are hazards that may adversely affect people's health. The identification of hazards and the determination of their relevance for health, as well as their control, is the function of risk analysis. Risk analysis is an emerging discipline in food safety, and the methodological basis for assessing, managing and communicating about risks associated with foodborne hazards is, at the international level, still developing. However, risk analysis is today widely recognized as the fundamental methodology underlying the development of food safety standards that both provide adequate health protection and facilitate trade in food.

The rules that govern international trade in food were agreed during the Uruguay Round of Multilateral Trade Negotiations and apply to all Members of the World Trade Organization (WTO). With regard to food safety, rules are set out in the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS agreement). According to the SPS agreement, WTO members have the right to take legitimate measures to protect the life and health of their populations from hazards in food, provided that the measures are not unjustifiably restrictive of trade. Such measures need to be based on risk analysis, and to take into consideration risk analysis techniques developed by relevant international organizations.

With regard to food safety, the relevant organization is the FAO/WHO Codex Alimentarius Commission (CAC). In order to facilitate

and harmonize risk analysis, the CAC has adopted a number of definitions. Risk analysis is a process consisting of three components: risk assessment, risk management and risk communication. The definitions of these three components as currently used by CAC can be found elsewhere (4).

There is a fundamental difference between a hazard and a risk. A hazard is a biological, chemical or physical agent in food, or a condition of food, with the potential to cause harm. In contrast, risk is an estimate of the probability and severity in exposed populations of the adverse health effects resulting from hazard(s) in food. Understanding the association between reduction in hazards associated with food and reduction in risk to consumers is of central importance in the development of appropriate food safety controls.

In the light of this association, the Study Group reviewed the biological and chemical hazards inherent in aquaculture products, along with their associated risks (sections 4 and 5); proposed strategies for food safety assurance applicable to the aquaculture sector (section 6); and identified research needs (section 7). The Study Group's conclusions and recommendations can be found in section 8.

4. **Biological hazards and associated risks**

4.1 **Parasites**

A large number of fish species, both marine and freshwater, are potential sources of medically important parasitic zoonoses. Some of these zoonoses are highly pathogenic, and the main cause of human infection is the consumption of raw or inadequately cooked fish. These infections are prevalent in only a few countries in the world and are found primarily among communities where eating raw or inadequately cooked fish is a cultural habit. Generally fish are the intermediate hosts of the parasites, and humans become the definitive host when the parasites are ingested. The principal human diseases are trematodiasis, cestodiasis and nematodiasis.

4.1.1 **Trematodiasis**

Fishborne trematodiasis are important diseases in various parts of the world. Although seldom fatal, trematodiasis can cause morbidity and complications leading to death. The cause of infection is the ingestion of viable encysted trematode metacercariae, which can be present in the flesh of raw, inadequately cooked or minimally processed freshwater fish. The two major genera of importance for human health are *Clonorchis* and *Opisthorchis*.

Clonorchiasis

Clonorchiasis, caused by *Clonorchis*, is endemic in some countries in East Asia, such as China (including Taiwan), the Republic of Korea, and northern Viet Nam (2, 5) but is not necessarily confined to these countries. Only one species, *C. sinensis*, is reported to cause human infections, and its distribution within endemic countries appears to be associated with snail hosts, particularly *Parafossarulus manchouricus* (2). Transboundary movements of infected fish have spread the disease beyond its original area of distribution.

In addition to humans, pigs, cats, dogs and rats serve as reservoirs of the parasite. Larvae are excreted by the hosts and ingested by freshwater snails. After multiplication, free-swimming cercariae are released from the snails and penetrate and form metacercarial cysts in fish muscle. More than 80 species of freshwater fish act as secondary intermediate hosts of *C. sinensis*, and about 70 species of Cyprinidae have been reported as hosts (2, 5), two species each from the families Ophiocephalidae and Eleotridae, and one each from the families Bagridae, Cyprinodontidae, Clupeidae, Osmeridae, Cichlidae, and Gobiidae, all of which are important in aquaculture. The traditional practices of building latrines above carp ponds and using nightsoil as fertilizer help to maintain infections in cultured fish populations (6, 7). Although recent reports indicate that farmed cyprinids are important hosts (8), there are no conclusive epidemiological data linking farmed cyprinids to clonorchiasis. However, the possibility of this link cannot be disregarded.

When ingested by humans, *Clonorchis* metacercariae excyst into the small intestine and migrate to the bile duct, where they cause clinical disease. The pathology of clonorchiasis has been extensively studied, and the infection has been implicated in recurrent pyogenic cholangitis, cholangiohepatitis and cholangiocarcinoma (2). The metacercariae can persist in fish muscle for a considerable time, for weeks in dried fish and for a few hours in salted or pickled products but are killed by adequate cooking (5, 9, 10). The disease can be effectively treated with praziquantel, administered orally at 60mg/kg body weight per day.

Opisthorchiasis

Opisthorchis viverrini and *O. felineus* are the trematodes responsible for opisthorchiasis in humans. The disease is endemic in communities that consume raw, minimally processed or inadequately cooked freshwater fish in Kazakhstan, the Lao People's Democratic Republic, the Russian Federation, Thailand and Ukraine, although it may not be confined to these countries (2). Snail species of the genus *Bithynia*,

predominantly found in rice fields in endemic areas, are the commonest first intermediate host. The pathogenicity, treatment and control of the two *Opisthorchis* species are similar to those of *C. sinensis*.

Although cyprinids are the principal intermediate fish hosts, none is known to be of importance to aquaculture. Consequently, the risk of acquiring opisthorchiasis by consumption of farmed fish is judged to be low.

Paragonimiasis

Paragonimiasis is endemic in China and the Republic of Korea and is present in Ecuador, Japan, Peru and countries in West Africa, but may not be solely confined to those areas (2). Some 40 species of *Paragonimus* have been reported, but by far the most common is *P. westermani*. The first intermediate snail host differs with locality and species of parasite, and the second intermediate host is generally a crustacean. Humans and various other mammals, especially those that feed on crabs, are the definitive hosts. The parasite infects the lungs, inducing symptoms often confused with tuberculosis. More people are affected by paragonimiasis than by clonorchiasis and opisthorchiasis combined (2).

The distribution of paragonimiasis is determined by many factors, such as the presence of certain snail species and crustacean hosts in the environment and dietary customs. However, there are no reports associating paragonimiasis with farmed crustaceans.

Intestinal trematodiasis

Heterophyiasis and echinostomiasis are enteric diseases caused by intestinal trematode parasites of the families Heterophyidae and Echinostomatidae. Several genera have been reported to cause disease, including *Heterophyes* and *Metagonimus*. *H. heterophyes* is prevalent in Egypt and the Philippines. Two species, *H. nocens* and *H. continua*, parasites of brackish-water fish, have been reported from humans in the Republic of Korea (11). Three morphological types/species of *Metagonimus* infect humans, and freshwater snails are the intermediate hosts. *M. yokogawai* is the most prevalent of all intestinal trematodes isolated from humans in the Republic of Korea and has also been reported in China, including Taiwan, and Japan.

The clinical symptoms of metagonimiasis and heterophyiasis are abdominal pain, diarrhoea, lethargy and anorexia. Infection may be mild and easily overlooked (11). In the Republic of Korea, almost all streams in the eastern and southern coastal areas are endemic foci of *Metagonimus*. Human infections are primarily attributable to eating

raw or inadequately cooked freshwater and brackish-water fish. Although infections of *Puntius gonionotus* with *Haplorchis* spp. in fish farms in northern Thailand have been reported (12), the risk of acquiring heterophyiasis from cultured fish species remains to be fully assessed.

4.1.2 **Nematodiases**

Fishborne nematodiases can be considered, in humans, as incidental infections with nematodes whose natural definitive hosts include marine mammals, birds and pigs. Second intermediate hosts can be marine, brackish-water or freshwater fish. The mode of infection is ingestion of fish containing infective larvae.

Capillariasis

Capillariasis caused by *Capillaria philippinensis* results in gastroenteritis and has been reported in Colombia, Egypt, Indonesia, the Islamic Republic of Iran, Italy, Japan, the Philippines, the Republic of Korea, Spain and Thailand. Most infected individuals had eaten raw small freshwater fish. Migratory fish-eating birds appear to be the natural definitive hosts and spread faeces contaminated with parasite eggs in freshwater fish ponds along migratory routes. Although capillariasis is generally a mild intestinal disease, untreated infections can be fatal. The disease can be effectively treated with oral mebendazole at a dose of 400mg/day for 20–30 days. To date no reports indicate any association between capillariasis and farmed fish (13).

Gnathostomiasis

Human gnathostomiasis is caused by *Gnathostoma spinigerum*. Larvae of the parasite are found in freshwater fish and frogs. The parasite has low host specificity and many species of copepods, amphibians, fish, birds and reptiles serve as intermediate and paratenic hosts. Consumption of raw, inadequately cooked or partially processed fish is the main mode of transmission to humans. The disease is characterized by eosinophilia and the presence of migratory swellings in different areas of the body. The only effective treatment is surgical excision of the worms.

Although many fish species of significance in aquaculture, such as snakeheads (*Channa* spp.), catfish (*Clarias* spp.), eels (*Anguilla* spp.) and carp (*Cyprinus* spp.), harbour *G. spinigerum*, there have been no reports linking the disease with products of aquaculture.

Anisakiasis

Anisakiasis is caused by larval ascaridoid nematodes whose normal definitive hosts are marine mammals. Fish are the secondary hosts

and become infected when they consume the invertebrate primary host or infected fish. The form parasitizing humans is the juvenile stage. The most common species causing disease in humans is *Anisakis simplex*. Other species causing anisakiasis in North America, Europe and Japan are *Pseudoterranova decipiens* and *Contracaecum* spp. (14).

Anisakiasis is uncommon in humans because the parasite is killed by normal cooking and by freezing (-20°C for 24 hours). There is some risk from fishery products consumed raw, for example sushi (the incidence of anisakiasis is 2000–3000 cases annually in Japan), or after only mild processing such as salting at low concentrations or smoking. Many countries now require that fish used for these mildly processed products be frozen before processing or sale. However, cooking and freezing may not protect against allergic reactions to ingested *A. simplex* antigens (15).

It has been reported that salmon farmed in Norway, Scotland and the USA do not harbour nematodes (16–18). This has been recognized by the European Commission, and farmed salmon from these countries are exempt from the provisions of the hygiene regulations that require minimally processed fish intended for consumption without cooking to be frozen before sale (19). This lack of infection is most likely a result of the salmon being artificially fed and not consuming naturally infected food. It must not be assumed that all farmed marine fish are free of nematode worms, since in the tropics cultured marine fish tend to be fed with raw fish. It has been reported that cage-cultured sea bass (*Lates calcarifer*), grouper (*Epinephelus suillus*) and snapper (*Lutjanus johni*) harbour anisakid nematodes (20). The source of infection may have been the fresh trash fish used as feed. However, the parasite species was not identified and its pathogenicity in humans not established.

4.1.3 **Cestodiasis**

In humans, cestode infections from the consumption of fish are not common. The cestodes that mature in the human small intestine are not very pathogenic and the diseases are never fatal. Diphyllbothriasis is the major human cestodiasis and is transmitted by various species of freshwater, marine and anadromous fish.

Diphyllbothriasis

Diphyllbothriasis is caused by the consumption of fish infected with the tapeworm *Diphyllbothrium latum*, found mainly in cold waters. Other species that have caused human infestation in Japan, the Republic of Korea and elsewhere include *D. yonagoense*, *D. pacificum*,

D. cameroni, *D. scoticum* and *D. hians* (21). Humans and fish-eating mammals are the definitive hosts, and freshwater copepods and fish are the intermediate hosts. The plerocercoid is present in fish flesh and infects humans following the consumption of raw, inadequately cooked or minimally processed fish. The recorded epidemiology of *D. latum* shows it to be prevalent in eastern Europe and the Russian Federation (22), and it has been reported elsewhere in the world (23). It has been estimated that there were 10 million carriers globally in 1947 (22) and 13 million in 1977 (24).

Diphyllobothriasis is not a serious disease and not usually notifiable to health authorities. However, in the USA the illness is thought to be much more prevalent than anisakiasis (25). Most reviews on diphyllobothriasis refer to the situation in the USA where salmon are the most common fish transmitting *D. latum*, although the parasite does not seem to be selective for the type of fish infected. Other *Diphyllobothrium* species, including species for which marine animals are the definitive and intermediate hosts, have been reported to cause illness in various parts of the world.

Considering the widespread distribution of *Diphyllobothrium* spp. in the world and their means of transmission, their presence in aquaculture systems cannot be ruled out. Fish become infected by consumption of either the first intermediate host or other infected fish. Although the incidence of infection might be expected to be considerably less in aquaculture systems using artificial feeds, *D. ditremum* has been found in cage-reared salmon in freshwater lakes in Europe, possibly due to opportunistic feeding (26). Infections can be treated with a number of anthelmintic drugs such as niclosamide, praziquantel, and paromomycin sulfate.

4.2 Bacteria

The hazards associated with human pathogenic bacteria in the finfish and crustaceans produced in aquaculture can be divided into two groups: bacteria naturally present in the aquatic environment, referred to as indigenous bacteria, and those present as a result of contamination with human or animal faeces, or otherwise introduced to the aquatic environment. Hazards may also arise through the introduction of bacteria during post-harvest handling and processing. Although the prevalence of bacterial pathogens appears to be higher in coastal and inland aquaculture environments than in the open seas, it is uncertain whether these differences affect the safety of products originating from the different areas.

4.2.1 *Enterobacteriaceae*

Pathogenic enterobacteria can be introduced into aquaculture ponds by animal (including bird) manure and human waste. However, there is evidence of the rapid die-off of enteric organisms and viruses in well-managed fish ponds (27). Despite this, significant numbers of organisms can be found in products harvested from waste-fed systems, and such products therefore pose a potential health risk (28).

Salmonella spp. are among the most important causes of human gastrointestinal disease worldwide and many seafood-importing countries will not accept products containing these pathogens. Studies have indicated that there is a higher prevalence of *Salmonella* in tropical than in temperate waters and, although seasonal variations occur, *Salmonella* spp. may be naturally present in some tropical aquatic environments. It is well established that aquatic birds spread these organisms and other pathogens in the environment (29, 30). *Salmonella* spp. have been reported in fish ponds: surveys have shown that 21% of Japanese eel culture ponds (31), 5% of North American catfish ponds (32), and 22% of shrimp ponds in one of the major shrimp-exporting countries in south-east Asia (33) are contaminated with the organisms. *Salmonella* spp. have been isolated from tropical aquaculture systems where faecal wastes are not used as fertilizer; this is most likely due to unavoidable contamination by scavenging birds and other animals. While *Salmonella* spp. tend to be associated with the intestinal tracts of warm-blooded animals, they have also been detected in the gut of tilapia and carp grown in waste-fed and non-waste-fed aquaculture ponds (28, 34).

Disease surveillance reports from public health authorities in Europe and North America indicate that *Salmonella* infections associated with the consumption of farmed freshwater and marine fish and crustaceans occur very rarely compared with those associated with poultry products. On the basis of available evidence, strains isolated from most human cases of salmonellosis appear to be different from those found in products from aquaculture (33). This implies that such products constitute a very low risk to public health with respect to salmonellosis.

Escherichia coli is often used as an indicator for faecal contamination; however, because of the ubiquitous nature of this organism in the tropics, this association is questionable there. Some strains of *E. coli* are capable of causing foodborne disease, ranging from mild enteritis to serious illness and death. Where animal manure, particularly bovine manure, is used as pond fertilizer, there is a risk that pathogenic strains of *E. coli* may be present in pond water. For instance,

there is good evidence for the occurrence of waterborne infection caused by *E. coli* O157:H7. As the occurrence of this strain in cattle is well established and its infectious dose is low, it poses a potential risk to public health where bovine manure is used as pond fertilizer (35).

A number of other human pathogenic enterobacteria, including *Shigella* spp., have occasionally been isolated in aquaculture systems and products. However, on the basis of epidemiological evidence, there appears to be very little risk of infection associated with the consumption of farmed fish products.

Campylobacter spp. are very common and important causes of diarrhoeal illness in humans. They are commonly found in the gut of warm-blooded animals, especially poultry, but they are not part of the normal flora of unpolluted aquatic environments. However, these organisms are frequently isolated from wastewater. There is very little information on the occurrence of *Campylobacter* spp. in aquaculture, although the use of poultry manure for fertilizing ponds may constitute a public health risk in inland and coastal aquaculture environments. There are some reports of the occurrence of *Campylobacter* spp. in bivalves, but there is insufficient information about their occurrence in finfish and crustaceans. Available data suggest that the risk of *Campylobacter* infection associated with the consumption of farmed fish products is low.

4.2.2 *Vibrio* spp.

Vibrios are generally salt-tolerant organisms occurring naturally in marine and brackish-water environments in both tropical and temperate regions, although *Vibrio cholerae* and *V. mimicus* also occur in fresh water. Vibrios have also been isolated from sediments, plankton, molluscs, finfish and crustaceans. While several studies have shown that the occurrence of vibrios does not correlate with numbers of faecal coliforms, there is a positive correlation between their occurrence and the admixture in water of contaminated human waste. There is also a positive correlation between water temperature and both the number of human pathogenic vibrios isolated and the number of reported infections. A seasonal correlation is particularly marked for *V. vulnificus* and *V. parahaemolyticus*.

Currently, 12 species of *Vibrio* are known to be associated with human infections acquired by consumption of contaminated foods and water. Some human pathogenic *Vibrio* spp. may also be fish pathogens. In general, the infectious dose necessary to cause intestinal disease is high, and the risk associated with eating fish is therefore likely to be low. For example, about a million organisms must be

ingested to cause cholera. Although more than 150 serotypes have been identified, only *V. cholerae* O1 and O139 cause cholera; non-O1 *V. cholerae* can cause diarrhoea, abdominal cramps, nausea and fever. While cholera has been associated with the consumption of raw fishery products, there are no reported cases resulting from the consumption of commercially imported farmed finfish and crustaceans (36).

Although not all strains are pathogenic, *V. parahaemolyticus* has been recognized as a major cause of gastroenteritis and is particularly associated with the consumption of raw marine crustaceans and fish. *Vibrio vulnificus* has been associated with primary septicæmia (following ingestion of raw bivalves and crabs) and with wound infections. The vast majority of people developing primary septicæmia are immunocompromised. Confirmed cases of septicæmia and gastrointestinal disease caused by *V. vulnificus* following consumption of products from aquaculture have not been reported.

4.2.3 ***Aeromonas* and *Plesiomonas* spp.**

Aeromonas and *Plesiomonas* spp. constitute part of the normal aquatic bacterial flora, with *Plesiomonas* spp. occurring more commonly in tropical waters. *A. hydrophila* is the species most often associated with foodborne disease (37) and *P. shigelloides* has been implicated in outbreaks of gastroenteritis from the consumption of fish (38, 39). Epidemiological evidence suggests public health risks from *Aeromonas* and *Plesiomonas* spp. in farmed fish are low.

4.2.4 ***Clostridium botulinum***

Clostridium botulinum is a ubiquitous, spore-forming, anaerobic organism that produces a neurotoxin causing life-threatening foodborne illness. This organism can be grouped into seven types on the basis of the antigenic nature of the neurotoxin produced. *C. botulinum* type E is naturally found in aquatic environments and is often isolated from fish. However, if the fish are properly handled and processed to prevent growth of the organism and production of the toxin there should be no risk of botulism.

4.2.5 ***Listeria monocytogenes***

Although *Listeria monocytogenes* is a foodborne pathogen, farmed finfish and crustaceans have not been implicated in any epidemic outbreaks. However, seafood, including fish, smoked fish, smoked mussels and smoked salmon, has caused sporadic cases of listeriosis in vulnerable populations. *L. monocytogenes* is frequently isolated from aquaculture products from temperate regions but is rarely reported in tropical fishery products. Fish produced in temperate inland

aquaculture systems may be contaminated with *L. monocytogenes* and thus present a potential health risk when consumed raw or without heat treatment.

4.2.6 **Other bacteria**

A number of other bacteria pathogenic to humans, including *Erysipelothrix rhusiopathiae*, *Leptospira interrogans*, *Yersinia enterocolitica*, *Pseudomonas* spp., *Streptococcus iniae* and *Mycobacterium* spp., are widely disseminated in nature, including the aquatic environment. There is little evidence, except in the case of *M. marinum*, that their distribution is affected by aquaculture activities. *M. marinum* has been isolated from disease outbreaks in food fish and ornamental fish. There are no reported cases of illness caused by *M. marinum* associated with the consumption of farmed finfish or crustaceans. On the other hand, *M. marinum* and *S. iniae* may present occupational hazards to workers handling infected fish.

4.3 **Viruses**

Although the consumption of raw molluscan bivalves is a major cause of viral disease associated with aquatic produce, finfish and crustaceans are not usually associated with the spread of viral foodborne disease. The Engelberg Report states that “based on epidemiological evidence the transmission of enteric virus diseases through wastewater reuse systems is not as important as transmission of bacterial and helminthic diseases” (40). Viruses causing disease in fish are not pathogenic to humans.

4.4 **Other biological hazards**

A large number of toxic compounds produced by aquatic organisms have been reported and can present significant human health risks (41, 42). Almost all toxic compounds relating to aquaculture are produced by aquatic microorganisms, such as the microscopic algae and detrital bacteria that serve as food for the larvae of commercially important crustaceans and finfish. Possible sources of infection in farmed finfish and crustaceans include ingestion of toxic microorganisms or toxic products in feed. There is some evidence to suggest that algal toxins affect a wide range of crabs (43), although there are no reports linking algal toxins with products from aquaculture. Mussel and oyster meat are occasionally used as components of home-made fish feed in the tropics, and farmers should be aware of possible hazards associated with such species when they have been exposed to toxic algal blooms. A recent report has identified paralytic shellfish poisoning in lobsters and crabs (43), and when these species are

fed on molluscan shellfish contaminated with paralytic-shellfish-poisoning toxins, they may pose a human health risk.

Cyanobacterial toxins, such as microcystins, are potent and widespread, especially in eutrophic fresh water. While there has been no study of the prevalence of toxic strains of cyanobacteria in fish ponds, experimental work with filter-feeding tilapia and silver carp show that these species avoid ingesting phytoplankton when toxic cells are present (44, 45). Prolonged exposure to high concentrations of free microcystins in the water column, such as may occur at the end of a plankton bloom, may lead to the accumulation of these compounds in the livers of freshwater fish (46). On balance it is concluded that there is a very small risk to human health associated with these toxins in farmed finfish and crustaceans.

5. Chemical hazards and associated risks

Chemical hazards can be present in products from aquaculture through exposure to compounds used in the aquaculture system itself and by acute and chronic pollution of waterways or sources of water. All the chemical products discussed in this section are considered in the context of food safety. While there may be occupational hazards for individuals working with these products, they are not considered here.

5.1 Agrochemicals

5.1.1 Chemical fertilizers

Chemical fertilizers are widely applied to semi-intensively managed ponds in the tropics and subtropics to stimulate phytoplankton blooms (47). Such fertilizers may be either organic or inorganic in nature. Generally, fertilizers are not used to the same extent in intensive aquaculture systems. Chemical compounds used as fertilizers are highly water-soluble, and they increase concentrations of nitrate, ammonia, phosphate, potassium and silicate. Chemicals used include:

- urea
- ammonium sulfate
- ammonium nitrate
- sodium nitrate and potassium nitrate
- calcium phosphate
- ammonium phosphate (mono- and dibasic)
- phosphoric acid
- potassium chloride
- sodium silicate

- trace element mixes (various compounds of iron, zinc, copper, boron and molybdenum).

Chemical fertilizers may be applied as individual compounds or blended to provide a mixed fertilizer containing two or more compounds. Trace elements are applied in microgram-per-litre quantities. Although some of the above compounds may be considered as hazards, they pose no risk to food safety in aquaculture products when used according to good aquacultural practice.

5.1.2 **Water treatment compounds**

Lime compounds are usually applied to coastal shrimp-pond waters and soils and to a lesser extent inland aquaculture ponds to regulate pH (47). They are also used to sterilize pond soils between production cycles. Commonly used compounds include:

- agricultural limestone (pulverized calcium carbonate or dolomite)
- lime (calcium/magnesium oxide)
- hydrated lime (calcium/magnesium hydroxide).

None of these compounds can be considered to pose risks to human health when used according to good aquacultural practice.

Other agrochemicals are used in ponds, the most important of which are oxidizing agents, flocculants/coagulants and osmoregulators. However, their use is rare.

Oxidizing agents

Oxidizing agents are occasionally used for controlling phytoplankton, killing disease organisms or oxidizing bottom soils (47, 48). Commonly used oxidizing agents include:

- potassium permanganate
- hydrogen peroxide and calcium peroxide
- calcium hypochlorite
- sodium nitrate.

Flocculants

Flocculants are sometimes applied to pond waters to cause suspended clay particles to precipitate in order to clear the water of turbidity (47, 49). Commonly used flocculants/coagulants include:

- aluminium sulfate (alum)
- ferric chloride
- calcium sulfate (gypsum)
- zeolite.

Osmoregulators

Osmoregulators are applied to water to increase the salinity or the calcium concentration and improve conditions for normal osmoregulation by certain aquaculture species (47). The most commonly used are salt (sodium chloride) and gypsum.

When used according to good aquacultural practice, none of the above water treatment compounds can be considered hazardous to the consumer of aquaculture products.

5.1.3 **Pesticides**

Algicides and herbicides are occasionally applied to inland ponds, especially in North American channel catfish farming, to control nuisance blooms of algae in efforts to reduce dissolved oxygen demand or to combat undesirable flavours caused by certain species of cyanobacteria.

The most commonly used algicides are:

- copper, including chelated copper compounds
- triazine herbicides
- chlorphenoxy compounds
- dyes (food-colouring compounds).

Copper must be considered as a hazard, but under the conditions in which it is used in aquaculture it poses no significant risk to consumers of aquaculture products.

Piscicides are used to kill potential predators or competitors in ponds prior to stocking, or for elimination of infected fish populations. They are principally used in the tropics. The most common piscicides are:

- teaseed and mahua oil cake (active ingredients: saponin glycosides)
- rotenone
- insecticides
- lime (calcium/magnesium oxide)
- potassium permanganate
- ammonia.

Saponin glycosides, rotenone and certain other piscicides are toxic to animals and humans. The view of the Study Group was that, although these compounds are unlikely to present a significant risk under normal conditions of use in aquaculture, available data are insufficient to permit a definitive statement.

5.1.4 **Disinfectants**

Disinfectants are widely used in aquaculture. As in many other areas of the food industry they are used to disinfect both portable equipment and holding units, generally in the interval between stocking. Commonly used disinfectant compounds include:

- benzalkonium chloride (alkyldimethylbenzylammonium chloride)
- polyvidone iodine (polyvinylpyrrolidone–iodine complex)
- glutaraldehyde
- formalin
- hypochlorite.

These compounds are washed away or decompose before restocking. As they do not come into contact with fish, they present no risk to consumers.

5.2 **Chemotherapeutants**

Infectious disease is an ever-present hazard in aquaculture, with the potential to cause both major stock losses and problems of animal welfare. To control infectious diseases in aquaculture, the same range of strategies is employed as in other areas of animal production. The most effective approach is to prevent the introduction of disease-causing pathogens. For most areas where aquaculture is practised, regulations to this effect are in place, although standards of enforcement differ. Good aquaculture management practices are essential to maintain a healthy environment for farmed finfish and crustaceans.

When disease occurs, veterinary medicines are employed to control the impact. In mature, intensive aquaculture industries, vaccines are increasingly used, and, in recent years, the use of chemotherapeutants has fallen exponentially (see Table 4, p. 28). In extensive aquaculture systems there has generally not been significant use of chemotherapeutants. Where chemotherapeutants are used, in most areas their use is strictly controlled under the same regulatory code as other veterinary medicines.

As a relatively new area, intensive aquaculture did not initially justify the development of chemotherapeutants specifically for use in the aquatic environment. Instead, pharmaceutical companies have tended to offer products developed for other areas of veterinary medicine for authorization for use in aquaculture.

5.2.1 **Antimicrobial agents**

It was recognized very rapidly that the use of antimicrobial agents in the aquatic environment would cause concern, in terms of both

potential environmental impact and potential human health implications. The latter concern arose from the possibility that such use might have a negative impact on the success of therapy of human infections. However, use of antimicrobial agents in aquaculture has always been subject to veterinary medicine controls, wherever national control systems exist. Examples of a number of national situations are given below.

In the United Kingdom, four antimicrobials are licensed for use in fish: oxytetracycline, oxolinic acid, amoxicillin and co-trimazine (trimethoprim + sulfadiazine). The slightly larger range currently permitted in Norway is:

- benzylpenicillin + dihydrostreptomycin
- florfenicol
- flumequine
- oxolinic acid
- oxytetracycline
- co-trimazine

Throughout Europe and North America a similar range of compounds is permitted for use with food fish species. Elsewhere in the world, wider ranges of antimicrobials have been approved, for instance in Japan and south-east Asian countries. In some countries, regulations may exist, but are not effectively enforced; in others no regulatory regime exists. Where no regulation exists, farmers can use any drugs they can purchase. In many cases, with antimicrobials purchased from unregulated sources, the quality may be poor. However, this problem is not restricted to aquaculture, but applies to all animal husbandry.

In 1995, with financial assistance from the Asian Development Bank, NACA completed a survey of approximately 11000 aquaculture farms, including 5000 coastal shrimp farms and 6000 inland carp farms (50, 51). The survey involved 16 countries in the region and collected information from aquaculture farmers on farming systems, economics and management, and environmental and social aspects of farming. The survey results show that the use of antimicrobial compounds in inland carp farms, which produce the bulk of freshwater fish in Asia, was very low. Less than 5% of surveyed farms in most countries use antimicrobial compounds, with oxytetracycline and oxolinic acid the most common compounds in use. In coastal shrimp culture, antimicrobial use is also low in extensive and semi-intensive farming systems, where farmers simply do not need, or do not have the necessary resources, to use such compounds. There was a higher frequency of antimicrobial use in intensive shrimp farming in some

countries, with oxytetracycline and oxolinic acid the main compounds in use.

5.2.2 *Routes of antimicrobial administration in aquaculture*

For finfish and crustaceans, antimicrobials are usually administered in feed, either compounded during manufacture or surface-coated onto feed pellets. Antimicrobials are usually added with a small quantity of oil, either by the feed manufacturer or at the farm. In the shrimp industry, they are also used in the hatchery as bath medication. For medication of finfish or juvenile shrimp, the antimicrobial is applied to feed as an oil-based coating as necessary. Awareness of the potential for residue problems means that the use of antimicrobials in older shrimp is now being increasingly restricted.

5.2.3 *Antimicrobial resistance in aquaculture*

Bacterial strains can be termed resistant if they can function, survive or persist in the presence of higher concentrations of an antimicrobial than the parent population can support. Resistance should always be seen as relative, and is determined by comparing the properties of two or more strains or species (52). Resistance is context-dependent; thus in fish therapy a strain may be either resistant or sensitive depending on how the antimicrobial is administered, the tissue distribution of the antimicrobial compared with the location of the pathogen in the fish, and the physicochemical environment of the fish. It is well established that the concentrations of Mg^{2+} and Ca^{2+} present in marine waters cause a dramatic reduction (>90%) in the biological activity of oxytetracycline, the quinolones, flumequine and oxolinic acid (52). Thus, a bacterial strain colonizing the fish gut may be sensitive or resistant to these antimicrobials depending on whether the fish is in a marine or a freshwater environment. “Resistance” or “sensitivity” must therefore have reference to a specific context.

It is generally accepted that the more antimicrobials are used, the higher will be the frequency of resistant microorganisms in that environment. The emergence of bacterial pathogens resistant to antimicrobial agents is a major factor limiting the value of such antimicrobials. Thus, the use of antimicrobials in aquaculture may lead to an increase in the frequency of resistance in pathogens of fish and crustaceans and in aquatic microflora (52). However, evaluating this assumption is difficult. There is little agreement as to how resistance in bacteria pathogenic to fish should be defined, and no consensus as to how it should be measured. The need for developing standard methodologies has been recognized by the European Association of Fish Pathologists and by the Working Group on Diseases

and Pathogens of Marine Organisms of the International Council for the Exploration of the Sea.

Before considering whether the use of antimicrobials in aquaculture can lead to an increased selection of genes for antimicrobial resistance, including strains containing antimicrobial resistance plasmids (R-plasmids), and the possible spread of resistance genes to microorganisms of medical interest, it should be noted that there has been a tendency to report potential risks rather than objectively to assess their importance (52).

Plasmid-mediated resistance to antimicrobials has been identified in a number of bacterial fish pathogens, including *Aeromonas salmonicida*, *A. hydrophila*, *Vibrio anguillarum*, *Pseudomonas fluorescens*, *Pasteurella piscicida* and *Edwardsiella tarda* (53), and *Yersinia ruckeri* (54). Transferable R-plasmids encoding resistance to chloramphenicol, sulfonamides and streptomycin have been found in *A. salmonicida* in Japan, and to combinations of sulfonamides, streptomycin, spectinomycin, trimethoprim and/or tetracycline in Ireland (55). In Scotland, transferable R-plasmids were found in 11 out of 40 oxytetracycline-resistant *A. salmonicida* isolates. Transferable resistance was detected to combinations of oxytetracycline, streptomycin, sulfamethoxine and/or trimethoprim (56).

Plasmid-mediated resistance to quinolones has not been reported in fish pathogens, presumably because these compounds appear to effectively inhibit the process of conjugative plasmid transfer, so that the spread of quinolone resistance by gene transfer is unlikely. In the case of *A. salmonicida*, laboratory studies have shown that resistance to oxolinic acid can readily be selected in the presence of the antibacterial (57). A similar study concerning the fluorinated quinolone sarafloxacin has been reported (58). However, studies such as these set out deliberately to exert maximum selection pressure for antimicrobial resistance in the absence of any competing microorganisms and do not realistically model the type of selection pressures present in aquacultural practice.

β -Lactamases occur widely among *Aeromonas* spp., including fish pathogens (59). The presence of up to 3 β -lactamases has been reported in *A. salmonicida* subsp. *achromogenes* (60, 61).

There is ample evidence that resistant strains of fish pathogens have developed since antimicrobials began to be used to control disease in aquatic animals. However, changing methods of determining antimicrobial resistance and susceptibility and gross differences in methodology between laboratories (52) render it difficult to quantify. The

proportion of isolates showing resistance to individual antimicrobials has fluctuated considerably over time (57). However, the occurrence of strains of *A. salmonicida* showing multiple antimicrobial resistance has posed serious problems for the salmon-farming industry (62); in one study, 23% of 229 cases of furunculosis diagnosed between 1988 and 1990 involved isolates of *A. salmonicida* resistant to three or more antimicrobial agents (63). Widespread use and abuse of antibiotics, especially in hatcheries, has also led to the development of multiple resistance among microbial populations associated with farmed shrimp production (64).

5.2.4 **Human health considerations**

There are limited data on the health risks associated with the use of antimicrobials in aquaculture. Several studies have argued that the use of antimicrobials in aquaculture is associated with risks for the therapy of human infections (65–67). To assess the likelihood of this being a problem, it has been suggested (52) that two risks should be considered independently:

- The risk associated with the transmission of resistant bacteria from aquaculture to humans, i.e. the frequency of resistance in human bacterial pathogens may increase as a direct result of the use of antimicrobials in aquaculture.
- The risk associated with the introduction to the human environment of non-pathogenic bacteria containing antimicrobial resistance genes and the subsequent transfer of such genes to human pathogens.

Few bacterial pathogens of farmed fish in temperate climates are capable of infecting humans. The risk of fish pathogens producing human disease is therefore low. In warmer climates, where organisms such as *A. hydrophila* and *Edwardsiella* spp. are important fish pathogens, this may be less true. In temperate climates, nevertheless, the putative risk to public health of the use of antimicrobials in aquaculture is probably limited to the indirect exposure to antimicrobials.

In developed countries, the possibility that bacteria resistant to antimicrobials used in aquaculture might reach the public through the drinking-water chain is remote, in light of the high dilution factors to which such bacteria would be subject and the fact that most fish pathogens are incapable of infecting humans. Treatment methods commonly in use for potable water should ensure that no viable pathogens reach the consumer. In low-income food-deficit countries,

on the other hand, drinking-water in many areas is untreated. Moreover, in these countries bacteria pathogenic to fish are acclimated to temperatures much nearer to that of the human body and may be capable of surviving in the human gut. Although there is a theoretical risk of the transfer of resistant pathogens to humans through drinking-water in the tropics, the risk is judged to be small in view of the extremely limited use of antimicrobial compounds in tropical fresh-water aquaculture.

5.2.5 *Antimicrobial drug residues in edible tissues*

The potential hazards associated with the presence of antimicrobial drug residues in edible tissues of products from aquaculture include:

- allergies
- toxic effects
- changes in colonization patterns of human-gut flora
- acquisition of drug resistance in pathogens in the human body.

As for other veterinary medicines, wherever there is an effective regulatory regime, authorization processes for the use of antimicrobials in aquaculture follow established processes. The establishment of appropriate withdrawal periods ensures that no harmful residues remain in edible tissues after use of a chemotherapeutant.

Since fish are poikilotherms, their metabolic rate is determined by environmental temperatures. As a result, withdrawal periods are based on time and temperature, i.e. degree-days: for example, 10 days at 5°C equals 150 degree-days.

The acceptable level of drug residue in edible tissues is set through the establishment of Maximum Residue Limits (MRLs). At the international level, this is the responsibility of the Codex Committee on Residues of Veterinary Drugs in Food. The data required to enable the determination of an appropriate MRL are costly to produce. As different animals may take up, deplete and metabolize antimicrobials differently, MRLs are generally specific to species and tissue type. However, aquaculture does not generally generate sufficient sales income to support the production of such data, and only a few species-specific MRLs have been established for fish.

Compliance with MRLs for products from aquaculture is beginning to be enforced. For instance, the European Union is in the course of implementing a monitoring programme in which fish muscle tissue will be routinely sampled for the presence of a range of veterinary drug residues. With the trend towards increasing harmonization of international food safety standards for products from aquaculture,

regional monitoring programmes will become more common. At present, the most developed monitoring programme is in Norway, which for more than 15 years has published its results on an annual basis. Norway is thus one of the few countries in which antimicrobial use in aquaculture can be accurately quantified (Table 4). Such monitoring programmes help provide assurance that no unacceptable human health risk is posed by veterinary drug residues in products from aquaculture. Unfortunately, some countries implement monitoring programmes for export products but do not offer the same assurance for domestic markets.

5.2.6 *Parasiticides*

Sea lice are a major problem for the culture of salmon in some countries. Sea lice are tiny crustaceans that infest and destroy the skin of fish. Infestation can be fatal. Present treatment methods use topical (“bath”) applications of delousing agents. Initially, organophosphate insecticides were employed almost exclusively. Metrifonate was widely used at first, with dichlorvos being introduced later. Examples of dichlorvos application include, but are not limited to, salmon farming operations in Ireland, the United Kingdom and countries of Scandinavia. Concerns have recently been raised with respect to the safety and toxicity of the carrier, di-*n*-butylphthalate (68).

In addition to dichlorvos and metrifonate, azimethphos is used in some regions. Other organophosphates have been employed to control ectoparasitic crustaceans in freshwater fish and monogenetic-trematode or ciliate infections in shrimp hatcheries. Organophosphates may also be used to eliminate snail vectors of white spot virus, and potentially other pests as well. Concerns have been raised about the use of these compounds because of their effect on all exposed

Table 4
Sale of antimicrobial drugs (in kg of active substance) for the treatment of farmed fish in Norway, 1987–1997^a

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Florfenicol	—	—	—	—	—	—	56	14	64	64	123
Flumequine	—	—	329	1959	3837	9833	2177	227	182	105	74
Furazolidone	15 840	4 190	1345	118	131	0	78	0	0	0	0
Oxolinic acid	3 700	9 390	12 630	27 659	11 400	7 687	2 554	811	2 800	841	507
Oxytetracycline	27 130	18 220	5 014	6 257	5 751	4 113	583	341	70	27	42
Co-trimazine ^b	1 900	670	32	1 439	5 679	5 852	696	3	0	0	0
Total	48 570	32 470	19 350	37 432	26 798	27 485	6 144	1 396	3 116	1 037	746

^a Data supplied by the Norwegian Directorate of Fisheries, in cooperation with the Norwegian Veterinary College, Department of Pharmacology and Toxicology.

^b Sulfadiazine + trimethoprim.

crustaceans, not just the target organisms (69). While organophosphates are not environmentally persistent, treatment doses do not disperse as rapidly from the fish cages as was initially expected. However, tissue depletion of organophosphate compounds is rapid, and no harmful residues are created. The principal human health hazard is to the farm staff working with the product.

Hydrogen peroxide is now often used as an alternative to organophosphates for the control of sea lice. However, it is expensive, difficult to use and presents the risk of explosion if not handled properly. On use it breaks down rapidly to oxygen and water and poses no food residue hazard.

Ivermectin has found limited use against sea lice in salmon farms in Ireland and the United Kingdom. As it has been approved in these countries as a veterinary drug for oral use in pigs, its use for other species is permissible, although no MRLs have been set for fish. In salmon, ivermectin requires a long withdrawal period if residues are not to occur. However, recent studies have demonstrated that ivermectin residues do not present a significant risk to human health. A number of other insecticidal compounds that would provide a wider range of control agents for sea lice are currently under development.

5.2.7 ***Other chemotherapeutants***

The use in aquaculture of chemotherapeutants other than antimicrobial agents is limited. Hormones are sometimes employed to control reproduction, especially in tropical fish species. Hormones are employed principally in hatcheries to induce spawning and to control the sex of offspring, especially for tilapia. In view of the stages in the production cycle in which the hormones are used and the rates at which they are excreted by fish, there is no risk to consumers of products from aquaculture.

5.3 **Metals**

Metals of concern for public health include those usually grouped together as heavy metals, and some metalloids such as arsenic. Metals and metalloids are present in the aqueous environment mostly as a result of geochemical processes that cause them to enter into solution and so ultimately into water courses and other bodies of water. They can also be introduced into aquaculture systems through certain cultural practices or as a result of pollution.

Anthropogenic sources include mining, metalworking and industrial processes. Municipal sewage, unless it comes entirely from domestic sources, often contains a range of metallic salts, as can animal faeces. The origins, fates and significance of metals in the marine environment, including the significance for human health, have been reviewed by the Joint Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP) (70–73). Most of the contents of the reports and their conclusions are also valid for the freshwater environment. Concentrations of metals are low in the open oceans and in unpolluted coastal waters, but can be high in estuaries and in enclosed bodies of water — often favoured sites for aquaculture systems — as a result of pollution and transport by rivers (74).

Many metals and metalloids of concern for human health are found in a number of forms and valencies, and the chemistry of the fates of such elements in the aqueous environment is complex. The pH of the water is important, since the solubility of metals decreases with increasing pH. Aquaculture pond systems are usually maintained with a pH greater than 7. In addition, ponds usually have an anaerobic sediment rich in organic compounds, and under these conditions, metals tend to precipitate into the sediment as insoluble sulfides or hydrated oxides. The pH of seawater is alkaline, and concentrations of metals in the marine environment are low. Sewage often contains high concentrations of heavy metals, but in sewage-treatment systems metals precipitate as insoluble salts in primary treatment ponds. In subsequent treatment ponds the pH is alkaline, and metal levels are reduced even further.

The concentration of metals in edible portions of products from aquaculture is of more relevance to public health. Metals can enter fish by absorption through the gills or by absorption from food, but it appears that the second mechanism is more important. Vertebrate fish regulate the concentrations of inorganic metal compounds in muscle tissue, and in such fish, concentrations of inorganic metal compounds do not exceed regulatory or recommended limits even when the fish are harvested from environments with high metal concentrations. Invertebrate fish have less capacity to regulate metal concentrations in their tissues and in crustacean shellfish tissue concentrations of metals can rise to high levels under certain circumstances.

5.3.1 *Antifoulants and molluscicides*

Copper, usually as copper sulfate, has a long history of use in aquaculture as a molluscicide during the preparation of ponds before

flooding and stocking. Ponds are usually limed at the same time, and the resulting high pH prevents high concentrations of copper in the water. In addition, as vertebrate fish can regulate the metal content of their tissues, the treatment of ponds with copper does not pose a risk to consumers of such fish.

Crustacean shellfish, however, concentrate copper in edible tissues including the hepatopancreas, and metal contamination in crustaceans may pose a small risk for food safety. Available data show that the copper content of farmed crustaceans is higher than that of farmed vertebrate fish from similar environments. However, it is not possible to quantify the risk to human health.

Tributyltin has been used in marine aquaculture as an antifoulant for nets and cages (26). However, after it was shown that salmon in treated pens could accumulate tin in their tissues, the use of tributyltin for this purpose was banned in Europe and North America. It remains in use in some parts of the world. On the basis of animal studies a limit of 3.2 µg/kg of body weight has been suggested (75). The highest concentration found in salmon held in treated cages would imply that, to exceed this level, a daily consumption by a 70-kg person of 150 g of salmon flesh would be necessary.

Triphenyltin is used as a molluscicide in agriculture and for pond preparation in aquaculture. Triphenyltin should be fairly resistant to degradation in water and soils, and fish and shellfish exposed to triphenyltin will concentrate it in their tissues. Though the human toxicity of tin compounds is uncertain, they should be considered as food safety hazards, and the risk to the health of those consuming fish contaminated by organotins should be evaluated.

5.3.2 **Pollutants**

Metals can enter aquaculture systems from natural sources and natural processes or from acute or chronic pollution. Although the risk of unsafe levels of metals in fish is very low, in some instances crustacean shellfish can pose a small risk.

The tissue concentration of mercury in its organic form, methylmercury, is poorly regulated by vertebrate and invertebrate fish. There is a large literature on the subject and authoritative reviews of environmental and human health aspects exist (71, 76). Inorganic mercury can be methylated by biological (predominately microbiological) processes in the aquatic environment. Methylmercury is taken up by

aquatic organisms such that the concentration in their tissues can be orders of magnitude greater than that in the ambient water. Methylmercury bioaccumulates in the food chain, with the result that the highest concentrations are found in predatory fish. More than 95% of the total mercury content in edible fish tissue is in the form of methylmercury.

Some data show the mercury content of products from aquaculture to be less than 1.0mg/kg. Most regulatory bodies have adopted this level as the maximum permissible limit in large predatory fish destined for human consumption.

There is a need for more information about the mercury content of products from aquaculture and the influence of aquaculture practices on it. Farmed vertebrate fish are likely to be safer than their counterparts caught in the wild. Methylmercury is predominantly taken up from food, and in marine aquaculture systems, as well as other systems, fish are generally fed formulated diets. As feeds will, or should, have low mercury content, the harvested fish will likewise have low tissue concentrations of mercury. Moreover, mercury accumulates in fish during their lifetime, and tissue concentrations are greater in older and larger fish. Since farmed fish are usually harvested young, they would be expected to have low tissue concentrations even if their feed contained mercury. In addition, the uptake of mercury is influenced by the chemistry of the ambient water. High pH, increased hardness and high content of soluble and suspended organic compounds — conditions that often prevail in pond aquaculture — reduce mercury uptake.

5.4 **Feed ingredients, additives and contaminants**

As in other forms of animal husbandry, the quality of feed, as well as its potential impact on human health, depends on a series of steps that begin with the growing and harvest of feed ingredients (2). In this section, the hazards and the risks associated with feed ingredients, additives and contaminants are considered. “Ingredients” are understood here as the basic component parts or constituents of feed, whereas the term “additives” is used to refer to components added to the basic feed mix to fulfil a specific need. Additives are usually used in very small quantities (2).

Nutritionally complete feeds are used in the intensive salmon, catfish and marine fish industries of Europe and the Americas and, in most instances, in shrimp farming. Such feeds are usually commercially manufactured; by contrast, supplementary feeds used in semi-intensive aquaculture are largely prepared on the farm. The principal

constituents of nutritionally complete feeds include proteins (e.g. fishmeal, plant oilseed meal), lipids (fish oils, plant oils), carbohydrates (cereals, plant-by-product meal), vitamins and minerals, binders, and occasionally pigments and antifungal agents (2). Feeds prepared on the farm, however, are considerably more diverse in their ingredients, and are usually made from locally available agricultural by-products and ingredients.

While some ingredients and additives used in aquaculture feed pose hazards, with the possible exception of those presented by contaminated fish oil, such hazards are not significant. In view of existing procedures in the aquaculture feed industry, the risks to human health were judged to be relatively low.

Fish oil is a by-product of the fish-meal manufacturing industry and comes from many different parts of the world. Highly chlorinated compounds and chlorinated insecticides have low solubilities in water and bioaccumulate in the food chain. As they accumulate in the lipid compartment of the animal, oil extracted from fish caught in polluted waters may be contaminated with chlorinated hydrocarbons. Furthermore, the consumption of chlorinated hydrocarbons is a known risk factor. For these reasons the Study Group judged there to be a hazard associated with fish oil from fish from polluted areas. However, for lack of data, this hazard cannot be quantified. The aquaculture sectors most dependent on the use of fish oil as a source of dietary lipids are the salmon and marine finfish industries.

Mycotoxins are metabolites of fungi of various genera. Such fungi can grow on feed ingredients (grain) before and after harvest or during transportation or storage. Fish ingesting mycotoxin-contaminated feed may accumulate mycotoxins in their tissues, although the extent to which this occurs is poorly understood. While data are available on the consequences to human health of the consumption of mycotoxin-contaminated foods, there is little information on the consequences of ingestion of mycotoxin-contaminated products from aquaculture.

5.5 Organic pollutants

Aquaculture systems can be affected by acute and chronic discharges of organic pollutants. Acute pollution results from single discharges of limited duration, for example accidental spillages into water courses from chemical works or from vessels run aground. In the case of inland systems, including integrated aquacultural/agricultural systems, pollution of the aqueous environment can arise from episodic agricultural treatment such as crop spraying. With acute pollution, the

risk to aquaculture systems will usually be obvious, and it may be possible to mitigate the effects by appropriate action such as delaying harvest or moving the fish. In addition, regulatory authorities can intervene to prevent distribution of contaminated fish until the danger is passed and the fish have been purged of the contaminant. With the exception of chlorinated hydrocarbons, most industrial chemicals and agrochemicals are readily degraded by chemical and biological processes in soils and waters, do not bioaccumulate to any large extent and are rapidly eliminated from fish.

Chronic contamination is more difficult to control. The main mechanisms of chronic contamination in aquaculture systems are use of polluted water supplies, leaching of agricultural or industrial chemicals from treated or contaminated soils into surface waters, and deposition from the atmosphere. A wide range of chlorinated compounds can be present in the aquatic environment but three groups in particular are of concern to environmentalists and public health officials: chlorinated insecticides (e.g. dichlorodiphenyltrichloroethane (DDT), dieldrin, lindane) and their degradation products, polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins and polychlorinated dibenzofurans.

Although there is a large literature on the presence and fate of chlorinated organic compounds in the aquatic environment and biota, most data relate to the natural environment and very little has been published on chlorinated compounds in aquaculture systems or products from aquaculture. Available data show that products from aquaculture sometimes contain chlorinated hydrocarbons, though reported values are below the maximum limits permitted in foodstuffs. Sewage and wastewater often contain high levels of industrial chemicals, but fish raised in systems using sewage and wastewater show only low tissue levels of chlorinated insecticides in most reports. However, one survey of chlorinated pesticides in foodstuffs (77) found that the one sample of farmed fish tested (origin not stated) had a much higher concentration of chlorinated hydrocarbons than any of the other foods, which included 111 samples of "marine products".

The few reported measurements are not sufficient to provide a general picture of chlorinated hydrocarbon contaminants in products from aquaculture. These measurements derive from countries with small aquaculture production compared with Asian countries. In Asia most aquaculture production comes from inland sites associated with agricultural activities and should therefore be considered at risk for contamination with agricultural chemicals. Pesticides like DDT and

lindane have been extensively used in Asian countries for control of agricultural pests and the mosquito vectors of malaria. Although the use of such chlorinated insecticides has been or is being phased out in these countries, chlorinated hydrocarbons are very persistent in soils and will continue to leach out into surface waters for a considerable period.

Polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins and polychlorinated dibenzofurans are of widespread occurrence. Now that the hazards of PCBs are known, their production has been banned. The dioxins and furans, however, are generated as products of combustion — including the burning of wood in forest fires or as cooking or heating fuel — or as by-products of the production of other chlorinated chemicals. They can enter the aqueous environment as effluents or through deposition from the atmosphere.

Data are available on the concentrations of these chemicals in fish from wild stocks, but a literature search revealed no data on their concentrations in products from aquaculture. Although dioxins and furans are mostly produced in developed countries and most aquaculture is conducted in less developed countries, these highly chlorinated hydrocarbons are globally distributed by atmospheric transport. Their physical properties are such that they are appreciably volatile from the water phase and therefore tend to accumulate in the polar regions. This property reduces the relative concentration of organochlorines in tropical waters, where most farmed fish are cultivated.

6. Strategies for food safety assurance

6.1 Introduction

Foodborne diseases associated with fishery products can be largely prevented and controlled through appropriate food-safety measures. Responsibility for food safety associated with products from aquaculture is shared between governments, the fish-farming and processing industries, and consumers. For its part, the aquaculture sector should institute farm management programmes, where appropriate, based on the principles of the HACCP system. The Study Group recognized that such measures are impractical in small-scale subsistence aquaculture, where attention should instead be focused on food safety education. However, the HACCP principles may be more applicable to intensive aquaculture systems.

The HACCP system can be applied at any stage, from production to consumption of food. It permits a systematic approach to the identification and assessment of hazards and risks associated with the production, distribution and use of aquatic foods, and puts the responsibility for the aquaculture of safe food products on the aquaculture sector. When the system is applied at the production level, specific hazards and corresponding control measures are identified and the measures are integrated into the production process. This leads to reduced requirements for end-product testing and to a cost-effective use of resources. The principles of the HACCP system should form an integral part of the farm-to-table food safety continuum, thereby increasing consumer confidence in products from aquaculture and expanding market opportunities.

There is an international movement towards the adoption of the HACCP system in the seafood sector, with such major markets as the European Union and North America introducing mandatory requirements for HACCP implementation. International bodies, such as the Codex Alimentarius Commission, are advocating a harmonized approach for the introduction of the HACCP system in the food sector, and the Codex Fish and Fishery Products Committee is in the process of revising all Codes of Practice for Fish and Fishery Products to include the principles of HACCP.

6.2 Risk assessment

Food regulations have been traditionally based on the principle that ideally all pathogenic microorganisms should be absent from food. In modern intensive food production systems, however, including fish and crustacean farming, the concept of “zero tolerance” is an unapproachable ideal. Experience with aquaculture production over the past few decades has clearly shown that complete elimination of pathogenic microorganisms from uncooked products is not always achievable. The concept of permitting a certain level of pathogens in some raw foods is explicitly acknowledged in the Codex Codes of Practice, which state that fish and fishery products should not contain microorganisms in any amount that may represent a hazard to public health. This provision necessitates a quantitative approach to risk assessment and presents a new challenge to the aquaculture and fisheries sector.

Quantitative risk assessment has been successfully applied to chemical hazards in food, water and the environment. However, the application of such a technique to risks posed by microbiological agents in

foods is an emerging science and is complicated by the following issues:

- The numbers of microorganisms in food may not be constant and can change with time and storage conditions, whereas the concentration of chemical contaminants cannot be increased and is rarely decreased by storage.
- Adequate cooking destroys microorganisms whereas few chemical hazards are destroyed by cooking.
- Most foods of aquatic origin are cooked before consumption, and microbiological agents generally cause illness only if cooking or subsequent handling procedures are inadequate.
- The pattern of distribution of microorganisms in foods may be very different from that of chemical contaminants.
- Person-to-person transmission is important for microorganisms but not for chemical contaminants.
- The role of the consumer in ensuring the microbiological safety of aquaculture products is essential, whereas for chemical hazards control lies with the fish farmer and food processor.

Microbiological risk assessment is further complicated by the ability of some microorganisms to cause a wide range of disease syndromes in susceptible individuals. For example, *Escherichia coli* O157:H7 can cause a spectrum of infections, ranging from mild diarrhoea to serious or fatal haemolytic uraemic syndrome. With respect to microbiological hazards in products from aquaculture, correct preparation for consumption is the ultimate hazard control point; there is consequently an urgent need for education of consumers on safe food handling practices.

6.3 Application of the HACCP system to aquaculture

While the implementation of HACCP-based food safety assurance programmes is well advanced in the fish-processing sector, the application of such programmes at the fish farm is in its infancy. The aquaculture sector is not unique in this respect: there are few examples of the application of HACCP principles in animal farming because of the lack of scientific data regarding the effectiveness of the on-farm control of pathogenic microorganisms. However, national and international agencies continue to recommend and promote the HACCP-based approach for all stages of food production, including on the farm. The view of the Study Group was that HACCP can be

applied to intensive aquaculture systems but is not practical for the subsistence level, where it is more important to convey food safety information to consumers and producers of products from aquaculture.

A prerequisite for implementing a HACCP system in any fish farming operation is compliance with the principles of good aquaculture practice. Good aquaculture practices can be defined as those practices necessary to produce high-quality products conforming to food laws and regulations. Governments should strive to promote the use of such practices through education of farmers and extension activities to promote food safety. The successful application of HACCP requires both the full commitment of the owner of the fish farm and the workforce and a team approach.

In applying HACCP it is necessary to examine carefully the nature and extent of any hazards associated with products from aquaculture and their methods of production. The first step is to assemble a HACCP team that should include a range of expertise relevant to the farming system. A multidisciplinary team could consist of experts in aquaculture, fish farm management, fisheries extension, public health, parasitology, and fish inspection and quality control. The second step involves a description of the product and its intended use by the purchaser, for example “fresh finfish or crustaceans harvested from ponds and chilled immediately for distribution to wholesale and retail markets, or to a specific processing facility”. The intended use may include processing as value-added products or consumption after thorough cooking. In certain cases, vulnerable population groups may need to be identified. The third and fourth steps in the application of HACCP involve the preparation of a flow diagram and the on-site confirmation of the flow diagram.

The next stage is application of the seven principles of the HACCP system (78), adapted here to aquaculture production:

Principle 1 Conduct a hazard analysis by identifying and evaluating the potential hazards associated with each stage of aquaculture production; assess the likelihood of occurrence of the hazards and identify measures for their control.

Principle 2 Determine critical control points (CCP). A CCP is a step where control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Principle 3 Establish critical limits that must be met to ensure that the CCP is under control.

Principle 4 Establish a system to monitor control of the CCP by scheduled testing or observations.

Principle 5 Establish corrective actions that must be taken when monitoring has indicated that a particular CCP is not under control.

Principle 6 Establish procedures for verification which include supplementary tests and procedures to confirm that the HACCP system is working effectively.

Principle 7 Establish a system of documentation concerning all procedures, and a record-keeping system appropriate to these principles and their application.

In conducting the hazard analysis, the following general points should always be considered:

- the possible hazards and the severity of their health effects;
- the means of qualitative or quantitative evaluation of hazards.

In addition, wherever possible, the following specific points should be considered:

- the survival or multiplication of microorganisms of concern;
- the production or persistence in foods of toxins, chemicals or physical agents;
- conditions leading to the above.

For the purpose of illustration, four CCPs that may be associated with an aquaculture system are discussed. The CCPs are the site of the fish pond, the water supply, the feed supply, and the rearing (growout) of the fish. It is essential to consider the unique conditions that exist within a specific fish farm when developing a HACCP plan for it.

6.3.1 **Site selection**

The siting, design and construction of fish farms should take into account potential food safety hazards. Hazards can arise from the location of the aquaculture facility as a result of chemical contamination of the environment or soil/water interaction influencing water quality. Soil properties affect pond water, and such factors as acidity or alkalinity of the water are related to soil quality. For instance, “acidic” soils reduce water pH and can cause the leaching of any

metals present in the soil. Fish ponds can receive pesticide or chemical run-off from adjacent agricultural land or other sources, which can in turn lead to unacceptable levels of chemical contaminants in aquaculture products. The selection of a site for a fish pond should include a soil survey in order to establish the suitability of the soil for aquaculture. Aquaculture facilities should be located in areas where the risk of contamination with hazardous effluents is minimal and where sources of pollution can be controlled. Parameters that can serve as critical limits for soil suitability and site selection for aquaculture have been established (79).

Monitoring procedures should assess whether a CCP is under control. This initially involves soil analysis in the proposed area, and also involves regular inspection of the locality for sources of pollution. Corrective actions need to be taken if the results of monitoring indicate that the CCP is not adequately controlled. For example, if soil analysis shows that the site is not suitable for a fish farm, an alternative must be found. Batches of fish may have to be isolated or the pond water treated if pollution of the fish ponds occurs after siting.

6.3.2 **Water quality**

Water quality is a CCP and likely hazards include chemical and biological contamination. Fish grown in cages in coastal zones are less likely to be exposed to agrochemical contamination than those grown on inland fish farms, but might be exposed to chemical contaminants if the cages are sited close to discharges of industrial wastes or near to shipping lanes. The use of wastewater for fish farming or the practice of fertilizing ponds with animal manure may result in products that harbour pathogenic bacteria and parasites. Aquatic birds are known to harbour pathogenic strains of *Vibrio cholerae* (80) and *Salmonella* spp. (29), and are a possible source of these organisms in fish farms. Freshwater fish cultured in certain parts of the world endemic for trematodiasis may harbour the infective stages of the parasites.

Where necessary, control measures can be readily implemented for the prevention of chemical contamination through the choice of the water supply and water treatment. The elimination from the water supply of parasites or their intermediate snail hosts in areas endemic for trematodiasis is difficult. It may also be impossible to control for contamination by pathogenic bacteria in all aquaculture systems. For microbiological hazards that may be associated with uncooked products from aquaculture, correct preparation for consumption is the ultimate CCP for elimination of these hazards.

International guidelines for the use of wastewater in aquaculture have been proposed by WHO (81) and these criteria can be applied as critical limits for water quality. Critical limits should also include the snail hosts of pathogenic trematodes. Laboratory analysis or certification of the water supply may be necessary. Corrective actions include water treatment or finding an alternative source of water. It may also be necessary to isolate batches of fish or to provide for their decontamination in clean water before sale.

In some aquaculture systems and in some locations, the control of water or feed quality is difficult, if not impossible. Current knowledge of the risks associated with fish produced in extensive farming systems, including integrated and wastewater reuse systems, is extremely limited, and the control of such risks by low-income farmers would be difficult. This is particularly relevant to developing countries where consumer education would be the most feasible and effective means of reducing the risk of foodborne hazards.

6.3.3 **Feed supply**

Feeding regimes vary widely from one aquaculture system to another. In extensive systems organic waste can be used as an inexpensive source of nutrients essential for the growth of the phytoplankton and algae that form the base of the aquatic food chain. Compound pelletized feeds produced to feed manufacturers' specifications for specific stages in the life cycle of different species are used in intensive systems. The hazards associated with manufactured feed include biological or chemical contamination, and the unregulated addition of veterinary drugs. Approved agrochemicals and veterinary drugs should be used according to manufacturers' instructions, and correct withdrawal times observed. As discussed in section 5.2.5, the main cause of drug residue problems is the failure to allow sufficient time for the drug to be metabolically reduced to levels that are not of public health concern. One control method is the purchase of feed from a reputable supplier that can guarantee the quality of its products, and the use of approved veterinary drugs administered by qualified personnel according to manufacturers' specifications. If the supplier has an effective quality assurance system, the fish feed will be safe for use. Supervision of the use of approved veterinary drugs and the monitoring of withdrawal times by qualified personnel will keep the CCP related to feed quality under control. Any chemicals used in aquaculture should be labelled with detailed information on active ingredients, potential hazards and recommendations as to use. Such information may need to be printed in different languages. If monitoring shows that unapproved chemicals have been used or

that approved drugs have been misused, the affected fish should be isolated and their withdrawal times extended.

6.3.4 ***Production (growout)***

Aquaculture production includes the selection of breeding stock, the rearing of fry and fingerlings and the growth of adult fish. There are wide variations in methods and practices for the production of different species. Hazards can be associated with the various production stages of aquaculture as a result of the use of agrochemicals or biological contamination. Finfish and crustaceans are sometimes harvested from coastal zones or inland habitats exposed to environmental contaminants. Veterinary drug residues or heavy metals may accumulate in aquaculture products at levels of concern for public health. Insecticides and herbicides can contaminate fish ponds through agricultural run-off and lead to unacceptable levels of these compounds in products from aquaculture (see section 5.5). Antibiotic residues can occur when correct withdrawal times are not observed or the sale and use of antibiotics are not controlled. Heavy metals can be a cause for concern if there is leaching from soil or environmental contamination by industrial wastes, sewage or oil spills.

Where national guidelines or standards regarding the safety of food additives, veterinary drug residues and chemical contaminants in products from aquaculture do not exist, recommendations published by the Joint FAO/WHO Expert Committee on Food Additives can be used as critical limits. Monitoring for pollution, the controlled use of approved veterinary drugs, and the use of control measures as necessary will guarantee the production of safe food products from aquaculture. Tables 5 and 6 summarize some of the chemical hazards, risks and appropriate control measures associated with inland and coastal aquaculture systems.

6.3.5 ***Verification procedures***

Verification of a HACCP plan for aquaculture production involves technical review by qualified personnel to verify that the CCPs are satisfactorily controlled, that the critical limits are adequate to ensure food safety and that the HACCP system is functioning effectively.

6.3.6 ***Record keeping***

Record keeping is central to implementing a HACCP system. The preparation of the HACCP plan and its implementation, including

Table 5
Chemical hazards, risks and appropriate control measures associated with principal inland aquaculture systems

Physical environment	Type of management/input	Chemical hazard	Qualitative estimate of risk	Control measures
Rice fields and swamps	Extensive or semi-intensive	Non-persistent pesticides Persistent pesticides	Low Low	Delay in harvest Monitoring for conformity with limits
Ponds	Extensive Semi-intensive mono- or polyculture Semi-intensive small-scale integrated/nightsoil, agricultural by-products and livestock manure Semi-intensive/livestock manure and fish Semi-intensive/wastewater Semi-intensive/nightsoil Intensive/slaughterhouse waste Intensive/formulated feed	Non-persistent pesticides Non-persistent pesticides Livestock chemotherapeutants Livestock chemotherapeutants Persistent hydrocarbons None Livestock chemotherapeutants Feed contaminants ^a	Low Low Low Low Low Low Low Low	Delay in harvest Delay in harvest Monitoring for conformity with limits Monitoring for conformity with limits Monitoring for conformity with limits Monitoring for conformity with limits Monitoring for conformity with limits Monitoring for conformity with limits, on-farm feed management
Tanks and raceways	Intensive	Pollutants in ambient water; feed contaminants ^a	Low	Application of WHO standards on waste-water use, monitoring for conformity with limits, on-farm feed management
Cages	Semi-intensive Intensive/trash fish Intensive/formulated feed	Pollutants in ambient water None Feed contaminants ^a	Generally low, locally may be medium Low	Proper site selection Monitoring for conformity with limits, on-farm feed management
Pens	Extensive or semi-intensive	Pollutants in ambient water; feed contaminants ^a	Generally low, locally may be medium	Proper site selection; monitoring for conformity with limits, on-farm feed management

^a Heavy metals, mycotoxins, chlorinated hydrocarbons.

Table 6
Chemical hazards, risks and appropriate control measures associated with principal coastal aquaculture systems

Physical environment	Type of management/ input	Chemical hazard	Qualitative estimate of risk	Control measures
Ponds	Extensive Semi-intensive mono- or polyculture Intensive/ formulated feed	Pollutants in ambient water	Generally low, locally may be medium	Proper site selection
Tanks and raceways	Intensive	Pollutants in ambient water; feed contaminants; ^a chemotherapeutants	Generally low, locally may be medium; low; low	Proper site selection; monitoring for conformity with limits, on-farm feed management; monitoring for conformity with limits
Cages	Intensive/trash fish Intensive/ formulated feed			

^a Heavy metals, mycotoxins, chlorinated hydrocarbons.

any updates, should be fully documented. Generally, records should be maintained on file for a period of 2 years and should be available for inspection by the relevant regulatory authority.

7. Knowledge gaps and research needs

The Study Group concluded that there were considerable needs for information associated with the aquaculture sector of food production. The gaps in knowledge hinder the process of risk assessment and the application of appropriate risk management strategies with respect to food safety assurance for products from aquaculture.

7.1 Biological hazards

7.1.1 *Parasites*

The Study Group recognized the importance of trematode and, to a lesser extent, cestode and nematode parasites as public health problems, particularly in Asia. It also recognized that little information is available on the role of farmed finfish and crustaceans in the spread of disease associated with these parasites.

Further research needs to be conducted on the epidemiology of trematode infection in farmed fish in relation to foodborne illness in humans. Prior to establishing the comparative risk to human health from consumption of farmed and wild fish it is necessary to determine the levels of trematode infection in such fish and the influence of cultural practices of fish consumption. Research on the elimination during processing of parasites in fish should be given importance, particularly the ability of infective stages of these organisms to survive heat treatment. Freezing as a means of eliminating hazards associated with parasites in fish should be evaluated with respect to the possibility of allergic reactions and hypersensitivity caused by retained parasite tissue.

Stocking fish ponds with wild-caught fry or allowing wild fish to enter ponds is common practice in many areas. Epidemiological data should be obtained to evaluate the association of trematode infections in humans with such farming practices.

7.1.2 *Bacteria*

The Study Group concluded that unavoidable contamination of products from aquaculture by foodborne pathogens, such as *Salmonella* and *Vibrio* spp., sometimes occurs under current commercial farming conditions. Studies that apply molecular typing methods are required

to distinguish between these pathogens and those of human origin that may occur as a result of poor hygienic standards during post-harvest handling and processing. There is also a need to develop methods for the detection of enteroviruses in aquaculture systems.

In view of the importance of wastewater-fed aquaculture systems in some developing countries, the potential for the growth and survival of human enteric pathogens, particularly newly emerging strains of *Escherichia coli*, needs to be investigated.

In light of increasing international trade in foods, microbiological risk assessment methods are required in many areas of food production. The Study Group noted that such work was under way in the Codex Committee on Food Hygiene and recommended following the Codex guidelines for the conduct of microbiological risk assessment for products from aquaculture (82). However, the evaluation of such risks is constrained by the lack of quantitative data.

Specific areas in aquaculture where the Study Group identified the application of risk assessment methods as necessary are the use of moist animal-based feeds (e.g. trash fish, bivalves, slaughterhouse waste); the ecology of *Listeria monocytogenes* in salmon aquaculture; the development of resistant bacteria as a result of the use of antimicrobials in aquaculture; integrated animal fish farming systems; and wastewater-fed systems.

7.1.3 **Other biological hazards**

Little information is available regarding the possible accumulation of algal and cyanobacterial toxins in farmed finfish and crustaceans. Epidemiological evidence to date suggests that associated risks to human health are low. However, the Study Group considered this to be an area requiring further investigation.

7.2 **Chemical hazards**

7.2.1 **Agrochemicals**

Chemical fertilizers, water treatment compounds and disinfectants, when used according to manufacturers' instructions, do not pose food safety hazards in products from aquaculture, so no further research is required in relation to these compounds. However, such compounds can pose a threat to human health if they are misused, and good regulations and enforcement procedures together with farmer education are essential to minimize risks. Pesticides used in aquaculture can pose food safety hazards, and more quantitative information is needed on the types of compounds in use and whether pesticide

treatment of ponds can result in residue levels in farmed fish that are potentially harmful to humans. Such information is necessary for developing regulatory policies, educational outreach activities and establishing research priorities.

7.2.2 **Chemotherapeutants**

The Study Group identified the following research needs for the safe and effective use of chemotherapeutants in aquaculture:

- With respect to antimicrobial resistance, internationally agreed and validated methods to determine minimum inhibitory concentration are needed. Support from international bodies such as FAO and WHO would assist progress in this area.
- Agreed and validated methods of residue analysis that do not impose excessive costs on consumers or producers are needed for compliance monitoring.
- Because of the limited number of veterinary medicines approved for use in intensive aquaculture in some countries, research is needed to enable products approved in one regulatory regime to be used in another without the cost of duplicate approval procedures.
- In integrated aquaculture systems, fish may be inadvertently exposed to antimicrobials that are used in livestock production, giving rise to the development of antimicrobial resistance or unexpected residues in fish. The health implications of this type of production combined with antimicrobial use are poorly understood and more information is needed before a proper assessment can be made.

7.2.3 **Feed ingredients, additives and contaminants**

Information is needed on the transfer of feed contaminants to edible fish tissues and any implications of this for human health. Research should take into account differences in the uptake of feed ingredients between finfish and crustaceans.

8. **Conclusions and recommendations**

8.1 **Shared responsibility**

The Study Group recognized that the production of safe foods from aquaculture was the shared responsibility of governments, industry and consumers, each having an important role to play in the protection of human health. Action at all levels is required for the development of regulations and the provision of resources for enforcement

of, education and training in, and research on, responsible practices of aquaculture.

The Study Group recommended the adoption of an integrated approach to the control of hazards associated with products from aquaculture. This will require close collaboration between the health, agriculture and aquaculture, food safety and education sectors.

8.2 **Food safety assurance**

The Study Group recognized that while it is possible to apply the HACCP principles to intensive commercial aquaculture systems, their application to small-scale, subsistence systems is difficult. Further investigation is needed to identify practical control measures for wastewater- and especially sewage-fed aquaculture systems and for systems using livestock manure and moist animal-based feeds. Some preliminary work to test the application of the HACCP principles for the control of fishborne trematode infections in Thailand and Viet Nam has been conducted on small-scale extensive fish farms under the auspices of FAO. However, further work, including scientifically adequate statistical analysis and replication, should be conducted to evaluate the effectiveness of HACCP-based methods in these systems.

Food safety assurance should be promoted by national fisheries inspection and extension agencies and included in fish-farm-management extension programmes. Food safety assurance should form an integral part of the farm-to-table food safety continuum. There is an urgent need to develop strategies to assist small-scale subsistence farmers in such programmes.

8.3 **Safe food processing**

Fishborne trematodiasis was recognized by the Study Group as an important cause of morbidity in various parts of the world. Research is required on the survival of encysted metacercariae in edible fish tissues during traditional processing and preparation. WHO should coordinate research in this area.

8.4 **Food safety education**

Food safety concerns associated with aquaculture are predominantly a problem in communities where eating raw or inadequately cooked fish is a cultural practice. Control strategies should focus on bringing about changes in traditional consumption practices. The potential risks of disseminating foodborne bacterial pathogens in products

from sewage-fed aquaculture systems need to be brought to the attention of consumers.

There is an urgent need to raise the awareness of fish farmers, especially small-scale rural subsistence farmers, of food safety issues associated with farmed fish and of the impact of the consumption of contaminated food on human health.

Education in the basic principles of food safety assurance should be integrated into existing regional and national training courses for aquaculture development, and WHO is urged to provide leadership in this initiative.

8.5 **Safe use of chemicals in aquaculture**

The Study Group recognized that while risks to human health from chemicals used as fertilizers and water treatment compounds are low, the risks from residues of chemotherapeutants in edible portions of finfish and crustaceans can be significant in countries where the sale and use of these compounds are uncontrolled. National governments are urged to enforce a licensing system for chemicals used in aquaculture and to establish withdrawal times appropriate to environmental conditions and fish species.

As certain pesticides required in aquaculture can pose food safety hazards, more information is needed on the types of compounds used. Studies should be conducted to determine whether the use of pesticides can result in residue levels in fish tissue that are potentially harmful to human health.

8.6 **Research needs**

The Study Group recommended collaboration at the national, regional and international levels to address the research needs identified in section 7.

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