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Food safety hazards and the application of the principles of the hazard analysis and critical control point (HACCP) system for their control in aquaculture production

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Abstract

During the past 20 years there has been a dramatic global expansion in fish farming, with both positive and negative consequences. Although commercial aquaculture has contributed positively to the economies of many producing countries, there are considerable negative environmental and social impacts. In intensive and semi-intensive systems, artificial feeds supplemented with antibiotics are used to prevent the spread of disease and to improve feed conversion ratios. Current knowledge of the health and environmental impact of antibiotics used in aquaculture is poor, particularly in tropical regions. Residues may remain in fish used for human consumption and antibiotics released into the environment can lead to the development of antibiotic-resistant bacteria in the food chain. The accumulation of waste feeds in ponds stimulates the growth of bacteria, including human pathogens, which can contaminate products and lead to foodborne disease and the rejection of products in export markets. In extensive systems, where fish are produced mainly for the domestic market, different food safety concerns exist. The consumption of aquatic plants and raw or partially cooked freshwater fish has been associated with foodborne trematode infections. These are a major public health problem in East and South East Asia and occur when products that are contaminated by the infective stages of the parasites are consumed. This paper reviews food safety hazards associated with products from aquaculture and proposes the application of principles of the hazard analysis critical control point (HACCP) system as a general strategy to control the hazards identified.

Introduction

The hazard analysis and critical control point (HACCP) system is a management tool for food safety assurance. It can be applied at any stage in the food chain, from the point where food is produced to the point of consumption. HACCP 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 farming safe aquatic foods into the hands of the aquaculture sector. When the system is applied at the primary food production level, specific hazards and control measures are identified, food safety controls are integrated into the production process, leading to reduced requirements for end-product testing, and a cost-effective use of resources is assured. The principles of HACCP should form an integral part of the fish 'farm-to-table' food safety continuum, thereby increasing consumer confidence in cultured products 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. The USFDA (1994) estimated that the introduction of

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HACCP by fish processors in the United States has averted some 20–60% of cases of seafood-borne illnesses. 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. Failure by countries to adopt and implement food safety assurance systems based on the HACCP concept will ultimately undermine export trade in fishery products, with considerable economic consequences.

Fish and fishery products have always been regarded as nutritious and healthy components of the human diet. Risks to consumer health from seafoods captured in unpolluted marine environments are low, provided these products are handled in line with principles of good manufacturing practice. The risks of foodborne disease associated with products from aquaculture are related to inland or coastal ecosystems, where the potential of environmental contamination is greater when compared with capture fisheries. Most of the food safety hazards associated with products from aquaculture can be controlled by good fish farm management practices and appropriate consumer education regarding such risks as eating raw or partially cooked products that may contain parasites or pathogenic bacteria.

The introduction of safety assurance systems, based on the HACCP principles, in fish farm management may initially add to the costs of aquatic products. However, the cost of placing unsafe food products on the market can be detrimental to the reputation of the fish farming sector in terms of product rejection in international markets and costs of foodborne disease to national economies. This paper discusses food safety hazards associated with finfish and crustaceans from aquaculture and proposes improved fish farm management practices based on the HACCP system as the desirable option to ensure safe food products from aquaculture.

Aquaculture production

During the past 20 years there has been a dramatic global expansion in fish farming and the potential exists to double this production over the next two decades. The increasing global importance of aquaculture is directly related to the contribution it makes towards reducing the gap between supply and demand for fish and fishery products. With overexploitation in the capture fisheries sector in some regions of the world, initiatives to strengthen environmentally friendly and sustainable aquaculture development, particularly among small-scale producers, need to be pursued to ensure a maximum contribution to world food security. Worldwide fish and fishery product production from aquaculture amounts to about 14 million tonnes, of which about 88% come from inland habitats (FAO 1994). Approximately 90% of global aquaculture production is based in Asia, where it provides an important source of dietary protein of the region and income for many small-scale farmers. Commercial aquaculture contributes significantly to the economies of many producing countries, where high-value species are a major source of foreign exchange.

There are many different forms of aquaculture that are practised around the world, ranging from small-scale subsistence fish farming to intensive commercial operations. These include brackish water shrimp ponds in South East Asia; integrated fish farming, where poultry or pig manure fertilizes pond water (widely practised in Asia); rice–fish farming, where farmers raise fish in ricefields as an additional source of income; wastewater-fed fish ponds, such as the Calcutta wetlands (Mara, Edwards, Clark & Mills 1993) with an annual production of ~ 13 000 tonnes; and freshwater fish farms and cage culture of salmon, widely practised in northern Europe, Australia, Canada and certain countries in South America. Aquaculture products include those that are cultured in coastal zones and inland environments. A practical classification is proposed as follows.

Coastal
- Marine
  - Cage culture (e.g. salmon farms)
  - Molluscan shellfish culture (e.g. oyster and mussel farms)
  - Seaweed culture
  - Prawn/shrimp farms
- Brackish water
  - Prawn farms (e.g. *Penaeus monodon* in South East Asia)
  - Fish farms
  - Cage culture

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Inland

- Fish farms (freshwater)
- Prawn culture (e.g. *Macrobracium* spp.)
- Cage/pen culture in lakes and rivers
- Integrated fish/animal systems (poultry, pigs, ducks in Asia)
- Integrated rice/fish systems.

Food safety hazards

A hazard is defined as a biological, chemical or physical agent or factor with the potential to cause an adverse health effect. Consumption of fish and fishery products is associated with a variety of human health hazards (Reilly, Howagte & Käferstein 1997). The risk of adverse health effects from particular hazards might be increased under certain circumstances in aquaculture products compared with fish from marine environments. Potential food safety hazards will vary according to the system of culture and may include foodborne trematode infections, foodborne disease associated with pathogenic bacteria, veterinary drug residues, and contamination by agro-chemicals and toxic metals. The reasons for these food safety issues are diverse, ranging from poor aquacultural practices, uncontrolled sale and use of veterinary drugs, environmental pollution and cultural habits of food preparation and consumption. The principal food safety issues arise from:

- antibiotic residues arising from the uncontrolled sale and misuse of veterinary drugs in intensive and semi-intensive aquaculture systems;
- the use of recycled sewage of human and animal origin in extensive aquaculture systems for stimulating primary production of plankton as fish feed;
- contamination of ponds by agro-chemicals, such as pesticides, and industrial chemicals, and possible bioaccumulation of these compounds in farmed fish;
- integrated animal husbandry–aquaculture systems;
- the consumption of raw or inadequately cooked aquaculture products that harbour either the infectious stages of trematodes, resulting in foodborne trematode infections, or pathogenic bacteria, that will result in foodborne illness.

Biological hazards

Parasites

The parasites known to cause disease in humans and transmitted by fish or crustaceans are broadly classified as helminths. The great majority belong to two phyla and three classes – Aschelminthes, class Nematoda; and Plathyheminthes, classes Cestoda and Trematoda; but members of a third phylum – Acanthocephala – have also been implicated. Fish are parasitized by protozoans, but there are no records of human protozoan disease being transmitted by fish (Roderick & Cheng 1989).

Trematodes

Foodborne trematode infections are a major public health problem that has largely gone unrecognized by the health sector in recent years. WHO (1995a) has reviewed the public health significance of foodborne trematode infections, which occur endemically in some 20 countries. It has estimated that over 40 million people worldwide, mainly in eastern and southern Asia, are affected by fish-borne trematode infections. The trematode species concerned all have similar, complex life cycles involving two intermediate hosts. The definitive host is man and other mammals. The first intermediate host is an aquatic snail; the second a freshwater fish or crustacean. Foodborne infection takes place through the consumption of raw, undercooked or otherwise underprocessed freshwater fish or crustaceans containing the infective stages (metacercariae) of these parasites. Table 1 summarizes the distribution, the principal reservoirs and freshwater fish or crustaceans involved in the transmission of these parasites in the food chain (Abdussalam, Käferstein & Mott 1995). The most important parasites, with respect to the number of people affected, are the species of the genera *Clonorchis*, *Opisthorchis* and *Paragonimus*. The diseases caused by foodborne trematodes include cholangiocarcinoma, gallstones, severe liver disease and gastrointestinal problems.

Clonorchiasis, the disease caused by *Clonorchis*, is endemic in some countries in East Asia, although the distribution and populations affected vary from country to country (WHO 1995a). Nine species of snails serve as first intermediate hosts and a total of 113 freshwater fish species, mostly cyprinids, have been recorded as second intermediate hosts (dos Santos 1994). Opisthorchiasis is endemic in Thailand and Laos, and in some countries of the

Table 1 Fish- and shellfish-borne trematodes (Abdussalem *et al*. 1995)

Parasite	Distribution	Principal reservoirs (other than human)	Food involved in transmission to humans
Clonorchis sinensis	Widespread in China, including Taiwan and Hong Kong, Macao, Japan, Korea and Vietnam Migrants to many other countries found to be infected; cases in Hawaii attributed to consumption of fish imported from China	Dogs, cats and many other species of fish-eating mammals	Many species (about 110) of freshwater fish, mainly Cyprinidae (e.g. carp, roach, dace), most important being the stone moroko, *Pseudorasbora parva* (T. & S.) Metacercariae in fish muscles
Opisthorchis felineus	Commonwealth of Independent States (CIS), eastern and central Europe	Cats, dogs and other mammals that eat fish or fish wastes	Freshwater fishes of family Cyprinidae (whitefish, carp, tench, *Tinca tinca* (L.), etc.) Metacercariae in muscle and subcutaneous tissue
O. viverrini	Laos and north-eastern Thailand (Mekong River Basin)	Dogs, cats, fishing cats (*Felis viverrina*) and other mammals that feed on fish and fish wastes	Some ten species of freshwater fish including *Puntius orphoides* (carp) and *Hampala dispar* (trey khamann) Metacercariae in fish muscles
Heterophyes heterophyes	Mediterranean basin, especially Egypt and eastern Asia	Dogs, cats, jackals, foxes, pelicans, hawks and black kite	Brackish- and freshwater fish, especially mullet (*Mugil* spp.), tilapia and others. In Japan, species of fish genera *Acanthogobius* and *Glossogobius* also involved Metacercariae in muscle and skin
Metagonimus yokogawai and related species	Eastern and southern Asia	Dogs, cats, pigs and fish-eating birds	Freshwater fishes, such as sweetfish, *Plecoglossus altivelis*, dace, *Tribolodon hakonensis*, trout and whitebait Metacercariae in gills, fin or tail
Nanophyetus sp.	Eastern Siberia (mountain tributaries or Amur river) and parts of Sakhalin Peninsula, north-west USA	Dogs, cats, rats (?) and badgers	Salmonid and other fish Metecercariae in muscles, fins and kidneys
Spelotrema brevicaeca	Philippines	Sea birds	Crustacea, Amphipoda, Isopoda and Brachyura
Paragonimus westermani and related species in Asia, Africa and the Americas	Siberia, West Africa (Nigeria, Cameroon), the Americas (Ecuador to USA), Japan, Korea, Thailand, Laos, China	Domestic and wild carnivores that feed on crustaceans	Fresh- and brackish water crabs (*Eriocheir, Potamon*, *Parathelphusa*), crayfish and shrimps Metacercariae in muscles, gills, liver (hepatopancreas) and cardiac region (Wild boar meat suspected as a source of infection)
Haplorchis sp.	Eastern and southern Asia	Cats, dogs and fish-eating birds	Fish, frogs and toads Metacercariae in muscle

Commonwealth of Independent States (WHO 1995b). Two species of parasite are involved, *Opisthorchis viverinni* and *O. felineus*. The former is found mainly in Thailand and Laos, and the latter mainly in Russia, Ukraine and Kazakhstan. Paragonimiasis is endemic in some countries in East

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Asia (China and Korea), in South America (Ecuador and Peru) and in West Africa, but is not confined solely to these regions (WHO 1995b). Some 40 species of *Paragonimus* have been reported to cause disease, but by far the most common agent is *P. westermani*. The prevalence of paragonimiasis in Korea has decreased in recent years owing to environmental changes brought about by industrialization, changes in farming practices, and the loss of freshwater snail habitats (Cho 1994).

Most freshwater fish in foodborne trematodiasis endemic countries, with the exception of China, come from wild sources and not from aquaculture. Products from aquaculture moving in the international trade are generally free from infectious trematodes because these are usually frozen. Freezing fish at –10°C for at least 5 days has been found to be effective in killing metacercariae of *Clonorchis* and *Opisthorchis* (WHO 1979). Recommendations from the United States for products that are intended for consumption, either raw or after light cooking, include freezing throughout at either –20°C or below for 7 days (168 h) in a freezer or –35°C or below for 15 h in a blast freezer (Food Code 1995) in order to destroy the infective stages of these organisms. However, there is an increasing trade in live fish in South East Asia and Cross (1984) attributed an increase in the incidence of clonorchiasis in Hong Kong to the importation of pond-reared fish from China. Most freshwater and brackish water species that are farmed have been shown to be a host for one or more trematode species, and trematode parasite infection must be accepted as a hazard of aquaculture products. Unfortunately, there is a lack of quantitative information on the relative importance of aquaculture products in the spread of foodborne trematodes when compared with products from the wild, and on the survival of the infectious stages of these parasites during fish processing.

Nematodes

The definitive hosts of the nematodes causing disease in humans are piscivorous marine mammals such as seals. Marine invertebrates and fish are the two intermediate hosts and humans are infected when they consume raw or minimally processed products. Fish are the secondary hosts and are infected when they consume the invertebrate primary host or fish that are already infected. There are many species of nematodes and a very large number of species of fish, worldwide, are known to act as intermediate hosts. The most common species of nematode causing disease in humans is *Anisakis simplex*. The other species involved in anisakiasis in North America, Europe and Japan is *Pseudoterranova decipiens*.

Nematodes are commonly present in fish caught in the wild, most frequently in the liver and belly cavity, but also in the flesh (Roepstorff, Karl, Bloemsma & Huss 1993). Anisakiasis is an uncommon disease because the parasite is killed by heating (55°C for 1 min), and by freezing (–20°C for 24 h). There is a risk from fishery products consumed raw, for example sushi, or after only mild processing, like salting at low concentrations or smoking. The survival of *Anisakis* larvae in marinated herring has been discussed by Karl, Roepstorff, Huss & Bloemsma (1995), who found that storage times of 5–6 weeks were required to kill the larvae. Many countries now require that fish used for these mildly processed products be frozen before processing or before sale.

It has been reported that salmon farmed in the USA, Norway, and Scotland do not harbour nematodes (Deardorff & Kent 1989; Bristow & Berland 1991; Angot & Brasseur 1993). This freedom from nematodes is recognized by the European Commission and farmed salmon are excused from the provisions of the hygiene regulations that require minimally processed fish intended for consumption without cooking to be frozen before sale. This lack of infection is most likely due to 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, because in some systems the cultured fish are fed with raw fish.

Nematodes other than anisakids can be transmitted to humans by fish and shellfish, and have been reported to cause disease (Cross 1991; Deardorff & Overstreet 1991). Some of them have terrestrial animals as their definitive hosts and Deardorff & Overstreet (1991) have drawn attention to the possibility of infection of farmed fish raised in ponds from these sources.

Cestodes

Cestodes are tapeworms and the species of major concern associated with consumption of fish is the fish tapeworm, *Diphyllobothrium latum*. Humans are one of the definitive hosts along with other fish-eating mammals. Freshwater copepods and fish are the intermediate hosts. The plerocercoid is present

in the flesh of the fish and infects humans following the consumption of raw or minimally processed fish. The recorded epidemiology of *D. latum* shows it to be prevalent in Eastern Europe, including Russia (von Bonsdofff 1977), and it had been reported elsewhere in the world (Deardorff & Overstreet 1991). In 1977, an estimated 13 million carriers existed globally (Crompton & Joyner 1980).

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

Cestodes must be considered as hazards of aquaculture products in all environments, freshwater, brackish and marine. The parasites are widespread in the world, and their means of transmission cannot rule out their presence in aquaculture systems. Fish become infected by consumption of the first intermediate host or of infected fish and, as with nematode infections, the incidence of infection might be expected to be considerably less in systems using artificial feeds, but *D. ditremum* has been found in cage-reared salmon in a freshwater lake in Ireland (Roger 1991).

Bacteriological hazards

The level of contamination of aquaculture products by pathogenic bacteria will depend on the environment and the bacteriological quality of the water in which fish are cultured. There are two broad groups of bacteria of public health significance that will contaminate products – those naturally present in the environment, referred to as the indigenous microflora, and those introduced through environmental contamination by domestic and/or industrial wastes. Examples of indigenous bacteria include *Aeromonas hydrophila, Clostridium botulinum, Vibrio parahaemolyticus, Vibrio cholerae, Vibrio vulnificus, and Listeria monocytogens.* Non-indigenous bacteria of public health significance include members of the family Enterobacteriaceae such as *Salmonella* spp., *Shigella* spp. and *Escherichia coli*.

Indigenous pathogenic bacteria, when present in fresh cultured products, are usually found at fairly low levels, and where these products are adequately cooked, food safety hazards are insignificant. During storage, indigenous spoilage bacteria will outgrow the indigenous pathogenic bacteria, thus fish will spoil before becoming toxic and will be rejected by consumers. Additionally, non-pathogenic environmental strains of indigenous pathogens exist and simple, inexpensive tests are not readily available to distinguish between different forms. Food safety hazards may arise when farmed fish are eaten without being subjected to a bactericidal process, such as cooking.

Bacterial pathogens associated with coastal aquaculture will include the indigenous and non-indigenous groups cited above. *Clostridium botulinum* is ubiquitous in aquatic environments, although botulism is a relatively rare disease and fresh fish have never been implicated in human botulism (Huss 1994). *Aeromonas hydrophila* is widely found in aquatic environments. Some strains are important fish pathogens in aquaculture (Pillay 1990), while others have been implicated in foodborne disease (Morgan & Wood 1988). Foodborne disease associated with this organism is uncommon and some studies suggest that only circumstantial evidence exists between eating fish and *Aeromonas* infection (Ahmed 1991).

Vibrio spp. are very common in estuarine and coastal environments and a number of these organisms are human pathogens. They are particularly prevalent in tropical waters and can be isolated in temperate zones during the summer months. Both *Vibrio cholerae* 01 and *V. cholerae* non-01 have been isolated from brackish water cultured shrimp in South East Asia, where these were present in 2% and 33% of samples, respectively (Dalsgaard, Huss, Kittikun & Larsen 1995). In similar studies, *V. cholerae* non-01 was isolated at the 3% level in brackish water ponds in South East Asia (Reilly & Twiddy 1992) and in cultured shrimp in India (Nair, Bhadra, Ramamurthy, Ramesh & Pal 1991). *Vibrio parahaemolyticus* is a common marine and brackish water isolate, and is an important cause of seafood borne disease (Ahmed 1991). *Vibrio vulnificus* is frequently isolated from tropical cultured fish from marine and brackish water areas. Human infections from this organism are rare and the population most at risk are those with underlying illnesses or who are immunocompromised.

Listeria monocytogenes is widely found in the

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environment and is a potential hazard in ready-to-eat foods, such as smoked fish (Fuchs & Reilly 1992). The incidence of listeriosis associated with cultured fish is low. However, this species is important because of its ability to grow at refrigeration temperatures and because of its occurrence in ready-to-eat aquacultured fish products that have not undergone a listericidal process. *Listeria* spp., other than *L. monocytogenes*, are more common in tropical environments (Fuchs & Reilly 1992).

Fish cultured in coastal and brackish water environments can be exposed to contamination by bacteria of faecal origin resulting from disposal of sewage and land run-off. Species of *Salmonella* have been isolated from brackish water prawn ponds in South East Asia (Reilly & Twiddy 1992), and from a similar environment in India (Iyer & Shrivastava 1989). The principal serotype of *Salmonella* isolated from the South East Asian and Indian studies was *S. weltevreden*, a serotype not commonly associated with salmonellosis. Evidence exists to suggest that certain serotypes of *Salmonella* are part of the indigenous microflora of fish farms and these pose minimal risks to public health as most crustaceans are cooked prior to consumption. High levels of faecal coliforms have been reported in coastal and pond waters, and particularly in pond sediments in a major shrimp production area in Southern Thailand, but *Salmonella* was absent in all samples (Dalsgaard *et al.* 1995). Faecal coliforms, including *E. coli*, have been isolated from unpolluted warm tropical waters, where these organisms exist as part of the natural microflora (Hazen 1988**)**.

Bacterial pathogens associated with products from freshwater aquaculture will include all the indigenous and non-indigenous bacteria discussed for coastal and brackish water systems. *Vibrio* spp. tend to be less important as contaminants of freshwater systems as they are moderately halophilic and require low levels of salt for growth and survival. However, they cannot be overlooked and should be included in a hazard analysis. *Clostridium botulinum* type E has been reported in trout cultured in two European countries (Huss, Pedersen & Cann 1974; Cann, Taylor & Hobbs 1975). Although botulism associated with aquacultured fish is very rare, it also should not be overlooked in carrying out a hazard analysis.

Plesiomonas shigelloides is mainly found in fresh water where it has been reported to be associated with mortality in fish (Shotts, Gaines, Martin & Prestwood 1972) and has been implicated in outbreaks of gastroenteritis associated with drinking water and consumption of fish (Tarabeak & Porazikova 1973; Bhat, Shanthakumari & Rajan 1974; Tsukamoto, Kinoshita, Shimada & Sakazaki 1978). *Salmonella* has been reported in cultured fish; for instance, a survey in Japan showed that *Salmonella* species were present in 21% of eel ponds (Saheki, Kobayashi & Kawanishi 1989) and cultured catfish in the USA have been found to harbour *Salmonella* species with an overall incidence of 5% (Wyatt, Nichelson & Vanderzant 1979).

Use of wastewater in aquaculture

The use of animal and human wastes has been practised for centuries to fertilize fish ponds and this is still a common practice in Asia. Wastewater reuse is an economic necessity in arid and semi-arid regions of the world and serious risks to public health exist where these wastewaters contain heavy metals and chemicals of industrial origin. Organic wastes are an inexpensive source of nutrients essential for the growth of phytoplankton and algae that form the base of the food chain for fish and crustaceans. However, wastes of human and animal origin are also a source of pathogenic organisms that may be transmitted to humans via products of aquaculture. The IRCWD (1985) reviewed available scientific data regarding disease transmission associated with aquacultural use of excreta and wastewater. Conclusions were that clear epidemiological evidence exists for the transmission of trematode diseases, such as *Chlonorchis* and *Fasciolopsis*. There was no conclusive evidence for bacterial disease transmission by passive transference of pathogens by fish and aquatic plants, although it was recognized that this risk does exist. Based on these conclusions, guidelines for the safe use of wastewater and excreta in agriculture and aquaculture were developed (WHO 1989). These recommend the absence of trematode eggs (zero eggs per litre or kilogram) and less than 10 000 faecal coliforms per 100 mL (or 100 g) of pond water. It is possible to achieve these recommended guidelines by minimal treatment of wastewater prior to use for fish culture (Ling, Den, Lu, Min, Wang & Yuan 1993; Mara *et al.* 1993).

Antimicrobial resistance

A further potential bacteriological food safety hazard exists from the use, especially the uncontrolled

use, of antibiotics as therapeutic agents, growth promoters and for increasing the efficiency of feed utilization in intensive and semi-intensive aquaculture systems. The hazard is related to the development of antibiotic resistance in the pond microflora. Resistance to antibacterial agents is a major global public health problem and one that is increasing as these agents continue to lose their effectiveness (WHO 1995b). In some parts of the world, the sale and use of antibiotics in aquaculture are unregulated (Choo 1994), however, in others, strict controls are implemented (Yndestad 1993). The public health consequences of using antibiotics as growth promoters in animals were reviewed by Levy (1987). However, the current knowledge of the health and environmental impact of antibiotics used in aquaculture is poor, particularly in tropical regions. There is a lack of sufficient epidemiological data to indicate that use of antibiotics in aquaculture can result in the transfer of antibiotic resistance from fish pathogens to human pathogens and thus into the food chain. However, the lack of data linking human illness with the therapeutic and subtherapeutic use of antibiotics in aquaculture does not mean that a hazard does not exist. Evidence suggests that human infections with drug-resistant bacteria double the risk of severe disease and hospitalization when compared with drug-susceptible strains (Holmberg, Solomon & Blake 1987)

Smith, Hiney & Samuelsen (1994) concluded that the risk to public health caused by the development of antibacterial resistance in aquaculture was minimal, as diarrhoeal diseases are not usually treated by antibiotics unless the disease is severe. D'Aoust, Sewell, Daley & Greco (1992) surveyed antibiotic resistance of agricultural and foodborne *Salmonella* isolates over a three-year period in Canada and their findings underscored a disturbing level of antibiotic-resistant *Salmonella* in the food chain. This study highlighted the need to reassess the use of subtherapeutically medicated feeds in animal husbandry practices. A similar survey in India over a two-year period (Hata & Lakshmanaperumalsamy 1995) on *Salmonella* isolated from fish and crustaceans found over 90% of isolates resistant to a range of antibiotics. Epidemiological studies in the USA (Cohen & Tauxe 1986) have traced antimicrobial-resistant *Salmonella* to foods of animal origin. Hayashi, Fuse, Inoue & Mitsuhashi (1993) found that more than 50% of *Vibrio* spp. isolated from the intestinal tracts of farm-cultured yellowtails in Japan were resistant to tetracyclines and chloramphenicol.

Transferable drug resistance was demonstrated in bacteria isolated from marine sediments collected from beneath fish farms in Norway (Sandaa, Torsvik & Gokoyr 1992). A range of bacteria were isolated that showed multiple antibiotic resistance which was plasmid borne and which had the ability to transfer resistant plasmids to non-fish pathogens, such as *E. coli*. The authors concluded that the pool of resistance genes in the marine environment is amplified by the use of antibiotics and/or chemotherapeutic agents in aquaculture, and that the transfer of resistance to pathogenic bacteria is possible. Similar findings were reported by Nygaard, Lunestad, Hektoen, Berge & Hormazabal (1992) where a significant increase in the percentage of drug-resistant bacteria was found in marine sediments containing antibacterial agents. Also, Spanggaard, Jorgensen, Gram & Huss (1993) compared antibiotic resistance in bacteria from fish farms using antibiotics with those from an unpolluted aquatic environment in Denmark and found higher resistance in the fish-farm isolates. Multiple antibiotic resistance was reported in a range of human pathogens from fish and pond sediments in integrated poultry–fish aquaculture systems in South East Asia (Twiddy 1995). Antibiotic resistant strains of *Salmonella*, *Aeromonas hydrophila* and *Plesiomonas shigelloides* were found and attributed to the presence of antibiotic supplements in the poultry feed. On a cautionary note, severe human illness due to *P. shigelloides* is treated with antibiotics, tetracycline being one of the effective drugs (Miller & Koburger 1985), and strains isolated in the South East Asian study were resistant to tetracycline. Similarly, *Aeromonas hydrophila* is an opportunistic human pathogen and tetracycline is commonly used to treat aeromonas infections in humans (DePaola, Flynn, McPherson & Levy 1988); *A. hydrophila* from this and other studies have been reported as being resistant to oxytetracycline (McPhearson, DePaola, Zywno, Motes & Guarino 1991).

Recommendations for developing strategies to decrease the emergence and dissemination of resistant organisms in veterinary medicine and the environment (WHO 1995b) include the control and regulation of sale and use, ensuring that antimicrobial agents are not used as a substitute for adequate hygiene in animal husbandry and aquaculture, prohibiting the use for growth promotion of any antimicrobial used in human

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therapeutics, and ensuring that the public is informed about the potential risks to humans of antibiotic use in animal husbandry and aquaculture.

Chemical hazards

Fish and crustaceans may be harvested from coastal zones and inland habitats that are exposed to varying amounts of environmental contaminants. Agro-chemicals, veterinary drug residues and heavy metals may accumulate in aquaculture products at levels that can cause public health problems. Insecticides and herbicides used near aquaculture operations may contaminate fish ponds through agricultural run-off and lead to unacceptable levels of these compounds in products. Antibiotic residues can occur in products when correct withdrawal times are not followed or when antibiotic sale and use are not controlled. The levels of heavy metals and other industrial pollutants can be a cause for concern when these are either leached from the soil or find their way into fish ponds through environmental contamination by industrial wastes or animal manures.

Agro-chemicals

Agro-chemicals used in agriculture and aquaculture that can accumulate in cultured fish species include a range of insecticides, herbicides, algicides, fungicides, disinfectants and antioxidants. In general, at least three special properties are required for a contaminant to accumulate in the aquatic food chain (Clarkson 1995). Firstly, it must be fairly insoluble in water (have a high octanol–water partition coefficient); secondly, it must be chemically and metabolically stable in water and in the organisms in the food chain; and thirdly, it must have low toxicity to the organisms in the chain so the prey–predator relationship is not broken.

Modern agriculture depends on the appropriate use of agro-chemicals to reduce crop losses and to produce affordable foods of dependable quality. WHO in collaboration with FAO have evaluated over the past 30 years the health risks posed by pesticide residues in foods. Through the Codex Alimentarius Commission, maximum residues levels for foods are recommended to governments. Products complying with these guidelines, which are based on the best available scientific information, are safe and nutritious and offer adequate health protection. However, human exposure through the consumption of aquatic foods has never been explicitly considered by Codex.

Potential food safety hazards exist where the sale and use of agro-chemicals are not regulated, from accidental exposure or where there is a risk of bioaccumulation of certain chemicals in the food chain. The magnitude of human exposure to agro-chemicals via the aquaculture food chain has not yet been fully assessed and the limited data available suggest that further studies are warranted. The potential for accumulation of certain pollutants within tissues of cultured species increases their potential as food safety hazards, even though the pollutants may be present at low initial levels in the water. For instance, high levels of chlorinated hydrocarbon pesticides have been reported in pond-cultured fish in Hong Kong (Ip 1990). A recent study that focused on fatty fish from the Baltic Sea (Rylander & Hagmar 1995) suggests that there is a link between the increased risk of breast cancer and the consumption of fish contaminated with persistent organochlorine compounds. Various studies have reported the bioaccumulation of chlorinated aromatic compounds, such as PCBs, DDT and related pesticides in fish from freshwater bodies (Perry, Gasith & Mozel 1983; Camanzo, Rice, Jude & Rossmann 1987; Swackhamer & Hites 1988; Urdaneta, Median & Acosta 1995). There is a higher risk that substances that are poorly metabolized and excreted by living organisms will accumulate in the aquatic food chain when compared with terrestrial animals used for foods. This risk arises because of the predatory nature of fish.

In certain parts of the world, a unique risk to human health is posed by culturing fish for human consumption in rice fields. Rice–fish farming in Asia is a practice that has existed for centuries, but with the introduction of new high-yielding varieties of rice that require the application of pesticides, the practice needs to be reviewed from a food safety perspective. Cagauan & Arce (1992) reported on the use of pesticides in South East Asia and effects on rice–fish farming. They concluded that carbamates and organophosphates were less toxic to fish than organochlorines and synthetic pyrethroids, and recommended the use of pesticides that degrade in less than 5–7 days as suitable for rice–fish culture. Meier, Fook & Lager (1983) reported the bioaccumulation of organochlorine pesticides in fish cultured in rice–fish systems over a six-month period. Populations eating fish cultured in rice fields where

pesticides have been applied are likely to be exposed to higher concentrations of pesticides in their diets. Fish cultured in this way are unlikely to be marketed in international trade and the problem must be solved at national level.

Antibiotic residues

With the increased use of veterinary drugs in food production, there is global concern about the consumption of low levels of antimicrobial residues in aquatic foods and the effect of these residues on human health. This concern is not limited to aquaculture products alone, but to all foods of animal origin where the use of antibiotics has become an integral part of intensive animal husbandry. However, the prophylactic use of antibiotics has led to a decrease in the costs of food production and a wider consumer choice, a good example being the wide availability of farmed aquatic products. With the successful development of vaccines against fish diseases over the past five years, the use of antibiotics has fallen dramatically in intensive aquaculture systems. When antibiotics are used according to recommended guidelines, foods from the aquatic food chain are unlikely to pose higher public health risks from antibiotic residues when compared with foods from land animals, where antibiotics are also used as growth promoters and for disease control.

Where antibiotics are incorrectly used or withdrawal times are not observed, residues in fish flesh may pose a potential threat to consumers, especially those who are hypersensitive, leading to possible allergic reactions. Safe levels of residues for some of the more common antibiotics used in aquaculture have been recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA 1996).

Concern has also been expressed about the effects of low levels of antibiotics on the microflora of the human intestine, although little has been reported on this topic. The occurrence of antibiotic residues in cultured shrimps in South East Asia has led to rejection of produce in export markets (Saitanu, Amornsin, Kondo & Tsai 1994). Common food processing methods do not seem to decrease levels of antibiotics, if present in food of animal origin. The effects of cooking and cold storage on residues of antibiotics in products of animal origin are minimal (O'Brien, Campbell & Conaghan 1981; Epstein, Randecker, Corrao, Keeton & Cross 1988); no similar reports exist for fish flesh.

Heavy metals

Water is a powerful solvent and water bodies become the ultimate recipients of a wide range of chemicals, some derived from natural sources and others as waste products originating from human activities. Some heavy metals are very toxic while others pose minimal public health problems. Ahmed (1991) classified metals according to their potential to cause food safety problems, and assessed those of public health concern in aquatic foods to include arsenic, cadmium, lead, mercury and selenium.

Mann & Ryther (1979) studied heavy metal accumulation by organisms grown in a pilot-scale marine waste recycling system using secondary treated sewage effluents. Their data suggest that heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) constitute a minimal public health problem in organisms cultured for human consumption in waste-recycling systems that contain relatively small volumes (1.8–2.4% v/v) of effluent. Hejkal, Gerba, Henderson & Freeze (1983) found increased levels of Hg and Cu in the flesh of carp grown in waste stabilization ponds, with levels of Hg in some samples exceeding the acceptable limit for edible portions of fish. Both Cu and Hg were bioaccumulated by fish during a four-month growing period, where levels of Hg were 70-fold higher than the average concentration found in the water from which the fish were taken. Pandey, Sarkar, Bhowmik & Tripathi (1995) examined 10 fish samples from the Calcutta sewage-fed aquaculture system and found no evidence of bioconcentration of Cu, Fe, Zn or Cr in fish products.

The principal area of concern in aquaculture is from the use of wastewater or sewage that may contain heavy metals or from industrial pollution of coastal zones where fish are cultured. A secondary area is from leaching of metals from soils owing to acidic conditions. The bioconcentration of heavy metals in farmed fish poses a serious public health threat, demonstrates the need to be extremely cautious in the use of wastewater that contains industrial effluents for aquaculture, and emphasizes the necessity for controlling the quality of water used for fish farming. The challenge that

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faces the aquaculture sector is to develop criteria that are not overly restrictive to the beneficial use of wastewater in fish farming and yet protect public health from harmful effects of toxic chemicals or other substances that may be present in effluents.

Aquatic biotechnology

The application of genetic engineering and biotechnology to aquaculture production is a relatively new field and one that has important potential for the future contribution of aquaculture to the food supply. Some examples include genetic improvement of stocks, enhanced growth rates, a wider range of species adapted for cultivation, greater disease resistance, vaccine development and improved ability to survive adverse environmental conditions. Through genetic modification, it is possible to breed for improved quality characteristics, such as colour, fat content, body shape and size (Mohr 1994). Advances in fish biotechnology include the modification of growth hormone genes in cultured salmon and trout, resulting in enhanced growth rates (Purdom 1994; MacKenzie 1996), and the introduction of genes that code for the antifreeze protein that will allow farmed fish to tolerate lower temperatures. Vaccine development will reduce the reliance on antibiotics for disease control in intensive culture systems.

Evaluation of transgenic fish from a food safety hazard viewpoint should include an analysis of the inserted DNA, the gene product and of the potential pleiotropic effects (Kryspin-Sorensen 1994). The application of modern biotechnology to aquatic organisms is unlikely to increase risks to human health (WHO 1991; OECD 1994). However, it is important to effectively communicate issues related to aquatic biotechnology to the public and to allay public concerns related to the release of transgenic fish into the environment.

Application of HACCP to aquaculture

While the implementation of HACCP-based safety assurance programmes are well advanced in the fish processing sector, the application of such programmes at the fish farm, to enhance food safety, is in its infancy. The aquaculture sector is not unique in this respect and there are certain stages of the food chain that are ideally suited to the application of HACCP principles. There are few examples of the application of HACCP principles in animal husbandry because of the lack of scientific data regarding the appropriateness of on-farm control of pathogenic micro-organisms. However, national and international agencies continue to recommend and promote the HACCP-based approach for all stages of the food chain, including application on the farm.

A prerequisite for implementing an HACCP system in any fish farming operation is that it must be preceded by compliance with the principles of good aquaculture practices. Good aquaculture (or good fish farming) practices are defined as those practices of the aquaculture sector that are necessary to produce quality food products conforming to food laws and regulations. The successful application of HACCP requires full commitment from the owner of the fish farm and the workforce, and will require a team approach.

In applying HACCP it is necessary to carefully examine the nature and extent of any hazards associated with methods of production and products from aquaculture. The first step is to assemble an HACCP team that should include a range of expertise in aquaculture production, relevant to the habitat and farming system. A multidisciplinary team could consist of experts in aquaculture, fish farm managers, 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. Products from aquaculture can be described as 'fresh fish 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 into value-added products or consumption of fresh products after thorough cooking. The next steps in the application of HACCP involve the preparation of a flow diagram and on-farm confirmation of the flow diagram. The flow diagram in Fig. 1 is a generalized model and will need to be modified according to specific fish farm conditions.

The next stage is to apply the seven principles of HACCP (CAC 1995), which have been adapted here to aquaculture production.

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 the measures for their control.

2 Determine critical control points (CCP). A CCP is a step where control can be applied and is essential

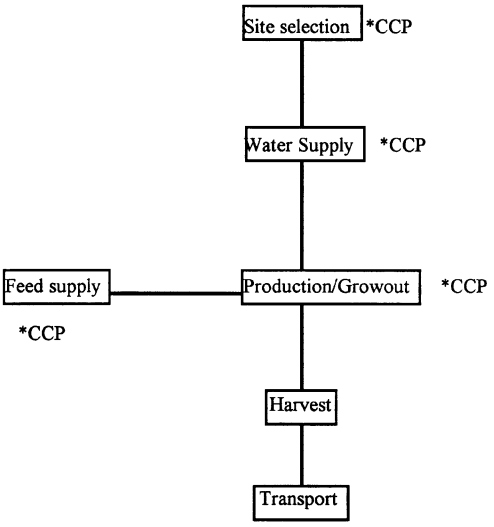

Figure 1 Model flow diagram for aquaculture production. CCP, critical control point.

to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

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

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

5 Establish the corrective actions that must be taken when monitoring indicates that a particular CCP is not under control.

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

7 Establish documentation concerning all procedures and records appropriate to these principles and their application.

Hazard analysis

There are four critical control points (CCPs) associated with the proposed model in Fig. 1, which are steps where control is necessary to prevent or eliminate a food safety hazard or to reduce it to an acceptable level. The CCPs are the site or location of the fish pond, the water supply, the feed supply, and production or grow-out steps. The nature of CCPs will depend on the aquaculture system and it is essential to consider the unique conditions that exist within each fish farm when developing an HACCP plan.

Site selection

The siting, design and construction of fish farms should follow principles of good aquacultural practice. CCP1 (the application of HAACP to site selection) may be summarized as follows.

Hazard
- Harmful chemical contamination

Control measures
- Review soil survey data when selecting farm site
- Implement pollution monitoring plan

Critical limits
- Water quality standards
- Soil limitation rating

Monitoring procedure
- Soil analysis of site and surrounding area
- Water analysis
- Survey pollution sources

Corrective action
- Water treatment
- Isolate batches of fish
- Relocate fish farm

Hazards may exist with the location of the fish pond and site selection, relating to chemical contamination of the environment and soil/water interaction that will influence water quality. Soil properties are directly related to the nutrients in the pond water, and such factors as acidity or alkalinity will be related to soil quality. Acidic soils may cause low pH and leaching of metals that may accumulate

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in fish. Fish farms can be subject to pesticide and chemical run-off from adjacent agricultural land or industrial sources, and this can lead to unacceptable levels of chemical contaminants in cultured products. Control measures involve activities that can be used to prevent or eliminate a food safety hazard or to reduce it to an acceptable level. Such measures relate to the selection of a site for locating a fish pond and will include a soil survey in order to establish the soil suitability for aquaculture. Fish ponds should be located in areas where the risk of contamination with hazardous chemical effluents is minimal and where sources of pollution can be controlled. Parameters that can serve as critical limits for soil rating and site selection for aquaculture have been established (Hajek & Boyd 1994).

Monitoring procedures include a sequence of observations or measurements to assess that a CCP is under control. With respect to the location of the fish pond, this will initially involve soil analysis in the immediate area, and will involve regular inspection of the locality for likely sources of pollution. Corrective actions have to be taken if the results of monitoring the CCP indicate a loss of control. If soil analysis shows that the site is not suitable to locate a fish farm, then an alternative must be found. Batches of fish may have to be isolated or pond water treated if unacceptable pollution of fish ponds occurs.

Water quality

In this proposed model, CCP2 (the application of HAACP to the quality of the water supply) may be summarized as follows.

Hazards
- Parasites
- Chemical contamination

Control measures
- Water supply selection
- Water treatment
- Eliminate foodborne trematodes or their intermediate hosts

Critical limits
- Conforming to national or international guidelines
- Absence of foodborne trematodes and intermediate host

Monitoring procedure
- Laboratory analysis or certification of the water supply
- Visual inspection for snails and fish infected with trematodes

Corrective action
- Alternative sources of water
- Isolate batches of infected fish
- Water treatment
- Remove parasites
- Re-condition ponds

Hazards that must be controlled include chemical and biological contamination. The hazards will vary according to location of the fish farm and system of culture. Fish grown in cages in coastal zones are less likely to be exposed to agro-chemical contamination when compared with inland fish farms, but might be exposed to chemical contaminants if sited close to discharges of industrial wastes or near to shipping lanes. The use of wastewater for fish culture 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 *V. cholerae* and *Salmonella*, and are a possible source of these organisms in fish farms, that are very difficult to control (Fenlon 1983; Ogg, Ryder & Smith 1989). Freshwater fish cultured in certain parts of the world that are endemic for trematodes may harbour the infective stages of these parasites.

Control measures can be readily applied for the prevention of chemical contamination through the choice of the water supply and water treatment, where necessary. Such treatment may be necessary to eliminate foodborne trematodes or their intermediate snail hosts, an important control measure where aquaculture products may be eaten raw or partially cooked. Snail control can be realized by means of the application of molluscicides, habitat modification or biological control. Habitat modification involves the removal of vegetation around the ponds that encourage proliferation of snails. Biological control by fish has met with limited success (Slootweg 1995). It is not possible to control contamination of products by pathogenic bacteria in all aquaculture systems. With respect to microbiological hazards associated with raw aquatic products, correct preparation in either the domestic or food service environments is the ultimate CCP that can eliminate these hazards.

International guidelines for the use of wastewater in aquaculture have been proposed by WHO (1989) and these criteria can be applied as critical limits for water supply quality. Critical limits would include

the absence of pathogenic trematodes or their snail intermediate hosts. Laboratory analysis or certification of the water supply may be necessary, depending upon the location of the fish farm. Corrective actions may include finding an alternative source of water, or some degree of water treatment may be necessary when the supply is contaminated. It may also be necessary to isolate batches of fish or to allow purification in clean water prior to sale, if the results of monitoring show that the water supply does not conform to critical limits.

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 phytoplankton and algae that form the base of the aquatic food chain. Compound pelletized feeds are used in intensive systems which are produced to manufacturers' specifications for specific stages in the life cycle of different species. CCP3 (the application of HAACP to feed supply) may be summarized as follows.

Hazards
- Biological or chemical contaminants
- Uncontrolled use of veterinary drugs

Control measures
- Obtain feeds from a reputable supplier
- Correct storage of feeds
- Selection of components for feeds prepared on-farm
- Supervised use of veterinary drugs according to manufacturers' instructions

Critical limits
- National or international guidelines
- Quantities used in line with manufacturer codes or regulatory limits

Monitoring procedures
- Certificates of quality from suppliers
- Laboratory testing
- Supervision of quantities used
- Withdrawal periods observed

Corrective action
- Reject uncertified feeds
- Isolate batches of fish
- Extend purification periods

The hazards associated with the feed supply may be biological or chemical contamination and the unregulated addition of veterinary drugs. Approved agro-chemicals and veterinary drugs must be used according to manufacturers' instructions and correct withdrawal times observed. The main cause of drug residue problems is failure to allow sufficient time between application and fish harvest for the drug to be metabolically reduced to levels that are not of public health concern. Feeds should only be purchased from reputable suppliers who can guarantee the quality of products. The use of veterinary drugs should be restricted to those that have been approved for aquaculture production and these should be administered by trained personnel, according to manufacturer's specifications. Confirmation of supplier quality assurance will guarantee that fish feeds are safe for use. Supervision by qualified personnel of the use of approved veterinary drugs and monitoring withdrawal times will keep this CCP under control. Uncertified feeds or those not conforming to specifications should be rejected. When monitoring shows that unapproved chemicals have been used or that approved drugs have been misused, batches of fish should be isolated and purification times extended.

Production/grow-out

Production includes the selection of breeding stock, rearing of fry and fingerlings, and grow-out of adult fish. There are wide variations in methods and practices of production of aquatic species. The application of HAACP to production/grow-out stages of aquaculture may be summarized as follows.

Hazards
- Agro-chemical residues
- Veterinary drug residues
- Foodborne pathogens

Control measures
- Use of only approved chemicals
- Use according to manufacturers' instructions
- Prevent contamination of fish farms

Critical limits
- Limits recommended in international codes of practice or national regulations

Monitoring procedures
- Supervision of type and use of agro-chemicals and veterinary drugs
- Monitoring treatment times and conditions
- Observance of withdrawal periods

Corrective action
- Isolate batches of fish where unapproved

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chemicals have been used or where an approved chemical or drug has been misused
Extend depuration times

Hazards are associated with the production or grow-out stages of aquaculture production relating to the use ago-chemicals and biological contamination. Fish and crustaceans may be harvested from coastal zones and inland habitats that are exposed to varying amounts of environmental contaminants. Agro-chemicals used in agriculture and aquaculture that can accumulate in cultured fish species include a range of insecticides, herbicides, algicides, fungicides, disinfectants and antioxidants. Veterinary drug residues and heavy metals may accumulate in aquaculture products at levels that can cause public health problems. Insecticides and herbicides used near aquaculture operations may contaminate fish ponds through agricultural run-off and lead to unacceptable levels of these compounds in products. Antibiotic residues can occur in products when correct withdrawal times are not followed or when antibiotic sale and use are not controlled. Heavy metals can be a cause for concern when these are leached from the soil or when, in combination with other industrial pollutants, they find their way into fish ponds or coastal zones through environmental contamination by industrial wastes or sewage and accidental oil spills.

Where national guidelines or standards regarding the safety of food additives, residues of veterinary drugs and chemical contaminants of aquatic foods do not exist, advisory data published by the Joint FAO/WHO Expert Committee on Food Additives can be used as critical limits. Continuous monitoring of potential sources of pollution and controlled used of approved veterinary drugs, and taking appropriate corrective actions where necessary, will guarantee production of safe aquatic products.

Verification of an HACCP plan for aquaculture production will involve a technical review by qualified personnel to verify that the CCPs are satisfactory; that the critical limits are adequate to ensure food safety; and that the HACCP system is functioning effectively.

Record keeping is an essential part of Good Aquacultural Practice and is central to implementing an HACCP system. The preparation of the HACCP plan, including updates, and its implementation, must be fully documented. Generally, records should be kept for a period of two years and be available for inspection by a regulatory authority.

Conclusions

There are many different methods of farming fish worldwide, ranging from intensive commercial operations to extensive small-scale or subsistence systems. Potential food safety hazards associated with aquaculture will vary according to the system that is practised and may include biological contamination, such as foodborne trematode infections and pathogenic bacteria, or chemical contamination by agro-chemicals, veterinary drug residues or heavy metals. The reasons for these food safety hazards are diverse, ranging from poor aquacultural practices, environmental pollution and cultural habits of food preparation and consumption. The implementation of the HACCP system in fish farms that have adopted good aquacultural practices, is recommended as a method to improve food safety of aquaculture products.

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