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Review

Foodborne Agents Associated with the Consumption of Aquaculture Catfish

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ABSTRACT

In the Food, Conservation, and Energy Act (Farm Bill) of 2008, Congress amended the Federal Meat Inspection Act to provide that catfish be inspected by the U.S. Department of Agriculture's Food Safety and Inspection Service (FSIS). As part of the development of its inspection program, the FSIS conducted an assessment of the food safety risk associated with consuming farm-raised catfish. To thoroughly identify hazards for consideration in the risk assessment, the scientific literature was surveyed for all potential agents that have been linked to illness associated with farm-raised catfish consumption. A review of microbial hazards suggested that *Salmonella* is the foodborne pathogen most likely to be associated with catfish, but the impact of other pathogens remains unclear. This review also summarizes the current data available on chemical residues in catfish, including pesticides and heavy metals, and any regulatory levels that have been established for these compounds. The current usage of veterinary drugs in aquaculture also is outlined, including information on unapproved usage of drugs in catfish.

Catfish are freshwater fish that have been commercially raised for food in the United States since the 1960s. Catfish is an important agricultural commodity that ranked as the sixth most frequently consumed aquatic food in the United States in 2008 *(77)*. U.S. consumption of catfish and international demand currently supports 115,000 acres (47,000 ha) of U.S. aquaculture catfish ponds, primarily within Mississippi, Alabama, Arkansas, and Texas *(76)*. In 2009, the United States imported more than 129 million pounds (59 million kg) of catfish from several countries, including Cambodia, Canada, China, Indonesia, Mexico, Panama, Peru, Thailand, and Vietnam *(75)*.

The species of catfish that accounts for virtually all of the commercial foodfish production in the United States is the channel catfish (*Ictalurus punctatus*), which belongs to the family Ictaluridae, order Siluriformes *(108)*. In recent years, other species of catfish within the order Siluriformes have been produced in Vietnam and imported into the United States in large quantities. Imports of basa (*Pangasius bocourti*), tra (*Pangasius hypophthalmus*), and swai (*Pangasius micronemus*) from Vietnam increased by about 800% from 1997 to 2002 *(108)*. China also produces a large quantity of catfish, including both channel catfish and basa *(43, 122)*.

In June 2008, the U.S. Congress amended the Federal Meat Inspection Act so that ''catfish, as defined by the Secretary,'' is considered an amenable species subject to regulation by the U.S. Department of Agriculture (USDA) Food Safety Inspection Service (FSIS) *(4)*. This classification has necessitated a comprehensive look at the foodborne hazards that could be associated with the consumption of catfish. To date, such a comprehensive literature review on the potential microbial and chemical hazards associated with catfish consumption has not been available. Most scientific literature on potential hazards has focused on ''catfish'' of the Ictaluridae, and limited information is available on possible hazards associated with related siluriforms farmed outside of the United States. To provide the most complete information possible, this review focuses on all available literature on siluriform catfish that addresses the prevalence of microbial hazards and chemical residues relevant to public health.

Microbial hazards considered include bacteria, viruses, and parasites. Most of the microbial hazards discussed in this review are known foodborne or waterborne bacteria that can cause human illness. Nonpathogenic bacteria that may be indicators of fecal contamination, process control, or spoilage also have been included in this review. Chemical residues in catfish products include veterinary drugs and environmental contaminants, such as pesticides and heavy metals.

MICROBIAL HAZARDS ASSOCIATED WITH CATFISH CONSUMPTION

Although catfish are generally thought to be low-risk vehicles for microbial foodborne illness because the shelf life is very limited and food preparation methods typically destroy foodborne pathogens, some outbreak data suggest that consumption of catfish may contribute to human illness.

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TABLE 1. *Nonmarine fish–associated outbreaks of foodborne illness with confirmed etiological agent (1998 through 2007)*[a]

Confirmed etiological agent	Illnesses No.	Illnesses %	Outbreaks No.	Outbreaks %
Salmonella	160	54.24	5	35.71
Norovirus	62	21.02	2	14.29
E. coli (enterotoxigenic)	41	13.90	1	7.14
Clostridium botulinum	12	4.07	4	28.57
Staphylococcus aureus	17	5.76	1	7.14
Bacillus cereus	3	1.02	1	7.14
Total	295	100	14	100

[a] From the CDC Foodborne Outbreak Online Database, 1998 through 2007 *(19)*.

According to the foodborne disease outbreak database of the Centers for Disease Control and Prevention (CDC), seven reported catfish-associated illness clusters or events were reported, with an estimated total of 66 illnesses, from 1991 to 2007 *(19)*. In 1991, 10 cases of salmonellosis associated with a New Jersey restaurant were attributed to *Salmonella* Hadar *(15)*. Investigation of the New Jersey outbreak clearly implicated catfish as the vehicle of transmission. As is common for foodborne disease investigations, the results were unclear about whether catfish served as the primary vehicle of illness for the remainder of the reported outbreaks or whether other foods may have played a role. One of these outbreaks involved 41 illnesses caused by enterotoxigenic *Escherichia coli* (ETEC) serotype O169:H49 following a catered party in Tennessee in 2003, where catfish and coleslaw were implicated as the vehicles for illness *(10)*. With regard to outbreaks associated with wild catfish, *Grimontia hollisae* (formerly known as *Vibrio hollisae*) was implicated in the foodborne illness of an elderly man who had eaten wild-caught catfish *(62)*.

Because few catfish-associated outbreaks have been documented, we reviewed the CDC data from 1998 to 2007 for outbreaks of foodborne disease associated with nonmarine fish *(19)*. Fourteen such outbreaks with confirmed etiological agents were reported to the CDC, which suggests that consumption of nonmarine fish was linked to approximately 295 human illnesses from 1998 to 2007 (Table 1): 54% of these cases were associated with *Salmonella,* and 21% were associated with norovirus (Table 1).

When analyzing foodborne outbreaks in which ''nonmarine fish'' was recorded as the vehicle, it is not clear how many outbreaks were associated with catfish. Raw fish products have been reported as vehicles for foodborne illness *(109)* and, like raw meat and poultry, offer the potential for cross-contamination in food service establishments and consumer kitchens *(63)*.

Of the few studies in which the potential for farm-raised catfish products to harbor microorganisms has been explored, some have included comparisons of the aquatic environment to catfish microbial loads, while others have focused on the processing equipment or on retail catfish products. This review covers reports from three decades, with the caveat that although some older reports have been included, it is unclear whether data from these studies reflect the current state of sanitation, aquaculture, and food technology.

Salmonella. *Salmonella* is among the leading agents of foodborne disease in the United States *(24),* with approximately 1.41 million cases of salmonellosis annually *(69)*. *Salmonella* is the bacterial pathogen most commonly associated with outbreaks of foodborne illnesses from nonmarine fish in the United States for 1998 through 2007 (Table 1). Because only a small percentage of salmonellosis cases are reported *(69),* it is often difficult to attribute *Salmonella* infections to specific food sources such as catfish. The most common *Salmonella* serotype associated with nonmarine fish outbreaks was *Salmonella* Enteritidis, which was identified in two outbreaks comprising 104 cases. *Salmonella* is the only microbial pathogen that has been linked by the CDC to catfish consumption alone (i.e., the 10 cases of *Salmonella* Hadar infection from the New Jersey restaurant *(15)*). *Salmonella* has been detected in catfish ponds, processing plants, and retail products. Since the 1970s, studies at these various points along the farm-to-fork continuum have produced various results for *Salmonella* prevalence. Differences over time and in sampling and testing methods and storage and production practices probably played a role in the variations among the results from these studies.

Salmonella can be introduced into aquaculture ponds from a variety of sources, including fecal contamination from birds and other wildlife *(11, 55, 71)* and contaminated feed *(64)*. After experimental exposure to *Salmonella,* catfish harbored the pathogen in the intestinal tract for up to 30 days with no clinical signs of infection *(61)*. Identification and limitation of the sources of *Salmonella* contamination at the catfish farm may reduce the possibility of contamination of the end product.

A multitude of environmental factors, such as pond temperature, stocking density, organic matter content, and the size of the fish, have been reported to affect *Salmonella* levels in aquaculture ponds. In one study, *Salmonella* was found only in densely stocked ponds with large fish and warm pond temperatures (26 to 29°C). In a heavily stocked pond that contained fish weighing 1 to 3 lb (0.5 to 1.4 kg) with a water temperature of 29°C, two (40%) of five skin and viscera samples and 11 of 15 dressed (fully skinned and eviscerated) catfish samples were positive for *Salmonella*. The source of contamination was not determined; *Salmonella* was not detected in the any of the samples taken from frogs, turtles, or crayfish that were living in the aquaculture ponds, from cattle manure samples from areas surrounding the ponds, or from samples of catfish feed *(135)*. In a more recent study, *Salmonella* was not isolated from catfish ponds, and stocking density did not affect *Salmonella* levels *(65)*. Studies of the fluctuation of *Salmonella* growth throughout the year also yielded conflicting results. For example, in one study an increased incidence of *Salmonella*-positive farm-raised catfish product collected from July through September was found compared with product collected from January to March *(2)*. In this case, samples were collected from finished product at various processing plants. However, in another survey of *Salmonella* contamination of catfish samples taken off the production line in various processing plants, no seasonal effect on growth was found *(68)*. More investigation is necessary to identify primary sources of *Salmonella* contamination in the catfish pond and to evaluate the potential seasonality of *Salmonella* in catfish and any impact of aquaculture practices on growth of this pathogen.

In a report to the Food and Agriculture Organization and the World Health Organization, Dalsgaard *(32)* suggested that the detectable presence of *Salmonella* in fish products from temperate region aquaculture may indicate ineffective process control or poor sanitary conditions. When catfish move from the pond to the processing plant, fish harboring *Salmonella* can cross-contaminate other fish and the processing facility. The outer skin and alimentary tract can be sources for *Salmonella* cross-contamination in the processing plant. *Salmonella* was found in 2.3% of catfish fillets (5 of 220) taken off the line from three processing plants *(68)*. In an additional study, 21% of samples (11 of 52) taken from farm-raised catfish randomly selected during processing were positive for *Salmonella (135)*. The findings of this study also demonstrated that using one processing line for catfish with skin and a separate processing line for catfish with skin removed can reduce the incidence of *Salmonella* cross-contamination. Before separation of catfish processing lines, 48.6% of samples (18 of 37) were positive for *Salmonella*. After a linear product flow was established in which the skin-on and skinned product did not cross paths, none of the 17 fully processed (skinned) samples were positive for *Salmonella (135)*. In addition to *Salmonella* being introduced to the processing facility from fish contaminated in the aquaculture pond, contamination may occur inside the processing facility *(32)*. Further research is necessary to explore all avenues by which *Salmonella* contamination might be introduced to catfish.

Prevalence of *Salmonella* on catfish is variable at retail markets and seafood distributors. In a study involving 335 fresh processed catfish from 41 processors and 342 frozen catfish product from 23 processors, 4.5% of fresh catfish product samples (15 of 335) and 1.5% of frozen product samples (5 of 342) were positive for *Salmonella (2)*. *Salmonella* serotypes detected in this study included many from the CDC's top 20 list of serotypes most commonly associated with human illness (e.g., Newport, Infantis, Montevideo, Saintpaul, Typhimurium, Heidelberg, Javiana, and Oranienburg) *(21)*. In one study, 42% of samples (25 of 60) taken from frozen fillets of domestic channel catfish and Vietnamese basa fish obtained from retail markets or distributors were positive for *Salmonella (82)*. However, in another study of 68 retail catfish fillets purchased from nine local Virginia markets and nine internet retailers during fall and summer, none of the fillets were positive for *Salmonella (83)*. Catfish samples were taken from both retail and processing facilities to compare fresh farm-raised and fresh commercially wild-caught catfish and catfish imported from Mexico and Brazil. Of the farm-raised fish, 21% (11 of 52) were positive for *Salmonella,* and of the wild-caught fish, 5% (2 of 40) were positive for *Salmonella*. All of the 61 imported samples were negative for *Salmonella (135)*. However, this study did not address catfish from Vietnam or China, countries that produce the vast majority of catfish imported into the United States *(75)*. However, one study did address these imports. For samples taken from live farmed finfish, including catfish, in the Guangdong Province of China, 5% of finfish samples (5 of 100), including 2 of 35 catfish samples, were positive for *Salmonella (13)*.

Another factor to consider that may affect public health is the propensity for *Salmonella* cultured from catfish to display antibiotic resistance. Currently, no studies have been conducted to examine the prevalence of antibiotic-resistant *Salmonella* isolates in domestic farm-raised fish. However, in one study all *Salmonella* isolates obtained from farmed finfish in the Guangdong Province of China were resistant to erythromycin and penicillin. The most resistant isolate was resistant to 9 of the 16 antibiotics tested, suggesting that antibiotic-resistant *Salmonella* strains are emerging in catfish *(13)*. Analysis of *Salmonella* isolates taken from a variety of imported foods, including catfish, also revealed antibiotic resistance. *Salmonella* isolated from catfish imported to the United States from Thailand were resistant to a variety of antibiotics, including nalidixic acid, streptomycin, tetracycline, and kanamycin *(139)*. In a more recent study, 11 antibiotic-resistant *Salmonella* colonies were isolated from the internal organs of 100 silver catfish (*Pangasius sutchi*) obtained in Malaysia *(57)*. These data imply that catfish are exposed to antibiotics that might affect bacterial resistance patterns. (Potential residue issues associated with the presence of antibiotic use in catfish are addressed in the ''Chemical Hazards'' section below.) More studies are needed to determine the prevalence of antibiotic-resistant *Salmonella* strains in both domestic and imported catfish.

Extensive studies to establish the baseline prevalence of *Salmonella* in catfish are needed. A *Salmonella* foodborne outbreak attributed to catfish consumption has been documented *(15),* and *Salmonella* was the most common bacterial pathogen in outbreaks of foodborne disease associated with nonmarine fish in the United States from 1998 through 2007 *(19)*. These outbreak data in combination with results of other reported studies suggest that *Salmonella* may be the foodborne pathogen most likely to be associated with catfish.

Campylobacter. Despite specific growth requirements and sensitivity to environmental changes, *Camplylobacter* species are a leading cause of foodborne and waterborne gastroenteritis outbreaks *(85)*. *Campylobacter* can be found in bodies of water primarily as a result of fecal contamination from birds *(52),* suggesting that aquaculture farms may be vulnerable to *Campylobacter* introduction. However, *Campylobacter jejuni* was not detected in the intestines of approximately 160 catfish harvested at various times throughout the year *(65),* and 240 fillets examined during a 12-month period from three processing plants were negative for *C. jejuni* and *Campylobacter coli (40)*.

***E. coli*.** Four categories of pathogenic *E. coli* cause diarrheal illness of varying severity: ETEC, enteroaggregative *E. coli* (EAEC), enteropathogenic *E. coli* (EPEC), and enterohemorrhagic *E. coli* (EHEC). The EHEC strains includes the Shiga toxin–producing serotype O157:H7 and are responsible for hemorrhagic colitis and hemolytic uremic syndrome *(74)*.

Feces of ruminant animals can contaminate aquaculture ponds with pathogenic *E. coli* O157:H7 *(100)*. Outbreaks of *E. coli* O157:H7 infection have been reported from exposure to contaminated municipal drinking water *(103)*. Food that comes into contact with water contaminated with *E. coli* O157:H7 can harbor the microorganism, providing a mechanism by which *E. coli* can enter the food supply. Despite the potential for aquaculture ponds to become contaminated with water containing pathogenic *E. coli* O157:H7 and the seasonal presence of *E. coli* in the intestinal contents of catfish *(65, 79)*, *E. coli* O157:H7 was not detected in a study of 240 processed catfish fillets obtained during each of the four seasons from three processing plants *(40)*. *E. coli* O157:H7 also was not detected in 68 catfish fillets sampled from nine local Virginia markets and nine internet retailers *(83)*. *E. coli* O157:H7 can survive in a catfish pond for up to 12 days, and the pathogen is able to spread to holding tanks and to fish *(103)*.

Although the presence of EHEC serotypes such as O157:H7 has been well documented in recent foodborne outbreaks related to beef and agricultural products *(18, 23)*, EAEC, ETEC, and EPEC strains are common waterborne pathogens in the developing world *(74)*. ETEC serotype O169:H49 was implicated in the largest documented outbreak associated with a catfish product. Catfish and coleslaw were the presumed vehicles for 41 cases of ETEC serotype O169:H49 infection after a catered party in Tennessee *(10)*. Although catfish was associated with this outbreak, the ultimate source of illness (catfish or coleslaw) could not be confirmed; therefore, the New Jersey *Salmonella* Hadar infection outbreak remains the only example where catfish was determined as the sole vehicle of foodborne illness *(15)*. Challenges to specifically detecting this serotype in both environmental and food sources are many, and no surveys have been conducted to assess the prevalence of *E. coli* O169:H49 in catfish ponds and catfish retail product. However, given the increased production of catfish in developing nations, future studies are needed to address the prevalence of non-O157 EHEC, Shiga toxin–producing *E. coli*, ETEC, EPEC, and EAEC in catfish.

In a study of the presence of antibiotic-resistant *E. coli* in catfish, 63 tetracycline-resistant *E. coli* strains were isolated from the intestinal contents of 407 farm-raised catfish whose pond water was prophylactically treated with antibiotics. Of the 63 tetracycline-resistant strains, 35% were resistant to penicillin, streptomycin, bacitracin, and rifampin, 32% were resistant to ampicillin, penicillin, streptomycin, bacitracin, and rifampin, 22% were resistant to ampicillin, penicillin, chloramphenicol, sulfamethaxazole-trimethoprim, streptomycin, bacitracin, and rifampin, and 11% were resistant to ampicillin, penicillin, chloramphenicol, streptomycin, bacitracin, and rifampin. None of the isolates were resistant to either nalidixic acid or ciprofloxacin *(79)*. Results of another study also revealed the potential for catfish to harbor antibiotic-resistant *E. coli* strains; 10 antibiotic-resistant *E. coli* colonies were isolated from the internal organs of 100 silver catfish in Malaysia *(57)*.

***Listeria monocytogenes*.** Although *L. monocytogenes* could contaminate raw fish, pasteurization and cooking eliminates the pathogen; therefore, consumption of cooked fish does not often cause illness due to *L. monocytogenes* infection *(22)*. *L. monocytogenes* is most commonly associated with foodborne illness due to consumption of ready-to-eat products, in which contamination occurs in the processing plant between the time of cooking and the time of packaging *(22)*. Cold-smoked fish products, which are typically consumed without further cooking, are among the ready-to-eat foods of particular concern because of the lack of a heat inactivation step during processing. The prevalence of *L. monocytogenes* in cold-smoked fish and cooked seafood products has been reported to range from 6 to 78% *(81)*. Although some strains of *L. monocytogenes* are unique to the processing plant, the pathogen can be present on raw fish, which can contaminate the processing facility *(49)*. Therefore, studies have been conducted on the prevalence of *L. monocytogenes* on raw fish.

L. monocytogenes can survive in soil and water *(12)*, suggesting that these microorganisms have the potential to survive in an aquaculture environment. The prevalence of *L. monocytogenes* is of specific concern for seafood because the growth rate of this pathogen is higher on catfish and shrimp than on beef and chicken because of the differences in pH of the muscle tissues *(96)*. In one study of the ecology of *Listeria* species on a farm raising rainbow trout, *L. monocytogenes* was found in 41 of the 223 samples taken from fishing nets, equipment, water, bottom soil, and fish gills throughout the year for 3 years *(70)*. Although no studies have been conducted on the prevalence of *Listeria* on catfish farms specifically, results from a study of the viscera of farm-raised catfish suggest that *Listeria* is present in catfish *(59)*. The results of these various studies suggest that *Listeria* may be present in the catfish aquaculture environment at the preharvest stage.

In addition to studies of contamination on the farm, some research has focused on the prevalence of *Listeria* in processing plants and in retail catfish samples. *L. monocytogenes* was not found in a study of processing equipment in two plants *(30)*. However, in another study *L. monocytogenes* was found in 13 of 220 catfish fillets taken off the line from three processing plants, establishing an incidence of 5.9% *(68)*. Several *Listeria* species, including *L. monocytogenes*, were isolated in a study of 240 skinless, boneless catfish fillets collected from three processing plants during 1 year, for an average prevalence of 37% *(27)*.

Results of studies of seasonal prevalence of *Listeria* in catfish are not in agreement. In one study, prevalence of *L. monocytogenes* increased during the warm weather months *(68)*. Conversely, in another study *L. monocytogenes* prevalence in catfish was 51% in the winter, 41% in the spring, 36.7% in the fall, and 19% in the summer *(27)*. In both studies, catfish fillets were collected from processing facilities. Additional research is needed to determine whether *L. monocytogenes* prevalence in catfish has a seasonal component.

In an effort to determine *L. monocytogenes* prevalence in fully processed catfish product, 68 catfish fillets purchased from nine local Virginia retail markets and nine internet retailers during fall and summer were sampled, and 23.5% (16) of these catfish fillets were positive for *L. monocytogenes (83)*. A recent publication included data on prevalence of *L. monocytogenes* throughout production. *L. monocytogenes* prevalence was determined to be 16.4% in the 195 samples collected from various surfaces in the processing plant *(26)*. Although *L. monocytogenes* was not detected in catfish skins and intestines, it was found in 76.7% of chilled fresh catfish fillets and 43.3% of unchilled fresh catfish fillets. Both *L. monocytogenes* and other *Listeria* species were detected on fish contact surfaces in the processing plant *(26)*. These results suggest that *L. monocytogenes* contamination in these processed catfish fillets did not originate in the pond but came from the processing environment. Results of an additional study support the hypothesis that *L. monocytogenes* contamination can originate from either processing or retail environments. The incidence of *Listeria* and *L. monocytogenes* on processing plant catfish fillets (58% of 100 samples and 2% of 100 samples, respectively) was lower than that on retail catfish filets (91% of 100 samples and 73% of 100 samples, respectively) *(37)*. Currently, *L. monocytogenes* has not been linked with any foodborne outbreaks associated with catfish. However, historical outbreaks of listeriosis have been linked to ready-to-eat fish products *(104)*, and results of recent prevalence studies indicate that smoked fish, potentially including smoked catfish, is a high-risk food for listeriosis *(129)*.

***Staphylococcus aureus*.** Enterotoxigenic staphylococci, such as *S. aureus*, can be present on food products, and time and temperature abuse can allow the formation of enterotoxin, which can cause foodborne illness *(58)*. In a large study, 240 catfish fillets collected during 1 year from three processing plants were examined. Samples collected during the summer contained the highest concentration of *S. aureus*, suggesting that *S. aureus* has seasonal prevalence in catfish *(39)*. Methicillin-resistant *S. aureus* (MRSA) has been detected in retail meat samples, although the current association of MRSA with foodborne illness has not been clearly established and needs further study *(53)*. To date, MRSA has not been reported in catfish. Although *Staphylococcus*-induced illness has not been reported to be associated with catfish consumption specifically, from 1998 through 2007 outbreaks of foodborne illness associated with nonmarine fish have occurred in which *S. aureus* enterotoxin was identified as the cause (Table 1). Most cases of illness caused by *S. aureus* enterotoxin were the result of food service and consumer temperature and time abuse, not the direct result of contamination at the farm or processing facility *(58)*.

***Yersinia*.** *Yersinia ruckeri* is the known causative agent of enteric redmouth disease in channel catfish *(33)*; however, no links to human illness have been reported. *Yersinia enterocolitica* is the species most often associated with foodborne illness, but this microorganism has rarely been studied in catfish. *Y. enterocolitica* was not found in the intestinal contents of 126 catfish sampled *(65)*. Similarly, in studies of the prevalence of *Y. enterocolitica* in other fish species, the pathogen was not detected *(80, 88)*.

***Clostridium botulinum*.** Botulinum toxin type E, a toxin produced by *C. botulinum*, has been identified as the causative agent of visceral toxicosis, a disease affecting catfish *(46)*. Type E toxin was responsible for causing botulism in an outbreak associated with smoked whitefish *(56)*, and the *C. botulinum* strain that produces type E toxin is often of concern in smoked fish because this strain can survive processing and can grow under refrigeration conditions *(127)*. *C. botulinum* also can grow in oxygen-reduced environments, which can lead to contamination of raw fish product sealed in vacuum packaging *(14, 87)*. To date, no studies have been conducted on the ecology of *Clostridium* in the catfish pond environment, although in samples of the intestinal flora of 108 farm-raised catfish *Clostridium* species were found during every sampling period except January *(65)*. *C. botulinum* toxin types A and F were isolated from four of nine U.S. farm-raised catfish tested *(9)*. Although *C. botulinum* has not been reported to cause disease in catfish consumers specifically, from 1998 through 2007 outbreaks of foodborne illness associated with nonmarine fish have occurred in which *Clostridium botulinum* was identified as the etiological agent (Table 1).

***Vibrio*.** Most *Vibrio* species, including *Vibrio parahaemolyticus* and *Vibrio vulnificus*, are halophilic and largely associated with foodborne illness associated with the consumption of raw saltwater shellfish, including oysters *(16)*. Of the approximately 12 *Vibrio* species linked to human illness, only *Vibrio cholerae* and *Vibrio mimicus* are found in fresh water *(32)*. Both *V. cholerae* and *V. mimicus* have been implicated in foodborne disease in the United States *(16)*.

No study has been conducted on the prevalence of *Vibrio* species in the catfish pond environment. At the preprocessing stage, *Vibrio* was not detected in catfish intestinal contents *(65)*. However, in a more recent study 15 antibiotic-resistant *Vibrio* colonies were isolated from the internal organs of 100 silver catfish in Malaysia *(57)*. In another study of 240 catfish fillets taken from three processing plants during 1 year, seasonal variation in *V. cholerae* prevalence was documented; 27.5% of fillet samples (33 of 120) taken during the summer and fall were positive for *V. cholera*, but none of the 120 fillet samples taken in the winter and spring were positive for this microorganism *(40)*.

A foodborne disease report indicated that *G. hollisae* (formerly known as *V. hollisae*) was the cause of septicemia in a 65-year-old man after he ate fried wild-caught catfish. The man may have been immunocompromised at the time of consumption. A definite link to catfish consumption could not be made because the fish was never tested for the presence of *G. hollisae (62)*.

Other bacterial pathogens. Many bacterial pathogens are found in the aquatic environment. Some of these pathogens can cause human illness and others affect only aquatic life. The following are catfish-associated bacterial species identified as having the potential to cause human illness but are primarily considered opportunistic pathogens, waterborne pathogens, or pathogens specifically affecting catfish. These organisms are present to varying degrees on almost all raw fish and are eliminated when fish is properly handled and cooked; therefore, the potential for these bacterial pathogens to cause disease in catfish consumers is low.

***Edwardsiella tarda*.** *Edwardsiella* species have been isolated from catfish. *Edwardsiella ictaluri* and *E. tarda* cause catfish-specific diseases *(73)*. The only *Edwardsiella* species that acts as a human pathogen is *E. tarda,* an opportunistic human pathogen and rare cause of gastroenteritis *(50)*. To determine whether catfish and/or the aquaculture environment harbored *E. tarda,* a central Texas catfish farm was monitored during February, May, June, and August. Samples were obtained from catfish on the farm; 47% of 16 skin samples and 88% of 16 visceral samples were positive for *E. tarda*. In the environment, 75% of 86 pond water samples and 64% of 86 pond mud samples were positive for this pathogen. Animals living with the catfish in the ponds, such as crayfish, turtles, and frogs, also harbored *E. tarda* (all 18 animals sampled). The bacterium was absent from five commercial feed samples but present in 2% of 46 cattle fecal samples *(136)*.

Water and mud samples were taken monthly from 10 catfish ponds in central Texas to test for *Edwardsiella* species. Seasonal prevalence of *Edwardsiella* was noted; it increased during the summer months. This variation was hypothesized to be due to an increase in water temperature, organic content of the pond, and the number of amphibians in the ponds *(136)*.

In domestic and imported catfish, 79% of 92 fresh domestic and 30% of 61 frozen imported catfish carcasses contained *E. tarda (136)*. On processing equipment from two plants, *E. tarda* was identified in 1 of 98 samples *(30)*. In the retail setting, of 335 fresh catfish product samples from 41 processors and 342 frozen catfish product samples from 23 processors only 2 fresh product samples (0.6%) were positive for *E. tarda (2)*.

Results of a new study suggest that catfish may harbor antibiotic-resistant *Edwardsiella* species. Twelve antibiotic-resistant *Edwardsiella* colonies were isolated from the internal organs of 100 silver catfish obtained in Malaysia *(57)*.

***Plesiomonas shigelloides*.** *P. shigelloides* generally causes human infection as a waterborne agent, although foodborne disease has been reported from eating raw seafood such as tuna *(17)*. *P. shigelloides* primarily inhabits freshwater ecosystems and marine estuaries, and this microorganism can be isolated from soil, aquatic animals such as fish, and terrestrial animals *(60)*. *P. shigelloides* has been isolated from the intestines of catfish *(65)*. In one study, 240 catfish fillets from three processing plants were samples at various times throughout the year, and *P. shigelloides* prevalence changed by season. During summer and fall, 4 of 120 fillet samples were positive for *P. shigelloides,* and no positive fillet samples (0 of 120) were found in winter and spring *(40)*. On processing equipment from two plants, *Plesiomonas* was isolated in 0.8% of 122 samples tested *(30)*.

***Aeromonas hydrophila*.** *A. hydrophila* is a waterborne pathogen known to cause illness in humans *(34)* and fish *(47)*. One study was conducted during September to determine the presence of *A. hydrophila* in 12 catfish from four catfish ponds. In another study, the intestinal flora of 18 pond-raised catfish was evaluated each month from October through March. *A. hydrophila* was isolated in every sampling period *(65)*. The authors concluded that *A. hydrophila* may be a common commensal organism in the intestines of catfish and could reflect significant concentrations of these bacteria in the aquatic environment or in catfish feed *(65)*. In the processing plant, 39 swab samples were obtained from catfish processing equipment in two plants. A total of 88 gram-negative isolates were recovered, 33 of which were *Aeromonas* species, including *A. hydrophila (30)*. In a more recent study, antibiotic-resistant *Aeromonas* colonies were isolated from 12% of silver catfish (*P. sutchi*) obtained in Malaysia *(57)*.

***Klebsiella pneumoniae*.** *K. pneumoniae* is typically associated with community-acquired pneumonia *(138)* but can also cause gastroenteritis from foodborne infection *(92)*. In a study in which the intestinal flora of 18 pond-raised catfish was sampled each month from October to March, *K. pneumoniae* was isolated with seasonal variation, i.e., higher prevalence in warmer months and lower prevalence in cooler months *(65)*. *K. pneumoniae* was not detected in 240 catfish fillets from three processing plants *(40)*.

***Pseudomonas aeruginosa*.** *P. aeruginosa* is an opportunistic pathogen and has been associated with disease in some aquaculture species *(8)*. *P. aeruginosa* also can act as a gastrointestinal pathogen in humans *(20, 31, 84, 132)*. Although no studies have been conducted on the prevalence of *P. aeruginosa* on catfish farms specifically, results from a study of the viscera of farm-raised catfish suggest that *P. aeruginosa* is present in catfish *(59)*. In two processing plants, processing equipment was swabbed and 27% of the 98 isolates obtained were *Pseudomonas* species *(30)*.

Indicator bacteria. Testing for levels of indicator bacteria is done to monitor food and water contamination and microbiological quality. Levels of indicator bacteria may be correlated with fecal contamination, may be used to gauge adherence to process control and good manufacturing practices, and may be used to assess the organoleptic characteristics and spoilage of food *(36)*. Common indicator tests include aerobic and anaerobic plate counts, counts of psychrotrophic bacteria, and coliform counts. Testing for indicator bacteria is used by the FSIS-regulated meat and poultry industry to monitor process control as outlined in the 1996 pathogen reduction and hazard analysis critical control point system for raw meat and poultry *(110)*. The following section describes the current knowledge of indicator bacteria levels in catfish.

In the processing plant, aerobic bacteria levels are measured by an aerobic plate count (APC). Aerobic bacteria have been detected on catfish fillets within a consistent range of 3.0 to 6.2 log CFU/g of fish throughout the year *(39)*. In the final retail product, testing of catfish fillets have yielded 7% of fresh and 5.5% of frozen samples with APCs in excess of 7 log CFU/g *(2)*. The range of APCs in this study was 3.8 to 8.3 log CFU/g catfish *(2)*. In another study, APCs were 4.3 to 6 log CFU/g *(67)*. In a study of frozen domestic channel catfish and Vietnamese basa fish, average APCs were 4.4 log CFU/g for channel catfish and 3.8 log CFU/g for basa *(82)*.

Coliform counts are a common sanitary indicator for food and water. In the processing plant, catfish fillet testing resulted in coliform values of 0.8 to 3.2 log CFU/g *(39)*. At retail, product in the distributor display case had fecal coliform levels (most probable numbers [MPNs]) of <0.48 to 3.4 log MPN/g in fresh product and <0.48 to 2.4 log MPN/g in frozen product. Total coliform counts were <0.48 to 6.4 log MPN/g in fresh product and <0.48 to 4.0 log MPN/g in frozen product *(2)*. Coliforms counts were determined in catfish fillets purchased locally and via the internet, with mean values of approximately 2.3 log MPN/g *(83)*. In another study, 80% of 30 frozen channel catfish samples and 90% of 30 Vietnamese basa fish samples had mean coliform counts below 0.48 log CFU/g, and all samples had counts below 6 log CFU/g *(82)*.

E. coli is part of the normal bacterial flora in the intestinal tracts of humans and most animals; thus, it is commonly used as an indicator organism for fecal contamination *(36)*. *E. coli* as an indicator in catfish ponds has been described as seasonally variable *(39, 65)*. Higher *E. coli* levels, i.e., 2.0 to 75.0 log CFU/g of fish, were detected during the summer months, whereas levels during other seasons (spring, winter, and fall) ranged from 0 to 4.0 log CFU/g of fish, for a yearly average of 2.2 log CFU/g *(39)*. An *E. coli* average of 1.7 log MPN/g was determined in retail catfish *(83)*.

Fecal streptococci are another potential indicator of fecal contamination *(66)*. In the catfish pond environment, streptococci levels were 0.78 log CFU/ml in the water, 3.07 log CFU/g in sediments, and 3.49 log CFU/g in catfish viscera *(59)*, in agreement with other findings of streptococci in the intestines of catfish *(65)*.

Psychrotrophs are organisms that can survive and reproduce at refrigeration temperatures *(91)*. In the catfish aquaculture environment, psychotrophs were detected in catfish viscera at an average of 7.25 log CFU/g *(59)*. Catfish fillets obtained from processing plants yielded 3.0 to 6.5 CFU/g of fish *(39)*. In retail product, psychrotrophs were found in catfish fillets purchased both locally and via the internet at mean values of approximately 6.6 log CFU/g *(83)*.

Although studies have been conducted to investigate a variety of indicator bacteria in catfish aquaculture and products, further investigation is needed to decide on the most appropriate indicator organism(s) and then to identify an acceptable range of levels in catfish. These values might ultimately be used to establish guidelines for the catfish industry.

Other bacteria. Other bacteria detected in the intestines of catfish include *Achromobacter* species, *Acinetobacter lwoffii, Actinomyces* species, *Aeromonas sobria, Bacillus subtilis, Bacteroides* species, *Bacteroides capillosus, Citrobacter diversus, Citrobacter freundii, Flavobacterium* species, *Fusobacteria necrophorum, Gaffky anaerobia, Micrococcus tetrogenes, Moraxella* species, *Providencia* species, *Pseudomonas cepacia, Pseudomonas fluorescens, Serratia liquifaciens, Serratia marcescens, Streptococcus* (group D), and other *Streptococcus* species *(65)*.

Other bacteria detected at catfish processing plants include *Acinetobacter* species, *Providencia alcaligenes, Citrobacter freundii, Hafnia alvei, Morganella morganii, Enterobacter* species, *Enterococcus* species, *Staphylococcus* species, *Streptococcus* species, and *Bacillus* species *(30)*. Fresh and frozen retail catfish fillets were screened for *Arizona* and *Shigella*; these microorganisms were not detected *(2)*. Most of these bacteria are common commensals that pose no significant human health risk at typical contamination levels.

Viruses. A recent analysis of outbreak data associated with finfish suggests that norovirus may be an important hazard associated with consumption of fish. Norovirus causes acute gastroenteritis in people of all ages. The viruses are transmitted by fecally contaminated food or water and by person-to-person contact *(93)*. Norovirus detection in food is often difficult because of the low number of virus particles; techniques addressing these issues are currently in development *(107)*. A review of the 1998 through 2007 CDC data for outbreaks of foodborne disease associated with nonmarine fish in which the etiological agents were identified revealed that norovirus was associated with these outbreaks in the United States (Table 1). Large numbers of cases of norovirus infection were reported in some outbreaks, most likely due to secondary person-to-person transmissions after the initial foodborne infection. Further studies are needed to determine whether norovirus is a foodborne hazard associated with catfish specifically and to better understand the potential public health impact of this virus.

Parasites. Some fish and waterborne parasites are capable of causing disease in humans and can be transmitted through contact with or consumption of raw or undercooked fish *(25, 98)*. No reports of parasite infection in humans from the consumption of catfish raised on farms in the United States have been published. However, a limited number of reports have been published on foreign farmed catfish. In one study, a 2.6% prevalence of metacercariae of

TABLE 2. *Organic compounds used in aquaculture worldwide*[a]

Approved for use in the United States	Restricted for use in the United States
2,4-Dichlorophenoxyacetic acid	Aldrin, dieldrin
Antimycin A	Chlordane
Alkyldimethylbenzylammonium chloride	Chlordecone
Benzenepropanoic acid	*p,p′*-Dichlorodiphenyltrichloroethane (DDT)
Butoxyethyl 2,4-dichlorophenoxyacetate	*p,p′*-Dichlorodiphenyldichloroethane (TDE)
Chlorophenoxy compounds	*p,p′*-Dichlorodiphenyldichloroethylene (DDE)
Copper ethanolamine complex	Endosulfan i, ii
Dicofol	Endrin
Diflubenzuron	Heptachlor
Dimethylamine	Heptachlor epoxide
2,4-Dichlorophenoxyacetate	Hexachlorobenzene
Diquat	Mirex
Dibromide	Polychlorinated biphenyls (PCBs)
Diuron	
Endothall	
Fluridone	
Glutaraldehyde	
Glyphosate	
Hydrogen peroxide and calcium peroxide	
Hypochlorite	
Imazapyr (isopropylamine salt)	
Lindane (y-HCH)	
Methylmercury	
Povidone iodine	
Rotenone (piperonyl butoxide technical)	
Simazine	
Sodium 2,4-dichlorophenoxyacetate	
Tartrazine, erioglaucine	
Teaseed and mahua oil cake (sapogenin glycosides)	
Triazine herbicides	
Urea	

[a] From the Federal Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, 2007 *(38)*, the U.S. FDA, 2001 *(120)*, and the World Health Organization, 1999 *(134)*.

a zoonotic trematode in the fish-producing region, the An Giang province of Vietnam, was found *(106)*. However, in another study performed in a different Vietnamese region the produces large amounts of fish, the Tien Giang province, no zoonotic trematodes were found in monocultured hybrid catfish *(105)*. The conflicting results from these studies suggest that additional prevalence research must be performed to determine the risk of parasitic infection from consuming imported catfish.

Prions. Transmissible spongiform encephalopathies and other prion diseases have not been reported in catfish.

CHEMICAL HAZARDS ASSOCIATED WITH CATFISH CONSUMPTION

Chemical residues pose a risk for human illness, but unlike the acute affects of microorganisms, chemicals may have chronic effects that can be difficult if not impossible to trace back to a source. The U.S. Food and Drug Administration (FDA) has established tolerances for animal drugs, food additives, and unavoidable contaminants under the authority of the Federal Food, Drug, and Cosmetics Act. The U.S. Environmental Protection Agency (EPA) sets tolerances for pesticides under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act. The FSIS is responsible for testing for the presence of restricted compounds and enforcing tolerances for FSIS-regulated products.

No epidemiological reports of chemical residues associated with consumption of farm raised catfish were found. Of the studies on the potential for catfish products to contain chemical contaminants, some include analysis of fresh-caught wild or farmed catfish and others include analysis of retail catfish fillet products. Below is a summary of chemical residues as reported in studies of farmed catfish. Information on organic compounds, inorganic compounds, and aquaculture drugs is provided.

Organic compounds. Organic compounds include environmental contaminants such as industry pollutants and agricultural chemicals (including pesticides) used in catfish aquaculture. Pesticides used in association with aquaculture include algicides, herbicides, invertebrate toxicants, and piscicides. Organic chemicals that have been used in aquaculture throughout the world are listed in Table 2. Although some compounds are restricted for agricultural use in the United States *(114)*, they may continue to be of concern in catfish because of persistent environmental contamination and/or use in other countries.

TABLE 3. *Organochlorine, organophosphate, and pyrethroid pesticides collected from 257 farm-raised catfish samples (1993 through 1995)*

Chemical with CASRN[a]	% of samples positive[b]	Mean concn (ppm)[b]	Maximum concn (ppm)[b]	Regulatory limit (ppm)	Health hazard[a]
Chlordane 12789-03-6	1.9	0.045	0.092	0.3[c]	Hepatic toxicity, accumulation in lipids, neurotoxicity, reproductive toxicity
Chlorpyrifos 2921-88-2	10.5	0.072	0.37		Decreases cholinesterase activity
DDT 50-29-3	55	0.043	0.29	5.0[c,d]	Hepatic and reproductive toxicity, accumulation in lipids, carcinogen
Dieldrin 60-57-1	2.7	0.019	0.03	0.3[c,e]	Hepatic toxicity, neurotoxicity, carcinogen
Heptachlor epoxide 76-44-8	1.9	0.012	0.02	0.3[c]	Hepatic toxicity, carcinogen
Hexachlorobenzene 118-74-1	0.8	0.01			Neurotoxicity, hepatic and dermal toxicity, arthritic changes, reduced growth, carcinogen
PCB 1336-36-3	7	0.133	0.32	2.0[f]	Carcinogen

[a] Information from the U.S. EPA Integrated Risk Information System *(116)*. CASRN, CAS registry number.
[b] From Santerre et al., 2000 *(95)*.
[c] From the U.S. FDA Compliance Policy Guide, section 575.100 *(117)*.
[d] Applies to DDT, TDE, and DDE.
[e] Applies to aldrin and dieldrin.
[f] From the U.S. FDA, 21 CFR 109.30 *(7)*.

Environmental contaminants such as organochlorine, organophosphate, and pyrethroid pesticides were quantified in U.S. farm-raised catfish muscle tissue from 1993 through 1995 (Table 3) *(95)*. In samples obtained from both producers and processors, dichlorodiphenyltrichloroethane (DDT), chlorpyrifos, and polychlorinated biphenyl (PCBs) were detected in 55, 10.5, and 7% of catfish tested, respectively. Chlordane, hexachlorobenzene, heptachlor epoxide, and dieldrin were detected in approximately 1 to 3% of catfish tested. The maximum detected concentrations of these compounds ranged from 1 to 15% of the pertinent regulatory limit (i.e., tolerance, action level, and guidance level) (Table 3). Many organochlorine insecticides and PCBs are no longer registered for use in the United States. Residues of these chemicals in catfish indicate environmental persistence and accumulation in tissues. Other pesticides assayed in this study but not detected in U.S. farm-raised catfish were mirex, heptachlor, methoxychlor, endrin, endosulfan, benzene haxachloride, diazinon, malathion, methyl- or ethyl-parathion, cypermethrin, and fenvalerate *(95)*. Although wild catfish from the United States may contribute to elevated PCB levels in the U.S. subpopulation (non-Hispanic black individuals) that has the highest PCB levels in the United States *(133)*, no epidemiological studies have identified similar trends for farm-raised catfish.

Regulatory limits have not been established for many environmental contaminants in fish. One such environmental contaminant is polybrominated diphenyl ether (PBDE), a flame retardant known to persist in the environment and to bioaccumulate *(89)*. Adverse human effects associated with PBDE exposure include endocrine disruption, thyroid toxicity, and developmental toxicity *(1, 97, 131)*. PBDE congeners have been found in U.S. farmed catfish products at 0.03 to 23.3 ng/g wet weight. The estimated average daily consumption is 3.0×10^{-8} to 1.8×10^{-6} mg/kg/day, which is below the EPA oral reference dose of 1.0×10^{-4} mg/kg/day *(101, 116)*. An oral reference dose is the estimate of the daily oral exposure throughout a lifetime that is likely to below the threshold for harmful effects *(113)*.

Dioxins are other chemicals without regulatory levels established for fish. Dioxins include polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and the most toxic dioxin, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin. Human health concerns associated with exposure to dioxins include dermal, hepatic, immunogenic, and reproductive toxicity; dioxins also are likely human carcinogens *(54, 78)*. In one study, 17 2,3,7,8-chlorinated dioxin and furan congeners were used to estimate a mean dioxin exposure of approximately 21 to 234 pg per person per day for an average catfish consumer, based on a range of dioxin contamination in the fish *(51)*.

In the mid 1990s, dioxins were detected in processed nuggets of farm-raised catfish *(29, 42)*. Further investigation by the same group revealed PCDD and PCDF in the catfish, pond sediment, and feed. These studies revealed that feed was the most likely source of dioxin contamination in the catfish *(28, 41)*. Further studies revealed that a soybean meal ingredient used in the feed was highly contaminated with PCDD, including the toxic 2,3,7,8-substituted congeners. The likely source of the contamination was the ball clay anticaking agent in the soybean meal *(90)*. These findings in combination with similar findings from other animal feeds triggered an FDA action to temporarily halt distribution of contaminated feed and an FDA recommendation for the discontinued use of ball clay as an anticaking agent in animal feed. Ultimately, ball clay was removed from the list of feed ingredients accepted by the Association of American Feed Control Officials *(3, 118, 119)*.

Inorganic compounds. Inorganic compounds of potential concern include environmental contaminants such as agricultural chemicals, metals, and industry pollutants

TABLE 4. *Inorganic compounds used in aquaculture worldwide*[a]

Permitted and unregistered for use in the United States	EPA approved for use in the United States
Agricultural limestone	Chlorine
Aluminum sulfate	Copper carbonate
Ammonia	Copper sulfate
Ammonium nitrate	Copper triethanolamine complex
Ammonium phosphate	Copper ethanolamine complex
Ammonium sulfate	Copper hydroxide
Calcium hypochlorite	Sodium bromide
Calcium phosphate	Sodium hypochlorite
Calcium sulfate (gypsum)	Sodium percarbonate
Ferric chloride	
Lime (calcium and magnesium hydroxide)	
Phosphoric acid	
Potassium chloride	
Potassium nitrate	
Potassium permanganate	
Sodium chloride	
Sodium nitrate	
Sodium silicate	
Zeolite	
Trace element mixes consisting of various compounds: iron, zinc, copper, boron, and molybdenum	

[a] From the Federal Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, 2007 *(38),* the U.S. FDA, 2001 *(120),* and the World Health Organization, 1999 *(134).*

and chemicals used intentionally in catfish aquaculture. Inorganic chemicals that have been used in aquaculture throughout the world are listed in Table 4. Some of these compounds are currently registered with the EPA as one or more of the following: algicide, aquatic herbicide, fish toxicant, or invertebrate toxicant *(38)*. Other than the EPA-registered compounds, none of the inorganic compounds listed in Table 4 are currently regulated in the United States.

Current literature on inorganic contaminants in catfish is limited to the analysis of heavy metals. Heavy metals can enter the environment and food supply through air, surface waters, and soil. In one study, heavy metals in farm-raised catfish from both producers ($n = 196$) and processors ($n = 61$) in the southeastern United States were quantified. Metals analyzed included arsenic, barium, cadmium, chromium, copper, silver, lead, selenium, and mercury *(94)*. Table 5 lists the average heavy metal contamination for 257 catfish samples collected from processors and producers. Arsenic was detected in multiple catfish samples at levels exceeding the EPA Region III risk-based concentration limit available at the time of publication *(94)*. EPA risk-based concentrations are the maximum concentration for a given hazard that is associated with an acceptable probability of risk *(99)*. Risk-based concentration limits are not regulatory limits but are used to estimate risk associated with the presence of a hazard *(115)*. Although all metals were detected in the study, no samples contained metal concentrations greater than the pertinent EPA risk-based concentration limits. Selenium and mercury were the most frequently detected compounds; each were detected in more than 80% of the samples *(94)*. Although tolerances exist for a few of the heavy metals in other aquatic food products, heavy metal tolerances specific for finfish and/or catfish are limited to methylmercury (Table 5).

The results from these studies suggest that additional testing of heavy metals in catfish should be performed to determine the public health impact of catfish consumption. Information has yet to be gathered for the remainder of the inorganic (nonmetal) contaminants. Future research will provide a better understanding about the risk to consumers from inorganic contaminants in catfish.

Aquaculture drugs. Aquaculture pharmaceuticals approved by the FDA for use in catfish include eight drugs (Table 6). Drugs given to fish can be administered as a medicated bath, injection, or a medicated feed. FDA low regulatory priority drugs (LRPDs) for aquaculture are substances that are available for off-label use as long as they are used in accordance with the Federal Food, Drug, and Cosmetic Act Section 201. This act states that a drug is an ''article intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals.'' LRPDs must be (i) used at prescribed levels, (ii) used in accordance with good management practices including the appropriate grade for food animals, and (iii) not likely to cause an adverse effect on the environment *(6)*. The FDA has identified a number of LRPDs for catfish (Table 7).

Copper sulfate and potassium permanganate are under review by the FDA for approved use in aquaculture and are currently classified as investigational new animal drugs *(128)*. Studies are underway to determine the potential use of copper sulfate for controlling *Ichthyophthirius* and other external parasitic infections. Copper sulfate is also used to control growth of algae. Potassium permanganate is used as

TABLE 5. *Metals detected in 257 U.S. farmed catfish samples (1993 through 1995)*

Heavy metal with CASRN[a]	% of samples positive[b]	Maximum concn (ppm)[b]	Regulatory level (ppm)[c]	Oral health hazard[a]
Arsenic 7440-38-2	5	0.18	Crustacean, 76 Mollusk, 86	Dermal and vascular toxicity
Barium 7440-39-3	11	1.34	NA	Renal and cardiovascular toxicity
Cadmium 7440-43-9	2	0.6	Crustacean, 3 Mollusk, 4	Renal toxicity, carcinogen
Copper 7440-50-8	83	0.63	NA	Liver toxicity[d]
Chromium 18540-29-9	25	1.72	Crustacean, 12 Mollusk, 13	None (inhalation toxicity, carcinogen)
Lead 7439-92-1	11	1.8	Crustacean, 1.5 Mollusk, 1.7	Neurotoxicity; renal, reproductive, and cardiovascular toxicity; carcinogen
Methylmercury 22967-92-6	84	0.089	All fish, 1.0	Neuropsychological impairment, carcinogen
Selenium 7782-49-2	82	0.77	NA	Dermal toxicity, neurotoxicity
Silver 7440-22-4	3	0.53	NA	Dermal toxicity

[a] Information from the U.S. EPA Integrated Risk Information System *(116)*. CASRN, CAS registry number.
[b] From Santerre et al., 2001 *(94)*.
[c] From the U.S. FDA, 2001 *(120)*.
[d] From Gaetke and Chow, 2003 *(45)*.

an organic oxidizing agent, and studies are underway to determine use of potassium permanganate for control of external bacteria, parasites, and fungus *(128)*.

Some drugs are banned in the United States for extralabel use in food animals under the Animal Medicinal Drug Use Clarification Act (AMDUCA). The FDA bans use of these drugs in food animals to protect consumers from antimicrobial resistance and adverse human health effects. These drugs are banned for use in catfish intended for consumption, and residues of these drugs are not permitted in imported catfish. AMDUCA-prohibited drugs are listed in Table 8.

All drugs that are neither approved nor prohibited by the FDA are considered unapproved drugs. One such drug is clove oil. This drug has been used as a fish anesthetic but is not approved for use in aquaculture by the FDA. According to FDA guidance documents, although though clove oil and its components are generally regarded as safe (GRAS) for use in dental cement and as a food additive, clove oil is not GRAS for use as an anesthetic for fish. Clove oil is made up of 85 to 95% eugenol, the remainder supplemented by isoeugenol and methyleugenol. These ingredients have the potential to act as carcinogens; therefore, the FDA has not approved clove oil for use in aquaculture *(124)*.

Because of concerns with carcinogenicity and antimicrobial resistance, many potential aquaculture drugs are unapproved for use in the United States. However, some of these drugs are legally used in countries that import to the United States. Residues have been detected in imported catfish products from countries such as Vietnam, China, and Indonesia. In 2007, 6 catfish samples tested positive for fluoroquinolones, 12 tested positive for malachite green, and 2 tested positive for crystal (gentian) violet *(125)*. In June 2007, an import alert was placed on China because of the continued presence of malachite green, gentian violet, nitrofurans, and fluoroquinolone residues found in imported fish *(123)*. Other countries, including the United Kingdom, are monitoring malachite green residues in imported product and have noticed a similar trend over the last decade *(130)*. Researchers should continue to monitor the use of malachite green and crystal violet and other drugs used in foreign aquaculture that might pose risks to human health. Table 9 summarizes drugs that may be legally used in foreign aquaculture but are currently not approved for use in aquaculture by the FDA.

Further studies are needed to identify the prevalence of FDA unapproved and banned drugs in catfish products. Although the present review covered the range of FDA unapproved or banned drugs, the aquaculture industry has access to many approved drugs and LRPDs that can be used in catfish production.

DISCUSSION

Scientific literature on foodborne hazards associated with catfish is limited and dated. Available data on hazards associated with imported and foreign-raised catfish are even more limited than data on U.S. farm-raised catfish. Catfish often are pooled into ''finfish,'' ''fish,'' and ''seafood'' categories, making it difficult to distinguish catfish-specific hazard prevalence. Identification of catfish-related foodborne outbreaks has been difficult for similar reasons. Therefore, to consider all possible outbreak data, this review included both catfish and finfish foodborne outbreaks *(10, 15, 19, 62)*.

Salmonella appears to be a common etiologic agent for both catfish and finfish foodborne illness outbreaks *(15, 19)*. In addition to outbreak data, this review included studies of pathogens at multiple points in the pond-to-plate continuum, and in many of these studies *Salmonella* was identified as a potential foodborne hazard associated with catfish consumption. Given the findings from these studies and additional data that suggest that some *Salmonella* strains found in catfish display antibiotic resistance *(13, 57, 139)*,

TABLE 6. *FDA-approved drugs for use in catfish aquaculture*[a]

Drug	Trade name	Indication	Route of administration	Limitations and/or withdrawal time
Chorionic gonadotropin	Chorulon	Aid in improving spawning of male and female brood stock	Injectable, intramuscular	Permitted only under the supervision of a licensed veterinarian, dosage limitations for fish used for human consumption. 0 days
Florfenicol	Aquaflor, Aquaflor-CA1	Control mortality due to enteric septicemia associated with *Edwardsiela ictaluri* and columnaris disease associated with *Flavobacterium columnare*	Medicated feed	Permitted only under the supervision of a licensed veterinarian. 12 days
Formalin	Parasite-S, Formalin-F, Formacide-B, Paracide-F	Control fungi of the family Saprolegniaceae on finfish eggs and to control external protozoa and monogenetic trematode parasites in finfish	Immersion	0 days
Hydrogen peroxide	35% Perox-Aid	Control mortality due to saprolegniasis in finfish eggs and control mortality due to external columnaris disease associated with *F. columnare* in finfish	Immersion	0 days
Oxytetracycline dehydrate	Terramycin 200	Control of bacterial hemorrhagic septicemia caused by *Aeromonas liquefaciens* and *Pseudomonas* disease	Medicated feed	21 days
Oxytetracycline HCl	Oxymarine, Oxytetracycline HCl Soluble Powder-343, Terramycin-343 Soluble Powder, Tetroxy Aquatic	Mark skeletal tissues	Immersion	0 days
Sulfadimethoxine-ormetoprim	Romet-30, Sulfamerazine	Control of enteric septicemia due to *E. ictaluri*	Medicated feed	3 days
Tricaine methanesulfonate	Finquel, Tricaine-S	Temporary immobilization	Immersion	21 days

[a] From the U.S. FDA, 2009 *(126)*.

Salmonella appears to be the most important microbial hazard associated with catfish consumption. This review also included studies of the prevalence of other microbial pathogens such as *Campylobacter*, pathogenic *E. coli, L. monocytogenes, S. aureus, Yersinia, C. botulinum, Vibrio,* other opportunistic pathogens, indicator bacteria, viruses, parasites, and prions.

In addition to microbial hazards, this review included studies on chemical hazards in catfish. Domestic catfish aquaculture products contain multiple chemical residues, but most residues were detected at levels below regulatory action limits. For some chemicals that have been identified in catfish product, such as hexachlorobenzene, PBDE, dioxin, and the majority of heavy metals, regulatory levels in fish meat have not been defined. Additional analyses are necessary to determine whether regulatory limits for these chemical contaminants should be established to protect public health. The U.S. dioxin feed contamination incident in the mid to late 1990s highlights the importance of chemical residue analysis of catfish products and catfish feed to identify contamination sources *(3, 118, 119)*.

The prevalence of chemical contamination in imported farm-raised catfish has not been studied extensively. Regional variations in industrial pollution and sanitation systems most likely have considerable impact on the prevalence of chemical residues in catfish raised in these areas. For example, coal-fired power plant emissions typically contain mercury, selenium, and arsenic, compounds that can ultimately contaminate fish. China, a significant catfish-producing nation, consumes twice as much total coal volume as does the United States *(111)*, leading to the possibility that mercury, selenium, and arsenic concentrations in Chinese fish could be greater than those in U.S. fish *(48, 102)*. In the United States, previous heavy use of DDT, a persistent pollutant, for cotton production in catfish aquaculture regions has contributed

TABLE 7. *FDA low regulatory priority drugs for use in catfish*[a]

Drug	Dose	Use
Acetic acid	1,000–2,000-ppm dip for 1–10 min	Parasiticide
Calcium chloride	Use dose necessary to raise calcium concn to 10–20 ppm $CaCO_3$	Ensure proper egg hardening
	Use dose up to 150 ppm, indefinitely	Increase the hardness of water for holding and transporting fish to aid in osmotic balance of the fish
Calcium oxide	Use dose necessary to raise concn to 2,000 mg/liter for 5 s	External protozoacide for life stages between fingerlings and adult fish
Carbon dioxide gas	NA	Anesthetic purposes
Fuller's earth	NA	Reduce the adhesiveness of fish eggs to improve hatchability
Ice	NA	Reduce metabolic rate of fish during transport
Magnesium sulfate	Immersion in solutions of $MgSO_4$ at 30,000 mg/liter and NaCl at 7,000 mg/liter for 5–10 min	Treatment of external monogenic trematode infestations and external crustacean infestations in fish at all life stages
Papain	0.2% solution	Remove the gelatinous matrix of fish egg masses to improve hatchability and decrease the incidence of disease
Potassium chloride	Use dose needed to increase chloride ion concn to 10–2,000 mg/liter	Aid in osmoregulation, relieve stress, and prevent shock
Povidone iodine	100-ppm solution for 10 min	Egg surface disinfectant during and after water hardening
Sodium bicarbonate	142–642 ppm for 5 min	Introducing carbon dioxide into the water to anesthetize fish
Sodium chloride	0.5–1.0% solution for an indefinite period	Osmoregulatory aid for relief of stress and prevention of shock
	3% solution for 10–30 min	Parasiticide
Sodium sulfite	15% solution for 5–8 min	Treatment of eggs to improve hatchability
Urea and tannic acid	Water concn of 15 g of urea and 20 g of NaCl per 5 liters for approximately 6 min followed by a separate solution of 0.75 g of tannic acid per 5 liters to treat approx 400,000 eggs	Denature the adhesive component of fish eggs

[a] From the U.S. FDA, 2007 *(121)*.

significant quantities of DDTs to the environment in these areas *(112)*. In China, DDTs have been detected in surface waters; however, the metabolite pattern of these residues suggests that these residues are the result of recent additions of DDT to the environment, and DDTs may not have accumulated to levels present in the United States *(137)*. Therefore, U.S. farm-raised catfish may be exposed to and may accumulate more DDT than farm-raised catfish in more recently developed nations. Farm-raised catfish are grown in a relatively controlled setting and may be less affected by environmental contaminants than wild catfish; however, many catfish ponds are constructed from local soil, are impacted by local runoff, and are open to the environment *(72)*.

In addition to organic and inorganic contaminants, drugs used in aquaculture may present foodborne hazards to catfish consumers. The FDA has approved various aquaculture drugs and has deemed some compounds as LRPDs for use in aquaculture. However, some FDA-unapproved drugs are being used in foreign aquaculture. Of particular concern is the foreign use of malachite green and gentian violet, compounds that have been found to be carcinogenic in laboratory studies *(123)*. Use of clove oil, also a carcinogen, also has been noted by the FDA *(124)*. Future research needs to include larger studies that address the prevalence of aquaculture drug residues in catfish. Investigation of the compounds used in foreign aquaculture is necessary to ensure the safety of imported catfish.

The global aquaculture industry has been growing rapidly over the last decades from 12 million metric tons in 1989 to 53 million metric tons by 2008 *(44)*. Aquaculture is currently the most rapidly increasing food production system, and the industry will most likely continue to grow through 2025 *(35)*. The results of the studies reviewed here support the need for continuing microbial and chemical testing to ensure safety of both U.S. and imported farm-raised catfish. Studies and testing are vital for ensuring a safe food supply in the future. Areas of further research should involve comparison of water source quality and feed quality to the amount of contaminant accumulated in edible portions of the catfish. These studies will provide information that can be used in the development of on-farm interventions that can limit the prevalence and concentration of foodborne hazards in catfish.

TABLE 8. *AMDUCA-prohibited drugs*[a]

Drug name or type	Drug name or type
Chloramphenicol	Furazolidone
Clenbuterol	Nitrofurazone
Diethylstilbestrol	Fluroquinolones
Dimetridazole	Glycopeptides
Ipronidazole	Sulfonamides
Other nitroimidazoles	Phenylbutazone

[a] From the U.S. FDA, 2009 *(5)*.

TABLE 9. *Drugs that are currently used in foreign aquaculture but are not approved by the FDA*[a]

Drug name or type	Drug name or type
Azamethiphos	Nifurpirinol
Chloramphenicol	Nitrofuran
Crystal violet	Nitrofurantoin
Dichlorovos	Nitrofurazone
Diflubenzuron	Norfloxacin
Enrofloxacin	Oxolinic acid
Eugenol	Praziquantel
Fenthion	Rifampin
Flumequine	Saponin
Furazolidone	Sarafloxacin
Glucans	Spiramycin
Isoeugenol	Streptomycin
Ivermectin	Teflubenzuron
Josamycin	Testosterone
Kanamycin	Thiamphenicol
Levamisole	Tributyltin
Malachite green	Trichlorfon
Methyltestosterone	Trifluralin
Nalidixic acid	

[a] From the U.S. FDA, Center for Veterinary Medicine, 2009 *(86)*.

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