Zoonotic bacteria and antimicrobial resistance in aquaculture: Opportunities for surveillance in Canada

Malcolm Weir, Andrijana Rajić, Lucie Dutil, Carl Uhland, Nathalie Bruneau

Introduction

The Canadian fish and seafood industry is worth approximately $5 billion CDN and provides more than 130 000 jobs in over 1500 communities across the country. Almost 70% of all fish is derived from lobster, crab, and shrimp, with other notable species including salmon, blue mussels, and oysters. Canada is the world's seventh-largest seafood exporter, with approximately 80% of domestic products exported to over 130 countries, primarily the United States (USA), the European Union, Japan, and China (1). The aquaculture industry is the fastest growing food animal production segment in the world, and will continue to grow due to an anticipated increase in the consumption of seafood and aquaculture products over the next few decades (2). In this article, we review the more important zoonotic bacteria in seafood, antimicrobial use and bacterial resistance in the aquaculture sector, and the main seafood safety regulations and surveillance programs in Canada and the potential opportunities for their enhancement.

Human illness due to exposure to zoonotic bacteria from aquaculture or seafood

A summary of the important zoonotic bacteria associated with cases or outbreaks reported in humans due to exposure to various types of fish and/or seafood is shown in Table 1 in approximate order of their importance in the Canadian context (3–5). Humans might acquire zoonotic bacteria via ingestion of contaminated seafood or water, or through direct topical contact via stings, bites, spine/pincer injuries, or through open wounds on the handler. Individuals frequently exposed to fish, their products, or their environment (for example fishermen or fish-processing workers), are at higher risk. Humans with immunocompromised health status may be at greater risk. Dietary choices, such as live and fresh seafood, and seasonality (i.e., due to higher *Vibrio* levels in warmer water) are consistent risk factors for seafood-related illness in humans (3–5).

Most of the bacterial causes of diarrhea are zoonotic. *Vibrio vulnificus* and motile *Aeromonas* can also cause bloodstream infections, especially in immunocompromised individuals, while *Clostridium botulinum* and *Listeria* can cause more severe diseases (3–7). Among the 4093 foodborne disease outbreaks reported globally from 1988 to 2007, 277 (6.8%) were attributable to seafood, primarily due to *Vibrio* spp. and *C. botulinum* (6). In Canada, 20 seafood-related outbreaks were reported from 1996 to 2005, mostly due to *Salmonella enterica* (25%), *C. botulinum* (15%), *Campylobacter* spp. (10%), and *Staphylococcus aureus* (10%) (7).

Antimicrobial use in aquaculture

Globally, only a few antimicrobials are approved for use in aquaculture but their usage varies considerably among countries and regions (8). In the USA and Canada, 3 classes of antimicrobials are registered for use in finfish: potentiated sulfonamides such as ormetoprim-sulfadimethoxine and trimethoprim-sulfadiazine (Canada only), tetracyclines (oxytetracycline), and phenicols (florfenicol) (8–10). Acording to a recent global survey of aquaculture-allied personnel (n = 199 respondents), "rare-to-occasional" antimicrobial use was reported across aquatic species and for most antimicrobials. However, the use of tetracyclines was frequently reported and, surprisingly, the use of quinolones was reported in North America where its use in aquaculture is prohibited (9).

Some Canadian provinces require yearly reporting of the antimicrobials used and the quantity applied, although the data are often presented in the form of summaries and therefore lack relevant temporal and spatial aspects. Data from British Columbia (BC) is publicly available, but this is not the case for the eastern Canadian provinces. According to the BC Ministry of Agriculture, antimicrobial use per metric ton (tonne) of fish produced in BC has steadily decreased from 1995 to 2008 (10).

Department of Population Medicine, Ontario Veterinary College, University of Guelph, Guelph, Ontario N1G 2W1 (Weir, Rajić); Public Health Agency of Canada, Laboratory for Foodborne Zoonoses, 110 Stone Road West, Guelph, Ontario N1G 3W4 (Rajić); Public Health Agency of Canada, Laboratory for Foodborne Zoonoses, 3200 rue Sicotte, PO Box 5000, Saint-Hyacinthe, Quebec, Canada J2S 7C6 (Rajić, Dutil*); Faculté Médecine Vétérinaire, 3200 rue Sicotte, Saint-Hyacinthe, Québec, Canada (Uhland); Canadian Food Inspection Agency, Aquatic Animal Health Division, 59 Camelot Drive, Ottawa, Ontario K1A 0Y9 (Bruneau).

Address all correspondence to Dr. Andrijana Rajić; e-mail: arajic@uoguelph.ca

*Deceased, August 15, 2011.

Table 1. Important zoonotic bacteria associated with human illness due to exposure to infected fish or contaminated seafood

Bacteria (incubation period)	Symptoms in humans	Associated seafood and/or environment	Distribution and/or public health risks
***Salmonella* spp.**[a] (8 to 72 h GI form; 8 to 28 d typhoid form)	Gastroenteritis; septicemia	Prawns, mollusks, eel, catfish, tilapia, carp	Worldwide distribution due to fecal contamination; a small risk after cooking of seafood
Clostridium botulinum[a] (12 to 72 h)	Weakness, visual deficits, death by respiratory paralysis	Trout, herring, salmon; vacuum-packed smoked fish products	Worldwide, processing level; rarely associated with seafood if products are correctly chilled
***Campylobacter* spp.**[a,b,c] (24 to 48 h)	Diarrhea	Shellfish	USA; limited risk
Vibrio vulnificus[a,b] (hours)	Septicemia; gastroenteritis; necrotizing fasciitis	Fish, mussels, oysters, prawns; in waters > 20°C; estuarine and marine environments	Accounts for most deaths associated with seafood in the USA; important in immunocompromised individuals; can arise due to fish handling and preparation injuries
Vibrio cholerae[a,d] [6 h to 5 d (O1); 48 h (non-O1)]	Gastroenteritis	Prawns, shellfish, squid, seafood	*V. cholerae* O1 epidemics uncommon in USA
Vibrio parahaemolyticus[a] (15 to 19 h)	Gastroenteritis; wound infection; septicemia	Shellfish, crustaceans, coastal sediment, plankton	Frequent cause of seafood-related illness in Japan, India, South Asia
Aeromonas hydrophila[d] (unknown)	Gastroenteritis, cellulitis, muscle necrosis, septicemia	Oysters, seafood; fresh and brackish water	Worldwide; low-moderate risk from refrigerated food products with extended shelf-life
***Shigella* spp.**[a] (12 to 50 h)	Dysentery	Shellfish	USA, Mexico (from raw seafood); low infective dose but long survival time in shellfish
Plesiomonas shigelloides[a,d] (2 to 24 h)	Gastroenteritis	Oysters, shrimp	Low to moderate risk due to seafood consumption
Listeria monocytogenes[a] (days to weeks)	Gastroenteritis; septicemia, meningitis	Freshwater, farmed fish; fish products	Disease uncommon, organism survives on processing equipment; grows at refrigerated temperatures
Clostridium perfringens[a] (6 to 24 h)	Diarrhea	Fish, shellfish; soil/environment	USA; low risk due to poor temperature control during cooking, storage
Streptococcus iniae[b]	Cellulitis; septicemia and sequelae	Tilapia, other finfish	Asia, Israel; due to preparation injuries, especially with live fish
Edwardsiella tarda[a,b]	Cellulitis, tissue infections, septicemia, diarrhea	Fresh and marine water	Endemic in tropical and underdeveloped countries; due to fish handling and preparation injuries
***Mycobacterium* spp.**[b,e] (1 to several weeks)	Granulomas of skin, subcutaneous tissues	Worldwide in > 160 species of fish	More common in ornamental fish handlers, aquarium owners; classed as "emerging infectious disease" by CDC

Possible routes of transmission: [a]foodborne; [b]contact; [c]fecal; [d]waterborne; [e]does not include tuberculous mycobacteria.

Antimicrobial resistance in zoonotic bacteria from aquaculture or seafood

While antimicrobial resistance in human pathogens is primarily the consequence of inappropriate use of antimicrobials in human medicine, there is growing evidence that their use in terrestrial agriculture has also contributed to the emergence of resistant foodborne pathogens such as *Salmonella* and *Campylobacter* (8). Associations between reported antimicrobial use and bacterial resistance have been demonstrated for specific aquaculture production environments and similar associations might exist at the higher aquaculture production levels such as by country of production. Globally and in the USA and Canada there have been increased frequencies of resistance to numerous antimicrobials, including some frequently used in aquaculture (8). In the above-mentioned survey-questionnaire (9), observed resistance to tetracycline in one or more species of bacteria was reported as "frequent-to-almost always" in isolates from catfish, salmon, tilapia, trout, and shrimp.

Although the risk to public health from antimicrobial use and subsequent development of bacterial resistance in aquaculture is estimated to be relatively low (9), there is a need to quantify this risk through generating representative Canadian data.

Regulatory framework for the aquaculture and seafood industry in Canada

Fish and shellfish products are inspected under the mandate of the Canadian Food Inspection Agency (CFIA), unless these are produced and remain within provincial or territorial boundaries. The CFIA registers federal fish-processing establishments, inspects imported fish and fish products (including tests for additives, allergens, pathogens, toxins, histamines, and drug residues), and develops and maintains international trade agreements (11).

The main objectives of the Canadian Shellfish Sanitation Program (CSSP), implemented by the CFIA, the Department of Fisheries and Oceans (DFO), and Environment Canada, are to protect the public from consumption of contaminated shellfish and to fulfill Canada's international obligations. The bacteriological component of the program includes testing for coliforms and may also encompass screening for *Vibrio parahaemolyticus* as part of outbreak investigations (11).

The CFIA also ensures the safety of fish and shellfish imports. Under the Fish Import Program, sampling, usually comprising a target of 5% of total annual imported lots, is based on the food safety risk, the history of compliance of a particular commodity or product, and scanning of information available or obtained for the source of the product. Currently, the products are tested for *E. coli,* coagulase-positive staphylococci, *Salmonella* spp., *Vibrio cholerae,* and *Listeria monocytogenes,* along with biotoxins, heavy metals, and chemical residues. Higher-risk products are inspected more often based on these criteria (11).

According to the Quality Management Program (QMP), all federally registered fish-processing plants are required to develop and implement an in-plant quality control program that is applicable to all consignments intended for export or inter-provincial trade. The QMP is based on the principles of Hazard Analysis and Critical Control Points (HACCP) with the main aim being to prevent biological, chemical, and physical hazards (11). Importers of seafood must also hold a QMP import license. Zoonotic bacteria screened under QMP include *E. coli,* fecal coliforms, *L. monocytogenes, Salmonella* spp., *S. aureus,* and *Vibrio* spp.

Evolution of surveillance for ensuring seafood safety: Opportunities for enhancement

The focus of existing CFIA or industry programs for ensuring seafood safety has been at the processing level. The programs will continue to evolve in the future due to anticipated increase in seafood production, consumption, and potential occurrence of emerging or new diseases affecting the safety of the aquatic food chain. *Vibrio* cases in humans are expected to increase worldwide in response to increasing water temperatures as a result of global climate change. In addition to *Mycobacterium marinum,* the Center for Disease Control (CDC) has also identified *Lactococcus garvieae* as an emerging pathogen in humans, possibly in association with aquaculture production (12). These new and emerging pathogens (except for *V. cholerae*) are not currently on the surveillance "radar" in Canada.

Leading international agri-food and health organizations have recently issued a joint call for developing national and international surveillance programs for antimicrobial use and antimicrobial resistance in farm-raised aquatic animals to prevent and reduce the development and spread of bacterial resistance in aquaculture. The use of antimicrobials is limited and tightly regulated in some countries (e.g., Canada), but in others, their use may be excessive, including the use of products of dubious quality. Such use of antimicrobials and lack of access to adequate veterinary services may result in an increased risk of exposure to antimicrobial resistant bacteria (8).

In Canada, there is an opportunity to implement the international recommendations at relatively low cost. Antimicrobial susceptibility testing could be added to the existing Canadian pathogen-based surveillance programs using their sampling frames and epidemiological information. The surveillance program could include testing of selected bacteria recovered from high-risk populations and periodic testing of a representative sample of selected imported or domestic products at the processing and, especially closer to the consumer, at the retail level. Initial focus of antimicrobial use surveillance could be at the farm level for the main domestically produced and consumed species. The enhancement of existing programs would require considerable funding and should be considered only if bacterial resistance is identified as a potential issue in domestic products. Successful implementation of these proposed initiatives would also require collaboration and trust across all stakeholders in the Canadian aquatic chain and better coordination of efforts among the various government agencies tasked with seafood safety.

A few pilot projects, recently completed or currently underway in the Laboratory for Foodborne Zoonoses (LFZ), Public Health Agency of Canada (PHAC) provide useful information for such considerations in the future. A global knowledge base on the main zoonotic bacteria in seafood was developed through a transparent and formal identification, evaluation, and synthesis of published scientific data (9). The baseline information on the frequency of antimicrobial use and observed bacterial resistance in aquaculture was obtained through a globally administered questionnaire survey of aquaculture-allied professionals (9). Retail surveys of imported shrimp and domestic salmon are being conducted to generate pathogen and bacterial resistance baseline information in the Canadian context. With this information at hand, relevant agencies such as the CFIA, PHAC, DFO, and Health Canada can evaluate the burden of illness attributable to pathogens or resistant bacteria in seafood in Canada, and harmonize their surveillance, research and policy efforts for ensuring consumer confidence in these products.

SPECIAL REPORT

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