Occurrence and Distribution of *Listeria* Species in Facilities Producing Ready-to-Eat Foods in British Columbia, Canada

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ABSTRACT

In British Columbia (BC), Canada, food processing facilities licensed under provincial authority are not required to sample for *Listeria monocytogenes* in food products or processing environments. In 2009, we conducted a survey of dairy, fish, and meat facilities under BC authority to estimate the prevalence of *Listeria* spp. and *L. monocytogenes* in ready-to-eat (RTE) foods and production environments. From August to October, 250 RTE food samples and 258 swabs from the food processing environments of 43 facilities were collected. Standard culture methods were applied to both food samples and swabs. Of swabs collected from all 258 environmental surfaces, 15% were positive for *Listeria* spp. Significantly (*P < 0.001*) more fish facilities than dairy and meat facilities had food contact surfaces contaminated with *Listeria* spp. *L. monocytogenes* was found in RTE foods from fish facilities alone (5 of 12); in all five of the fish facilities with contaminated product, one or more environmental swabs were also positive for *L. monocytogenes*. The results suggest that while control of *L. monocytogenes* in BC-inspected dairy and meat facilities is effective in limiting food contamination, there is a need for provincial inspectors to initiate improved monitoring and management of contamination by *L. monocytogenes* in RTE fish processing facilities.

Despite the efforts of industry and food safety authorities to prevent microbiological contamination of food, pathogenic microorganisms continue to enter the food supply. Of particular concern is *Listeria monocytogenes*, the organism responsible for the deaths of 23 Canadian consumers of ready-to-eat (RTE) meat products during a nationwide outbreak in 2008 (4).

In the province of British Columbia (BC), Canada, human cases of listeriosis (i.e., invasive listeriosis, caused almost exclusively by *L. monocytogenes*) were made reportable to public health authorities in 2002 following two outbreaks associated with consumption of BC-produced soft, mold-ripened, pasteurized milk cheese (2). An annual average of 110 cases of listeriosis, few of them linked to any particular exposure, was reported in Canada during 2003 to 2007 (50). A sharp increase in medical testing and reported cases (*n* = 239) occurred in 2008, largely related to the nationwide outbreak (1, 50). Outside of Canada, the United States and France have reported fewer cases of listeriosis subsequent to the implementation of hazard analysis and critical control point (HACCP) programs and more aggressive control measures for *L. monocytogenes* in foods and processing environments (3, 24).

Even with the implementation of HACCP and other food safety practices, the control of *L. monocytogenes* in food processing environments remains a challenge as these bacteria can form biofilms (39) and are able to survive in refrigerated environments (i.e., temperatures <4°C), high salt concentrations (i.e., 20%), limited oxygen atmospheres, and moderate to low acidity (pH 4.4 to 9.6) (20). With these traits and its widespread distribution in the environment, *L. monocytogenes* has become a common inhabitant of food processing establishments, with almost no food category free from its presence (20). As different species of *Listeria* are often found living together (39), the presence of any *Listeria* species in a food processing environment is an indication that conditions are favorable for the survival and potential growth of pathogenic *L. monocytogenes* (38, 45).

The sources and pathways of contamination by *L. monocytogenes* in food processing facilities vary by facility type (43). In facilities in which foods undergo multiple handling steps, contaminated equipment or processing environments (9) and food handler practices (13) play a role in product contamination. The complex equipment found in larger food processing facilities is difficult to clean and sanitize, potentially harboring *L. monocytogenes* and resulting in ongoing contamination of food products (12, 32). In smaller facilities, food product trays, crates, slicers, knives, carts, and countertops may harbor *L. monocytogenes*, leading to food contamination (5, 30, 47). In most cases, however, it is difficult to determine the primary source of *L. monocytogenes* found in food processing environments (28), and, given its ubiquitous nature, complete elimination seems impossible.

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TABLE 1. Types of surfaces sampled for recovery of Listeria spp. in ready-to-eat dairy, fish, and meat processing facilities

<table>
<thead>
<tr>
<th>Type of surface:</th>
<th>Non–food contact</th>
<th>Close–to–food contact</th>
<th>Food contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain</td>
<td></td>
<td></td>
<td>Work table</td>
</tr>
<tr>
<td>Sides/legs:</td>
<td></td>
<td></td>
<td>Packaging counter</td>
</tr>
<tr>
<td>Cart</td>
<td></td>
<td></td>
<td>Food racks/shelves</td>
</tr>
<tr>
<td>Conveyor</td>
<td></td>
<td></td>
<td>Slicer</td>
</tr>
<tr>
<td>Vat</td>
<td></td>
<td></td>
<td>Cutting board</td>
</tr>
<tr>
<td>Table</td>
<td></td>
<td></td>
<td>Food bin</td>
</tr>
<tr>
<td>Refrigerator</td>
<td></td>
<td></td>
<td>Food display basket/bin/insert</td>
</tr>
<tr>
<td>Doors</td>
<td></td>
<td></td>
<td>Food mold</td>
</tr>
<tr>
<td>Area under wash sink</td>
<td></td>
<td></td>
<td>Filler bowl</td>
</tr>
<tr>
<td>Support beams</td>
<td></td>
<td></td>
<td>Inside of vat pipes</td>
</tr>
<tr>
<td>Trolley wheels</td>
<td></td>
<td></td>
<td>Cutting utensils</td>
</tr>
<tr>
<td>Bottom shelves of packaging/wrapping tables</td>
<td></td>
<td></td>
<td>Showcase/display cooler door handle and interior</td>
</tr>
</tbody>
</table>

to achieve (21, 50). However, careful assessment of known hazards, combined with regular microbial testing of foods and processing environments, worker training, and ongoing vigilance are key to reducing food contamination and public health risk (26).

In BC, food processing facilities that export foods outside of the province are inspected by the federal Canadian Food Inspection Agency, while those producing for consumption in-province alone are inspected by provincial public health officers. Recent amendments to the Canadian Food Inspection Agency’s Meat Hygiene Manual of Procedures (8) have placed more attention at the federal level on testing for *Listeria* spp. and/or *L. monocytogenes* in the manufacturing environment and in foods produced. More rigorous monitoring and increased frequency of inspection and sampling have been introduced at both government and processor levels in federally registered RTE meat processing facilities (8).

Although prevalence studies on *Listeria* in foods and food processing environments have been performed in other countries, there are no BC data and limited Canadian data on the occurrence of *Listeria* spp. in RTE food processing sectors. In BC, there are no provincial regulations or guidelines referring specifically to *Listeria* spp. or *L. monocytogenes* in the environment or products from provincially licensed (but not federally registered) dairy, fish, and meat facilities producing RTE foods. In response to recent nationwide outbreaks of listeriosis and notable BC outbreaks related to cheeses, the BC Centre for Disease Control conducted a survey of *Listeria* spp. and *L. monocytogenes* in RTE food processing facilities subject to provincial inspection. The goals of the survey were to (i) estimate the occurrence of *Listeria* (including *L. monocytogenes* and other species of *Listeria*) in the production environments of dairy, meat, and fish-based facilities and in their RTE products; (ii) assess differences in the occurrence of *Listeria* between facility categories; and (iii) estimate the prevalence of *Listeria* across three production line sub-environments: non–food contact surfaces, close-to-food contact surfaces, and food contact surfaces.

**MATERIALS AND METHODS**

**Selection of food processing facilities.** The selection of facilities to be sampled was guided by three principles: (i) the inclusion of facilities and RTE products from three producer classes, namely, dairy, fish, and meat; (ii) coverage of major geographic areas within BC; and (iii) practicability within a 3-month sampling period. Facilities were less likely to be visited if they had inconvenient production timetables or were geographically isolated. From August to October 2009, a total of 53 non–federally registered food processing facilities that produce RTE foods were visited; 10 of these facilities (mainly butcher shops and delis) were excluded due to incomplete sampling, resulting in a total of 43 facilities included in the survey. These comprised all 17 dairy facilities under provincial licensing authority, 12 of the 17 finfish facilities producing RTE products, and 14 RTE meat producers, including all four eligible slaughterhouses and 10 delis and butcher shops (a small fraction of such facilities).

**Sampling plan.** Trained government food hygiene inspectors collected samples during unannounced visits; however, smaller facilities where production was occasional were contacted prior to sampling to ensure that the facility was in operation on that day. Environmental swabs and RTE food products present at the facility were collected on the same visit.

Inspectors were requested to collect six swabs from the three production line subenvironments where RTE products were handled: two from surfaces not in contact with food, two from surfaces close to food, and two from surfaces in contact with food (Table 1). The rationale for surface selection was based on previously published reports that examined the presence of *Listeria* spp. in food processing facilities (35, 49). Swabs were collected aseptically at least 3 h after the facility began operations, in order to increase the likelihood of capturing environmental and product contamination incidents during processing (8, 48). Sterile prewetted sponge applicators (Qualicum Scientific Ltd., Nepean, Ontario, Canada) were used to swab areas (30 by 30 cm), five times vertically and five times horizontally. Sponges were then placed aseptically in sterile bags and refrigerated for no more than 48 h.

Six RTE food samples (ca. 150 g per sample) were also requested from each facility. These were collected aseptically, either in sterile sample bags or as prepackaged consumer-ready product. Foods sampled had been produced on the day of the visit or, in the case of foods normally aged prior to shipment (e.g., aged...
chesse and meats), were collected at the end-stage of production ready for shipment to retailers. Food samples were kept on ice or refrigerated prior to shipping to the Provincial Health Services Authority Reference Laboratory, where they were analyzed within 48 h of sample collection. Samples from dairy processing facilities included milk and fluid dairy products, hard and soft cheeses, yogurt, and ice cream. Fish and seafood products included cooked, heat-dried, or hot-smoked salmon products with various flavors (e.g., teriyaki, honey garlic, Cajun, candied), as well as cold-smoked salmon products, smoked sablefish, sardines, and cooked prawns. Meat samples included varieties of beef and pork sausages, pepperoni, prosciutto salami, meatloaf, hot dogs or Wieners, beef and deer jerky, turkey, chicken, ham and beef deli meats, as well as buffalo and bison salami and sausages.

**Isolation of Listeria spp. from environmental swabs.** Environmental swabs were analyzed for the presence of *Listeria* spp. according to Health Canada’s MFHPB-30 enrichment (40) method, with slight modifications. Briefly, 225 ml of *Listeria* enrichment broth (LEB; Difco, BD, Sparks, MD) was added to bags containing sponges, after which they were incubated at 30°C for 24 h. Following gentle manual squeezing of the bags, a 0.1-ml aliquot of LEB culture was transferred to 10 ml of modified Fraser broth (MFB; formulation as per Health Canada’s MFHPB-30 method (40)) and incubated at 35°C for 48 h. In addition, after 24 h of incubation, LEB samples were streaked onto PALCAM and Oxford agars for *Listeria* spp. and incubated at 35°C for 24 h and 48 h. Following incubation, plates were examined for typical *Listeria* colonies at 24 h and 48 h, while MFB was examined for change in color. Additionally, MFB samples were streaked following 48 h of incubation onto selective agars (Oxford and PALCAM); plates were examined for typical *Listeria* colonies after 24 and 48 h incubation at 35°C.

**Isolation of Listeria spp. from food samples.** Food samples were analyzed for the presence of *Listeria* spp. according to Health Canada’s MFPL-74 enumeration (41) and MFHPB-30 enrichment (40) methods, with slight modifications. Similar to environmental swabs, 225 ml of LEB was added to 25 ml or 25 g of randomly selected analytical units of the food sample. Samples were then stomached for 30 s (Stomacher 400, Seward Medical, Worthing, UK), after which 0.1 ml was spread plated onto duplicate plates of each agar (PALCAM and Oxford). The plates were incubated at 35°C for 24 h and 48 h; at each time interval they were examined for typical *Listeria* colonies and colony counts were recorded. The inoculated LEB broth was also incubated at 30°C for 24 h, after which time it was streaked onto PALCAM and Oxford agars and 0.1 ml was transferred to 10 ml of MFB. Selective plates were incubated at 35°C for 24 h and 48 h, while MFB was incubated at 35°C for 48 h. Examination and/or streaking of the plates and MFB were performed as for the environmental samples, described above.

**Isolate screening and confirmation.** Screening of presumptive *Listeria* spp. was conducted using horse blood agar (Dalynn Biologicals, Calgary, Alberta, Canada) selecting both β-hemolytic and nonhemolytic isolates, after which isolates were streaked onto defibrinated sheep blood agar (Oxoid) and optionally onto Trypticase soy agar (Difco) to obtain pure colonies. Further confirmation was based on Gram stain, catalase and oxidase reactions, and motility (Deep *Listeria* Motility; Difco) at room temperature. Biochemical test strips (Microgen Listeria ID, Microgen Bioproducts Ltd., Camberland, Surrey, UK) were used to differentiate *Listeria* spp.

**Statistical analysis.** Statistical analyses of the prevalence of all *Listeria* spp. and *L. monocytogenes* alone were analyzed separately for environmental swabs and foods. The proportion of facilities having positive results was compared across facility categories and production line subenvironments; two-tailed Fisher’s exact test was used to assess differences. In addition, the proportion of positive samples was also compared across facility categories and production line subenvironments; statistical tests of samples (as contrasted with tests of facilities) accounted for the aggregation of positive results by facility. The association of environmental swab (or separately, food sample) positivity with facility type was assessed by logistic regression, adjusted for the effect of specific facilities by weighting the samples from individual facilities according to the probability of finding positive samples within that facility. This relatively conservative assumption would be expected to lead to wide confidence intervals (CI) around the prevalence estimates. All analyses were performed using R software (version 2.10.1; R Foundation for Statistical Computing, Vienna, Austria).

**RESULTS**

Overall, 43 RTE food processing facilities were included in the analyses of the prevalence and distribution of *Listeria* spp. and *L. monocytogenes* in their foods and production environments. We first report on contamination in individual environmental swabs and food samples. Next, facilities are considered as the unit of analysis, with environmental and/or food contamination separately compared across dairy, fish, and meat categories. Results for *Listeria* spp. as the indicator for pathogenic *L. monocytogenes* are reported for environmental surface contamination, whereas results for RTE foods emphasize the presence of *L. monocytogenes*. Values for all *Listeria* spp., species other than *L. monocytogenes*, and *L. monocytogenes* alone are reported in the tables and figures, where applicable. Throughout the study, unless otherwise indicated, *Listeria* spp. refers to all species of *Listeria*, including *L. monocytogenes*.

**Environmental surfaces contaminated with Listeria spp.** Six environmental swabs, two from each production subenvironment, were collected from each of the 43 facilities, for a total of 258 (86 swabs of each non-food contact, close-to-food contact, and food contact surfaces). *Listeria* spp. were found on 31% of non–food contact surfaces, 6% of close-to-food contact surfaces, and 7% of food contact surfaces. While *Listeria* spp. were most commonly seen on non-food contact surfaces, more fish facilities had close-to-food and food contact surfaces contaminated with the bacteria (Fig. 1).

Of the eight dairy swabs positive for *Listeria* spp., seven were from non–food contact surfaces such as drains, areas under wash sinks, and on and around conveyors. A draining rack was the only positive close-to-food surface. In environmental swabs from meat processors, all positive swabs came from non–food contact surfaces, including drains, floors adjacent to drains, and a cart transporting raw meat to the RTE production area. In fish processing environments, in addition to drains, legs of a sink, tables, and carts commonly contaminated with *Listeria* spp., contamination was also found on close-to-food surfaces,
such as walls adjacent to food handling, slicer legs, packaging table and work table shelving, as well as on surfaces in direct contact with RTE foods, including cutting boards, work tables, and shelves holding the finished product. In weighted logistic regression analyses, *Listeria* spp. was 3.9 (95% CI = 1.6 to 9.7) times more likely to be found in any area of fish processing environments than in dairy and meat environments. For non–food contact subenvironments, the weighted estimate was 3.1 but was not statistically significant (95% CI = 0.96 to 9.92).

**Foods contaminated with *L. monocytogenes***. Of the 250 RTE food samples analyzed, the highest proportion of foods contaminated with *Listeria* spp. was seen in the fish category (20 of 71), followed by meat (2 of 79) and dairy (0 of 100) (Fisher’s exact *P* < 0.001). A weighted regression also indicated that *Listeria* spp. were 7.5 (95% CI = 1.4 to 40.6) times more likely to be found in RTE fish products than in meat products.

*L. monocytogenes* was found in 6% of all RTE food samples. The bacterium was cultured solely from fish products (Fig. 2 and Table 2) and was detected in 13 hot-smoked, heat-dried, or cooked products and in one cold-smoked salmon product. None of 100 dairy and 71 meat samples harbored *L. monocytogenes*, although other non-pathogenic species of *Listeria* were recovered from a small proportion (2%) of meat samples (Table 2). Of the 22 samples contaminated with *Listeria* spp., 16 had bacterial counts of fewer than 100 CFU/g, while 6 (27%) of them met or exceeded 100 CFU/g. Gross listerial contamination (i.e., greater than 30,000 CFU/g) was seen in three salmon products, all of which cultured *L. monocytogenes*.

**Processing environment contamination by facility type.** *Listeria* spp. were recovered from the processing environments of 18 (42%) of the facilities. Environmental swab cultures indicated the presence of *Listeria* spp. on non–food contact surfaces in 18 (42%) facilities, close-to-food contact surfaces in 4 (9%) facilities, and food contact surfaces in 5 (12%) facilities. Considering the three production subenvironments together, swabs from 5 (29%) dairy, 5 (36%) meat, and 8 (67%) fish processing facilities were contaminated. Fish facilities were more likely than dairy or meat facilities to have at least one environmental swab positive for *Listeria* spp., but the differences were not significant (Fisher’s exact *P* = 0.14). Considering the three production subenvironments separately by facility type, differences were small in the proportions of dairy, fish, and meat facilities in which swabs of drains and other non–food contact surfaces tested positive (*P* = 0.14) for *Listeria* spp. The same comparison for close-to-food contact surfaces produced similar findings with nonsignificant results (Fisher’s exact *P* = 0.09). However, fish processors were significantly more likely than meat and dairy processors to have food contact surfaces positive for *Listeria* spp. (*P* < 0.001).

Altogether, there were nine facilities (three dairy, five fish, one meat) in which both non–food contact swabs tested positive for *Listeria* spp. Both swabs tested positive for *Listeria* spp. on close-to-food contact surfaces at one fish facility, and in three facilities (one dairy, two fish) a single swab tested positive. Finally, for food contact surfaces there...
was one fish facility in which both swabs tested positive and four fish facilities in which one of two swabs tested positive (Table 3). In all cases (all environmental swabs, non–food contact, close-to-food contact, and food contact) the meat and dairy facilities were not significantly different from each other (Fisher’s exact $P$ range = 0.9 to 1.0), and the fish facilities were significantly different from both (Fisher’s exact $P$ range = 0.00 to 0.03).

In fish facilities, between one and five (median, 2.5) of the six swabs taken at each of the eight positive facilities were contaminated with *Listeria* spp. In comparison, in meat and dairy facilities, between one and three (median, 1) swabs were positive. Most positive swabs in subenvironments of meat (6 of 6) and dairy (8 of 9) facilities came from non–food contact surfaces, whereas in fish facilities, nearly half (10 of 23) came from close-to-food contact (4 of 23) and food contact (6 of 23) surfaces (Table 3).

**RTE food contamination by facility type.** Statistical comparison by facility type showed a significant difference between facilities with respect to the presence of foods contaminated with *Listeria* spp. (Fisher’s exact $P$ = 0.002) and *L. monocytogenes* (Fisher’s exact $P$ < 0.001).

No dairy facilities had foods contaminated with *Listeria* spp. A single food sample contaminated with nonpathogenic *L. welshimeri* was found in 2 of the 14 meat processors, including a slaughterhouse and a deli store. Of the 12 fish facilities, 6 (50%) had *Listeria* spp. recovered from RTE foods, and further speculation found that 5 (42%) facilities had *L. monocytogenes* cultured in one or more products. Among the facilities where *L. monocytogenes* was found in foods, one had only one positive sample, two had two positive samples, one had four positive samples, and in one there were five food samples positive for *L. monocytogenes* (Table 3).

**Overall facility contamination.** Although *L. monocytogenes* was found in the production environments of all three facility categories (dairy, meat, and fish), it was only found in RTE foods from fish facilities (Fig. 3). Four of the five fish processing facilities with at least one RTE food sample positive for *L. monocytogenes* also had two or more environmental swabs positive for *L. monocytogenes*.

The joint presence of *L. monocytogenes* in foods and *L. monocytogenes* and other *Listeria* spp. in swabs of the processing environments is shown in Figure 3. This figure illustrates that non–food contact surfaces were contaminated with *Listeria* spp. in facilities of all three categories, but that food contact surfaces were contaminated only in RTE fish facilities. It also shows that *L. monocytogenes* was found only in RTE fish products. More importantly, it shows that in all facilities in which product was contaminated with *L. monocytogenes*, *Listeria* spp. were present in the processing environment.

**DISCUSSION**

*Listeria* species, and in particular *L. monocytogenes*, have been found in food products and retail and processing environments of fish (12, 32), dairy (18, 23), and meat (7, 17) facilities. While considerable variability has been noted in the levels of contamination of food and food processing facilities with *Listeria* from region to region (45), the overall
TABLE 3. Number of samples and facilities with *Listeria monocytogenes* and other *Listeria* spp. (non-∗L. monocytogenes∗) positive swabs and RTE foods, by facility category, environmental surface, and number of samples positive within a facility (0 to 5)∗

<table>
<thead>
<tr>
<th>Facility category and sample type</th>
<th>No. of positive samples</th>
<th>No. of facilities positive (0–5 samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L.m.</td>
<td>Non-L.m.</td>
</tr>
<tr>
<td>Dairy facilities (∗n = 17∗)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swabs: all surfaces</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Non-FCS</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Close-FCS</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>FCS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Food</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Fish facilities (∗n = 12∗)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swabs: all surfaces</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Non-FCS</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Close-FCS</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>FCS</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Food</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Meat facilities (∗n = 14∗)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swabs: all surfaces</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Non-FCS</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Close-FCS</td>
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<td>—</td>
</tr>
<tr>
<td>FCS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Food</td>
<td>—</td>
<td>2</td>
</tr>
</tbody>
</table>

∗L.m., *Listeria monocytogenes*; FCS, food contact surface; —, none.

FIGURE 3. The joint presence of *Listeria* spp. and *L. monocytogenes* in the processing environment and *L. monocytogenes* in food.
occurrence of *Listeria* spp. in food processing facilities in the current survey is comparable to earlier Canadian studies (17, 19) and reports from outside Canada (14, 22). While the prevalence of *Listeria* spp. in dairy and meat facilities was lower than expected, the prevalence of *Listeria* spp. in fish processing facilities was considerably higher. Even though no outbreaks of listeriosis have been reported from consumption of RTE fish products in BC (10), the finding that *Listeria* spp. were only recovered from food contact surfaces and RTE foods in fish processing facilities is of particular importance. In fact, *L. monocytogenes*, the organism associated with human listeriosis, was recovered from 20% of RTE fish products and in 42% of the fish facilities surveyed. This suggests that the potential for cross-contamination from non–food contact to food contact surfaces and subsequent contamination of RTE foods in fish facilities exists, but is present to a lesser degree in meat and dairy facilities.

Considering historical issues with *Listeria* in the dairy industry in BC, it was somewhat surprising to see *Listeria* spp. only on surfaces not in direct contact with RTE food and no dairy product contamination. Similarly, the low prevalence of *Listeria* spp. observed in the environment and food products of RTE meat processing facilities was unexpected, as other studies have indicated that *Listeria* spp. are not uncommon in these facilities. In the United States, 3.3% of 830 dry and semidy fermentated sausages and 4.4% of 1,509 sliced ham and luncheon meats sampled over a period of 3 years (37) contained *L. monocytogenes*. In Alberta (Canada), 3 to 5% of turkey breast, beef wiener, and chicken wiener samples, as well as 4% of retail fermentated sausages, contained *L. monocytogenes*, indicating that *L. monocytogenes* may be present in a variety of retail products (6). The absence of *L. monocytogenes* in the tested RTE meat samples and its presence in only a small percentage of environmental swabs in this survey suggests that control of *L. monocytogenes* is adequate in those BC RTE meat facilities. However, *Listeria* spp. were 3.9 times more likely to be found in fish processing environments than in dairy and meat processing facilities. In three fish facilities in which all subenvironments were positive for *Listeria* spp., foods also contained *L. monocytogenes*; this suggests failure of hygiene and effective controls along the processing chain. Cross-contamination from processing environment to food may occur if foods are processed inadequately or if the food processing environment is poorly cleaned and sanitized (43). Swabbing of the processing surfaces has been suggested as a valuable tool for effective monitoring of listerial contamination of food products (44, 48).

Although the occurrence of *Listeria* spp. and *L. monocytogenes* in smoked fish is not entirely uncommon (11, 25), the prevalence of *L. monocytogenes* in RTE fish products reported here was notably higher than what has been reported in previous Canadian studies (15, 16). Farber (16) reported the marked absence of *L. monocytogenes* in RTE seafood products tested between 1997 and 1999 as part of the Canadian Food Inspection Agency’s Quality Management Program. A 1991 Canadian study, also by Farber (15), examined 113 RTE seafood products for the presence of *L. monocytogenes*. Overall, 13% contained *L. monocytogenes*, which is notably lower than the contamination reported here. In the current study, of RTE hot-smoked fish samples contaminated with *L. monocytogenes*, 4 (31%) exceeded the Health Canada limit of greater than 100 CFU/g (26) and 3 (23%) had counts in excess of 30,000 CFU/g. In a larger 2006 United Kingdom survey, 3.4% of RTE hot-smoked fish samples were positive for *L. monocytogenes*, and only 0.06% of these samples exceeded 100 CFU/g (22). In a European Union member state survey of retail RTE fish products, only 0.4% of samples exceeded 100 CFU/g (14). Higher levels of bacterial contamination in RTE foods incur a greater risk. A dose of 100 organisms conveys a probability risk for infection ranging from 10−9 to 10−13, while a dose of 1,000,000 organisms increases the risk of infection to 10−6 to 10−9 (27). Efforts to reduce gross contamination in RTE smoked fish products made in BC are required to lower the likelihood of illness from consuming these products.

It is worth noting that fish samples tested in the current survey were collected from food processing facilities at the beginning of their shelf life and were not exposed to shipping or handling in retail stores. As a result, the listerial counts, and perhaps the proportions positive, that we report here may underestimate counts at the end of the products’ shelf life or those present in products at the retail level (14, 46).

During the survey, when contaminated RTE product was identified, health authorities were alerted for follow-up actions. While the issues noted during follow-up inspections were mainly related to inadequate sanitation and hygiene in food processing facilities, a previously unidentified issue related to product type was also observed. During the investigation of contaminated RTE smoked salmon nuggets it was noted that these products are often sold to consumers in unlabeled bags. Salmon nuggets were first sold in bulk packages to retailers who displayed them on ice, and the name of the facility where the product originated may or may not have been present on the tag information. Based on this scenario, even if *Listeria* were identified in a RTE product, it is questionable whether the public would be able to recognize where the food was manufactured and, thus, respond appropriately to specific recall advice. In addition, consumers who purchase these products may not be aware that many of them are categorized as potentially hazardous foods requiring refrigeration. This is of particular concern to highly vulnerable consumers, such as pregnant women, immunocompromised persons, and the elderly, for whom infection with *L. monocytogenes* can lead to fatal listeriosis.

It has been recognized worldwide (21) that control of *L. monocytogenes* is a challenge in the fish industry. Effective control requires facility management of conditions that lead to food contamination. For cooked products, such as hot-smoked fish, a heat treatment process should be adequate to destroy *L. monocytogenes*. Following heat treatment, it is crucial that foods are handled appropriately so as to avoid recontamination prior to or during slicing, packaging, handling, and sale to the consumer. For cold-smoked
products, cold smoking does not have a heat treatment adequate to destroy *L. monocytogenes* (smoking temperatures are usually below 30°C), and control of fish quality, refrigeration, and strict hygiene during slicing, packaging, and handling are necessary (21). Raw fish may be contaminated with *L. monocytogenes* and may introduce the bacterium into processing environments, although evidence suggests that environmental contamination is largely independent of the incoming raw materials (42, 48). Studies that tracked *L. monocytogenes* in fish processing facilities further suggest that environmental contamination is the most likely source of finished product contamination (29, 48). In this study, one cold-smoked and several hot-smoked fish products were contaminated with *L. monocytogenes*, indicating a control failure somewhere along the processing chain (21).

In summary, based on findings reported in the current study it is clear that *Listeria* species are present in BC’s fish, dairy, and meat processing facilities. In those facilities with good manufacturing practices, employees trained in food safety, and effective cleaning and sanitation, the likelihood of finding *Listeria* in foods and food processing or handling environments is generally low. A correlation between the level of hygiene practiced in a facility and the incidence of *L. monocytogenes* has been demonstrated in many studies (23, 33, 34, 36), emphasizing the need not only for stringent but also for ongoing control strategies.

Some of the limitations of this study are the underrepresentation of small deli and retail butcher meat facilities, as well as the inclusion of only those BC facilities under provincial authority inspection (i.e., non–federally registered facilities). A more comprehensive assessment of bacterial prevalence in smaller deli and butcher shops as well as larger federally registered facilities would be useful in assessing the risk associated with facility size and product handling. In addition, assessment of HACCP programs and other control measures in place in facilities producing RTE foods in conjunction with follow-up microbial testing would allow more objective assessment of the effectiveness of control measures.

Although no listeriosis illnesses were linked to contaminated products tested as part of the survey (31), the results presented here indicate that the potential exists for illness related to consumption of RTE fish in BC, in particular smoked salmon products. Further research and enhanced inspection should aim to improve the consumer food safety of fish products in BC. Greater emphasis should be placed on environmental sampling programs that detect the presence of *Listeria* spp. in the environment and in RTE products before they reach the consumer. When positive results are detected, intensive investigation and follow-up sampling for compliance should be initiated.

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