

# Statistical Distributions Describing Microbial Quality of Surfaces and Foods in Food Service Operations

REBECCA MONTVILLE AND DONALD W. SCHAFFNER\*

Food Risk Analysis Initiative, Food Science Building, Rutgers University, 65 Dudley Road, New Brunswick, New Jersey 08901-8520, USA

MS 03-155: Received 10 April 2003/Accepted 26 July 2003

## ABSTRACT

Data on the microbial quality of food service kitchen surfaces and ready-to-eat foods were collected over a period of 10 years in Rutgers University dining halls. Surface bacterial counts, total aerobic plate counts, and total and fecal coliform counts were determined using standard methods. Analysis was performed on foods tested more than 50 times (primarily lunch meats and deli salads) and on surfaces tested more than 500 times (36 different surface types, including pastry brushes, cutting boards, and countertops). Histograms and statistical distributions were determined using Microsoft Excel and Palisades Bestfit, respectively. All data could be described by lognormal distributions, once data above and below the lower and upper limits of detection were considered separately. Histograms for surface counts contained one peak near 1 CFU/4 cm<sup>2</sup>. Surfaces with higher levels of contamination tended to be nonmetal, with the exception of buffalo chopper bowls, which commonly had high counts. Mean counts for foods ranged from 2 to 4 log CFU/g, with shrimp salad, roast beef, and bologna having higher means. Coleslaw, macaroni salad, and potato salad (all commercially processed products, not prepared in the dining halls) had lowest overall means. Coliforms were most commonly found in sealeg salad (present in 61% of samples) and least commonly found in coleslaw (present in only 7% of samples). Coliform counts (when present) were highest on average in shrimp salad and lowest in coleslaw. Average coliform counts for most products were typically between 1 and 2 log most probable number per gram. Fecal coliforms were not typically found in any deli salads or lunch meats.

Randomized inspections of food service establishments are an important tool in ensuring food safety. Over 30 years ago, a food safety program was developed at Rutgers University in response to a foodborne disease outbreak (19). The program focuses on surface sanitation and microbial content of foods as indicators of risk of foodborne disease (18). Random inspections are conducted weekly, year-round, at six large dining halls and many smaller facilities at Rutgers. Data collected for foods include time, temperature, and location of food on pickup; total aerobic count; coliform, *Escherichia coli*, *Clostridium perfringens*, and *Staphylococcus aureus* counts; and presence of salmonella. For surfaces, it includes time of sampling, location in the kitchen, condition of surface (wet, dirty, etc.), and total bacterial count. Data from surfaces and foods sampled over 10 years (1991 to 2001) have been entered into a relational database (2). The object of this study was to characterize the statistical variability in this large dataset.

## METHODS

**Microbial analysis.** All data were obtained from samples taken from dining facilities operated by Rutgers University between 1991 and 2001. Facilities ranged from large dining halls serving thousands of meals every day to small cash operations. Bacterial counts on surfaces were obtained by pressing approximately 4-cm<sup>2</sup> sterile CON-TACT-IT tape (Birko Corp., Henderson, Colo.) onto the test surface and then gently pressing onto

total plate count agar media (Difco, Detroit, Mich.). Plates were incubated overnight at 37°C and enumerated the following day.

Temperatures of foods were obtained using a sterilized, calibrated thermometer before pickup. Foods were taken from serving lines or the kitchen and placed into sterile whirl-pak bags (Fisher Scientific, Pittsburg, Pa.) using sterilized utensils, then they were transported back to the laboratory in an insulated bag with ice, and stored in a lab freezer until testing.

Total aerobic count of foods was determined using Food and Drug Administration standard methods (5). Thirty-five grams of each food was weighed into a stomacher bag (Fisherbrand, Pittsburgh, Pa.) with 315 ml of peptone water. The food was homogenized in a stomacher (Seward, London, UK) for 1 to 2 min depending on texture. Homogenate was serially diluted and plated on total plate count agar.

Presumptive and confirmed total coliform and fecal coliform counts were determined using the most-probable-number (MPN) method (5). Aliquots of homogenate and dilutions up to 10<sup>-5</sup> were added in triplicate to lauryl tryptose broth containing Durham tubes and incubated at 37°C. At 24 and 48 h, tubes were checked for gas production, and transfers were made from positive tubes with a sterile loop to tubes containing brilliant green broth and *Escherichia coli* (EC) broth. Brilliant green tubes were incubated at 37°C and EC tubes were incubated at 45°C. Tubes were checked for gas production at 24 and 48 h. An MPN chart was used to calculate the number of coliforms.

**Data analysis.** Statistical analysis was performed on surfaces tested more than 500 times and foods tested more than 50 times (except for turkey salad, tested 48 times). Foods meeting this criterion were primarily deli salads or lunch meats, whereas many food contact surfaces were juice or soda dispenser tips.

Data were exported from Paradox (Borland, Scotts Valley,

\* Author for correspondence. Tel: 732-932-9611 Ext. 214; Fax: 732-932-6776; E-mail: schaffner@aesop.rutgers.edu.

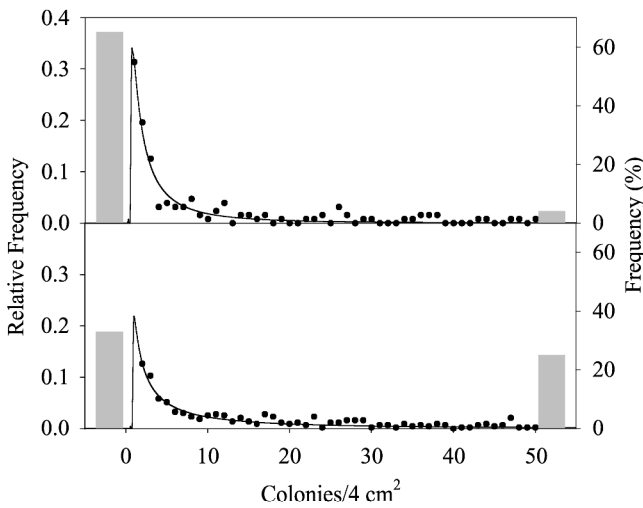


FIGURE 1. Distributions and raw data of aerobic surface counts on cola (top) and hot chocolate (bottom) dispenser tips. Raw data (solid circles) were fit to lognormal distributions (gray lines). Bars indicate percentage below and above the level of detection.

Calif.) to Excel (Microsoft, Redmond, Wash.), histograms were created, and correlations were determined. Similar data sets were combined where appropriate. Counts of 0 CFU/4 cm<sup>2</sup> and >50 CFU/4 cm<sup>2</sup> were considered separately from the rest of the surface contamination: they were not included while fitting data to distributions. Distributions were created using Bestfit (Palisades, Newfield, N.Y.) (4). The Kolmogorov-Smirnoff test was used to determine goodness of fit (14). After initial analysis, the lognormal distribution was selected to represent the bacterial count on both surfaces and foods on the basis of its generally high statistical

ranking, visually acceptable fits, and accepted use of describing microbial distributions in foods (9). The lognormal distribution is a two-parameter distribution with parameters  $\mu$  and  $\sigma$ , where  $\mu$  is the mean and  $\sigma^2$  is the variance.

**RESULTS**

**Surface samples.** Although beverage dispenser tips are not known to have ever been a source of cross-contamination in a foodborne disease outbreak, these surfaces regularly had high total bacterial counts and, as a result, were tested quite frequently (over 10,000 times in 10 years) in the Rutgers program. An example of raw data fit to a lognormal distribution is given in Figure 1 for hot chocolate and cola dispenser tips. The parameters for hot chocolate and cola were  $\mu = 34.39$  and  $\sigma = 200.62$ , and  $\mu = 6.46$  and  $\sigma = 16.81$ , respectively. Although the lognormal distributions are similarly peaked (at 1 CFU), the cola distribution approaches 0 more quickly and the proportion of hot chocolate tips containing greater than 50 CFU/4 cm<sup>2</sup> was much higher (25% compared to 3.8%). Beverages with higher counts (and a higher percentage of counts exceeding 50 CFU/4 cm<sup>2</sup>) tended to be thicker, such as fruit shakes or orange juice, or beverages served warm, such as hot chocolate or espresso (data not shown).

The lognormal distributions that describe contamination on kitchen surfaces showed many similarities (Table 1). A sampling of lognormal distributions for nonmetal surfaces is shown in the top panel of Figure 2. The means (as determined by the lognormal equation) for plastic hotel pans, plastic cutting boards, and rubber spatulas were 7.47, 10.16, and 4.52 CFU/4 cm<sup>2</sup>, respectively. The correspond-

TABLE 1. Statistical analysis of bacterial contamination of food service food contact surfaces in Rutgers University dining facilities (1991 to 2001); data represent lognormal distribution parameters (log CFU/g) or the percentage of results with no colonies or colonies too numerous to count

Surface tested	Lognormal parameters ( $\mu$ , $\sigma$ )	No colonies (%) <sup>a</sup>	With colonies TNTC (%) <sup>b</sup>	No. of samples
Buffalo chopper blade	(5.42, 9.43)	65.2	1.4	784
Buffalo chopper bowl	(9.78, 24.12)	58.5	7.5	750
Buffalo chopper shaft	(6.04, 10.19)	61.1	1.5	893
Chef's knife	(6.98, 13.04)	61.6	1.5	1,143
Countertop (stainless)	(7.35, 13.78)	52.2	3.4	3,480
Cutting board (plastic)	(10.16, 19.71)	47.6	6.7	3,241
Dispenser tips	(13.50, 27.53)	40.2	16.2	10,036
Hotel pan (plastic)	(7.47, 15.73)	78.2	2.3	1,862
Hotel pan (stainless steel)	(4.89, 7.93)	75.3	1.4	1,840
Meat slicer bed	(3.56, 4.87)	74.1	0.3	1,257
Meat slicer blade	(3.37, 4.73)	72.7	0.2	1,524
Meat slicer cover	(3.27, 4.40)	75.5	0.6	890
Meat slicer holder	(4.29, 7.05)	77.8	1.1	1,272
Meat slicer pan	(3.54, 4.89)	73.3	0.4	960
Pastry brush	(11.20, 23.14)	35.3	12.2	987
Portions scale pan	(4.29, 5.56)	45.9	0.7	962
Rubber spatula	(4.52, 7.00)	66.5	1.0	831
Scoop	(5.30, 9.04)	70.5	0.8	840
Serrated knife	(6.13, 11.49)	63.4	1.7	982
Serving spoon	(4.79, 8.10)	73.4	1.1	728

<sup>a</sup> Less than 1 CFU/4 cm<sup>2</sup>.

<sup>b</sup> Too numerous to count (>50 CFU/4 cm<sup>2</sup>).

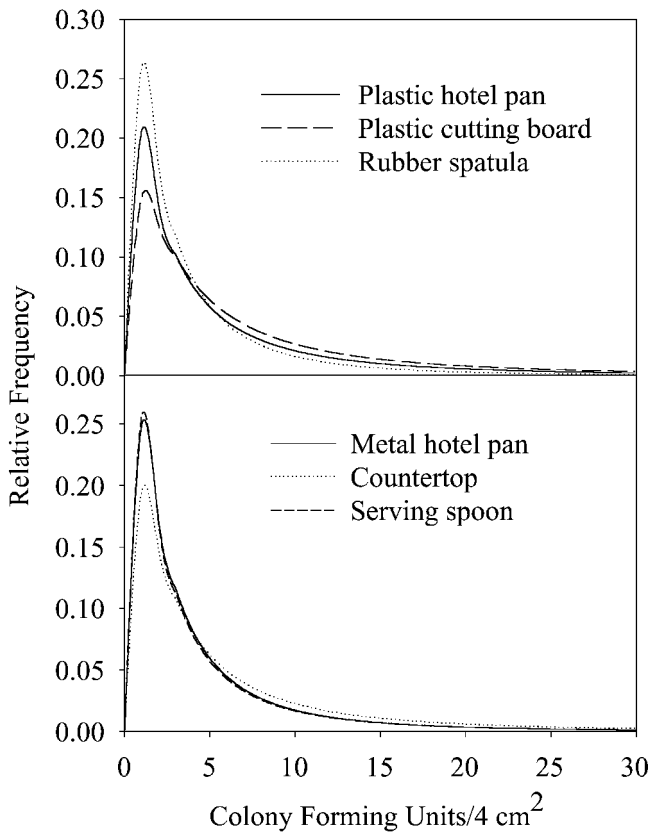


FIGURE 2. Lognormal distributions fit to aerobic surface counts for select nonmetal (top) and metal (bottom) surfaces in food service kitchens at Rutgers University. Top panel: solid line, plastic hotel pans; dashed line, plastic cutting boards; dotted line, rubber spatulas. Bottom panel: solid line, hotel pans; dashed line, countertops; dotted line, serving spoons.

ing parameters for similar metal surfaces (hotel pans, countertops, and serving spoons) were 4.89, 7.35, and 4.79 (Fig. 2, bottom panel). Although the mean counts tended to be lower for metal surfaces, there were some exceptions (such as metal countertops and buffalo chopper bowls).

The fraction of the time that a surface contained colonies too numerous to count (% TNTC; about 50 colonies per 4 cm<sup>2</sup>) and mean count (as determined by the lognormal equation) were highly correlated ( $r^2 = 0.94$ ). Juice dispenser tips, pastry brushes, and buffalo chopper bowls had the highest incidence of counts exceeding 50 CFU/4 cm<sup>2</sup> (16.2, 12.2, and 7.5%, respectively). Cutting boards also exceeded 50 CFU/4 cm<sup>2</sup> at a rate higher than that seen for many other surfaces (6.7%). Surfaces that exceeded 50 CFU/4 cm<sup>2</sup> less than 1% of the time included meat slicer beds, blades, pans and covers, portions scale pans, and metal scoops. Most surfaces with low % TNTC had no countable colonies a correspondingly high fraction of the time.

**Food samples.** An example of total plate count data fit to a lognormal distribution is given in Figure 3 for tuna salad, the most frequently tested food ( $n = 441$ ). The parameters of the lognormal distribution were  $\mu = 2.96$  and  $\sigma = 1.03$ . Logistic distribution parameters for all foods are given in Table 2. Little variation was seen between total

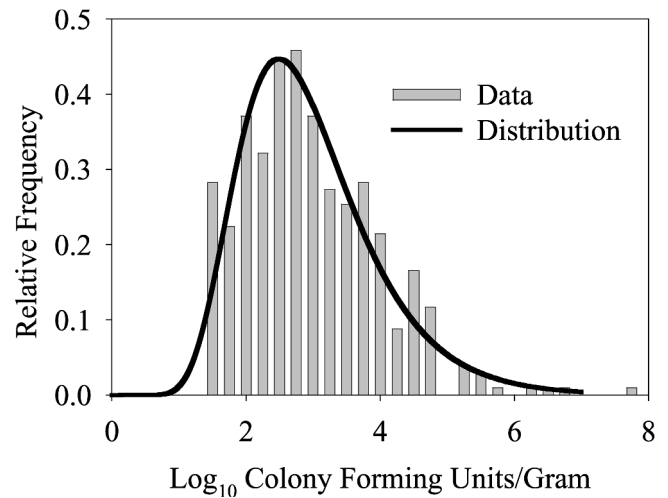


FIGURE 3. Example of lognormal distribution (line) fit to raw data (bars) for log total aerobic count per gram of 441 samples of tuna salad.

plate count distributions for meat or seafood containing deli salads (Fig. 4A and 4B). Deli salads containing poultry or eggs (chicken salad, egg salad, turkey salad) had nearly identical mean total plate counts of 3.30, 3.30, and 3.33 log CFU/g, respectively. Deli salads containing seafood (sealeg salad, shrimp salad, tuna salad) had mean total plate counts of 3.24, 3.74, and 2.96 log CFU/g, respectively. Shrimp salad had a higher mean and higher standard deviation in total plate counts compared with the other seafood-containing deli salads, and this difference is also apparent from Figure 4A. Logistic distributions for meatless deli salads

TABLE 2. Statistical analysis of log total aerobic count per gram for foods picked up from Rutgers University dining facilities (1991 to 2001); data represent lognormal distribution parameters (log CFU/g) or the percentage of samples below the limit of detection

Food	Lognormal parameters ( $\mu$ , $\sigma$ )	Below limit of detection (%)	No. of samples
<b>Deli salads (poultry or egg)</b>			
Chicken salad	(3.30, 1.22)	3.1	97
Egg salad	(3.30, 1.09)	5.2	96
Turkey salad	(3.33, 1.31)	0.0	48
<b>Deli salads (seafood)</b>			
Sealeg salad	(3.24, 1.02)	1.9	54
Shrimp salad	(3.74, 1.60)	0.0	57
Tuna salad	(2.96, 1.03)	7.3	441
<b>Deli salads (meatless)</b>			
Coleslaw	(2.48, 0.86)	2.9	68
Macaroni salad	(2.55, 0.58)	6.8	59
Potato salad	(2.73, 0.73)	3.6	83
<b>Lunch meats</b>			
Bologna slices	(3.61, 1.32)	4.6	65
Ham slices	(3.29, 1.05)	5.3	95
Roast beef slices	(3.71, 1.56)	6.2	113
Turkey slices	(3.40, 1.47)	6.4	157

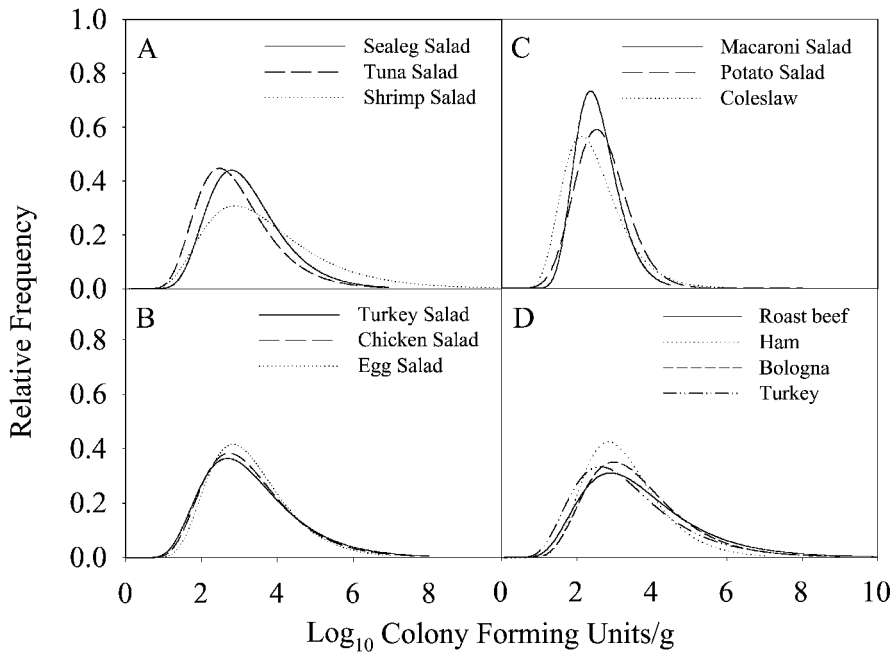


FIGURE 4. Lognormal distributions fit to log total aerobic count per gram data for various foods. (A) Seafood salads: solid line, sealeg salad (tested 54 times); dashed line, tuna salad (tested 441 times); dotted line, shrimp salad (tested 57 times). (B) Poultry salads: solid line, turkey salad (48 replicates); dashed line, chicken salad (97 replicates); dotted line, egg salad (90 replicates). (C) Nonmeat salads: solid line, macaroni salad (59 replicates); dashed line, potato salad (83 replicates); dotted line, coleslaw (68 replicates). (D) Various lunch meats: solid line, roast beef (tested 113 times); dotted line, ham (tested 95 times); dashed line, bologna (tested 65 times); dotted and dashed line, turkey (tested 157 times).

(coleslaw, macaroni salad, and potato salad) were quite different than for the other deli salads (Fig. 4C), with means well below 3 log CFU/g and standard deviations below 1 log CFU/g (Table 2).

Lunch meats had similar microbial quality to meat- and seafood-containing deli salads (Fig. 4D). The derived log-normal distributions were similar in all cases. Bologna,

TABLE 3. Summary of total coliform and *E. coli* most probable number per gram for foods picked up from Rutgers University dining facilities (1991 to 2001)

Food	No. of samples	Total coliforms <sup>a</sup>		Fecal coliforms	
		Average	SD	Below limit of detection (%)	below limit of detection (%)
<b>Deli salads (poultry or egg)</b>					
Chicken salad	37	1.64	1.32	62	96
Egg salad	45	1.94	1.12	52	98
Turkey salad	22	1.62	0.80	54	98
<b>Deli salads (seafood)</b>					
Sealeg salad	33	1.43	1.02	39	96
Shrimp salad	26	2.18	1.32	54	95
Tuna salad	207	1.57	0.98	64	98
<b>Deli salads (meatless)</b>					
Coleslaw	5	1.28	0.86	93	100
Macaroni salad	7	1.45	0.98	88	100
Potato salad	17	1.81	1.21	80	98
<b>Lunch meats</b>					
Bologna slices	7	1.75	0.85	85	94
Ham slices	22	1.35	0.74	77	99
Roast beef slices	41	1.58	1.13	64	98
Turkey slices	39	1.42	0.90	75	99

<sup>a</sup> Average and SD are log MPN/g.

ham, roast beef, and turkey slices had means of 3.61, 3.29, 3.71, and 3.40, respectively.

No correlation was found between pickup temperature and total plate count (data not shown), likely because the range of pickup temperatures was small (~40 to 45°F for most samples).

A summary of total and fecal coliform results for all foods tested more than 50 times is given in Table 3. Coliforms were most commonly found in sealeg salad (present in 61% of samples) and least commonly found in coleslaw (present in only 7% of samples). Meatless deli salads generally had considerably fewer samples that contained detectable coliforms (7 to 20%), whereas other deli salads contained coliforms a greater fraction of the time (45 to 61%). Coliform counts (when present) were highest on average in shrimp salad and lowest in coleslaw. Average coliform counts for most products were typically between 1 and 2 log MPN/g. Fecal coliforms were not typically found in any deli salads or lunch meats. They were most common in bologna slices (present 6% of the time) and were least common in coleslaw and macaroni salad (never found). It would not be meaningful to report fecal coliform average counts because the number of samples containing these organisms was generally few (1 to 4 observations). When more observations were available (tuna salad,  $n = 14$ ), average fecal coliform counts were  $0.87 \log \text{MPN/g} \pm 0.37$ .

## DISCUSSION

**Surface samples.** Previous research has shown that routine inspection of restaurants can be a good predictor of foodborne disease outbreaks (10). Ensuring proper surface sanitation, in particular, is important for reducing the risk of cross-contamination and can be an important aspect of hazardous analysis critical control point (HACCP) (17).

Surfaces with higher mean microbial levels and higher % TNTC tended to be plastic (e.g., juice dispenser tips,

pastry brushes, plastic cutting boards). Most of these items are also commonly encountered wet, which can provide a good environment for bacterial growth (2) and provide a higher bacterial transfer rate than dry surfaces (13).

Tessi et al. sampled 25-cm<sup>2</sup> areas in school kitchens in Argentina (21). They found mean aerobic counts of 3.74, 0.71, and 0.68 for plastic cutting boards, stainless steel countertops, and knives, respectively, before use at the beginning of the day. These results were always lower than what we observed, perhaps because our samples included both clean and in-use surfaces.

Although microbial testing of surfaces has drawbacks (i.e., high cost, more time needed to obtain results) it has been found to be a more reliable indicator of sanitation than visual inspections (12). Our research has identified surfaces more likely to be highly contaminated. Whether surface sanitation is monitored by visual or microbial inspection, extra attention should be given to plastic surfaces and surfaces that are commonly encountered wet.

**Food samples.** Other surveys of deli salads at retail have produced varying results. Deli salads obtained from butchers in Germany were found to have a range of 5 to almost 8 log CFU/g (1). Christensen and King found chicken salad to have bacterial levels ranging from 4 to 7 log CFU/g, with a median of 5.8 (3). They also reported lower contamination with coleslaw (a range of 2.7 to 4.5, and a median of 3.6, log CFU/g). In another study of deli salads from various manufacturers, shrimp and egg salads were found to have the poorest initial quality (6.1 log CFU/g for shrimp and 4.1 and 6.8 log CFU/g for egg salads) (7). However, possibly because of a limited number of samples, they were unable to determine any trends linking salad type and microbial load.

In a particularly extensive survey of cold lunch meats ( $n = 3,494$ ), Gillespie et al. found the modal level of contamination to be in the range of  $10^3$  and  $10^4$  log CFU/g, which is consistent with the data presented here (8). A study of ready-to-eat foods at retail in Japan found mean plate counts of 3.5, 3.4, and 3.7 log CFU/g for potato salad, macaroni salad, and coleslaw, respectively (11), which are similar with the levels of contamination that we found for meat- and seafood-containing deli salads. The Rutgers University Division of Dining Services obtains its macaroni salad, potato salad, and coleslaw directly from the manufacturer(s), and these items are not made in the dining halls (unlike all other deli salads). Because packages are simply opened and placed into pans, there is less potential for cross-contamination. These products could also contain preservatives and are processed and packed to ensure a long, safe shelf life, all of which likely contribute to lower total and coliform counts.

The "acceptable" level of contamination at Rutgers dining halls had previously been set at  $10^5$  for ready-to-eat foods (2). The data presented here and those of others (8) suggest that this specification can be met easily in meatless deli salads prepared by food processors and generally can be met most (~90%) of the time for other deli salads and luncheon meats. Shrimp salad prepared in Rutgers Univer-

sity Dining Halls was only able to meet this specification about 80% of the time.

**Application of these results to other settings.** The results presented here can be used in a variety of ways by others interested in surface sanitation and microbial food quality. Because this study was carried out over a long period of time, and because Rutgers dining halls are provided with test results and feedback on how to improve, these data represent a useful benchmark for comparison purposes. Other facilities matching these results should consider themselves to be performing in an acceptable manner. Facilities not matching these benchmarks can be confident that their results can be improved. The results presented here are achievable over a long period of time by typical large and small food service facilities.

The creation of statistical distributions, following the approach outlined here, or the use of the distributions presented here can be useful in defining a quantitative approach to setting surface sanitation and microbial food quality. A risk manager might decide, for example, that 95% of all tuna salad should meet a certain total plate count quality standard. If the distribution of the data is known (as it is here), it is simple to calculate that a sample taken from the lognormal distribution for tuna salad (2.96, 1.03) is expected to exceed a total plate count of 4.8 log CFU/g about 5% of the time. An operation which exceeds this count more than 1 in 20 times might not be meeting the quality standard, and measures should be taken to determine the cause.

It should be noted that the data presented is for the presence of indicators, and not actual pathogens, and despite their name, indicators are notoriously unreliable as true indicators for the presence of pathogens (15, 16, 20). That being said, data on the presence and concentration of indicator organisms can still be very useful as an indication of process control. One recent example of such a use can be found in the recent FDA regulations for juice pasteurization, in which the presence of generic *E. coli* is used as an indicator for process control when surface treatment of citrus fruit is to be included as part of a 5D process for pathogen reduction (6). An operation that produces food that exceeds a particular quality standard more often than expected could be viewed as not "in control," and, as such, at higher risk of producing a food that does contain pathogens.

## CONCLUSIONS

Surface bacterial counts for a variety of food service surfaces and total aerobic plate counts for a variety of foods can be described by lognormal distributions. The results presented here can be used in a variety of ways (e.g., as a benchmark for comparison purposes) by others interested in surface sanitation and microbial food quality. The creation of statistical distributions could be useful to risk managers in defining a quantitative approach to setting surface sanitation and microbial food quality. Data on the presence and concentration of indicator organisms could be useful as an indication of process control.

## ACKNOWLEDGMENTS

The authors acknowledge Dr. Myron (Mike) Solberg (1931 to 2001) for creating this visionary and unique project many years ago. We also thank the Rutgers University Division of Dining Services (especially the University Sanitarian, John Nason, and Director, Charles Sams) for their continued support and cooperation. We also recognize Jim Buckalew for his passion for dispenser tip sanitation and tuna salad quality.

## REFERENCES

1. Becker, B., B. Trierweiler, J. Fehler, T. Bohme, W. E. L. Spiess, and W. H. Holzapfel. 2002. Attended chilling cabinets in the food retail sale—3. Hygienic quality of delicatessen salads. *Fleischwirtschaft* 82:104–107.
2. Buckalew, J. J., D. W. Schaffner, and M. Solberg. 1996. Surface sanitation and microbiological food quality of a university foodservice operation. *J. Food Serv. Syst.* 9:25–39.
3. Christiansen, L. N., and N. S. King. 1971. The microbial content of some salads and sandwiches at retail outlets. *J. Milk Food Technol.* 34:289–293.
4. Evans, M., N. Hastings, and B. Peacock. 1993. Statistical distributions. John Wiley, New York.
5. Food and Drug Administration (FDA). 1998. Bacteriological analytical manual. AOAC International, Gaithersburg, Md.
6. Food and Drug Administration (FDA). 2001. Hazard analysis and critical control point (HACCP); procedures for the safe and sanitary processing and importing of juice; final rule. *Fed. Regist.* 66:6138–6202.
7. Fowler, J. L., and W. S. Clark. 1975. Microbiology of delicatessen salads. *J. Milk Food Technol.* 38:111–113.
8. Gillespie, I., C. Little, and R. Mitchell. 2000. Microbiological examination of cold ready-to-eat sliced meats from catering establishments in the United Kingdom. *J. Appl. Microbiol.* 88:467–474.
9. International Commission on Microbiological Specifications for Foods (ICMSF). 2002. Microorganisms in foods 7: microbiological testing in food safety management. Kluwer Academic/Plenum Publishers, New York.
10. Irwin, K., J. Ballard, J. Grendon, and J. Kobayashi. 1994. Results of routine restaurant inspections can predict outbreaks of foodborne illness: the Seattle-King County experience. *Am. J. Public Health* 79:586–590.
11. Kaneko, K., H. Hayashidani, Y. Ohtomo, J. Kosuge, M. Kato, K. Takahashi, Y. Shiraki, and M. Ogawa. 1999. Bacterial contamination of ready-to-eat foods and fresh products in retail shops and food factories. *J. Food Prot.* 62:644–649.
12. Kasa, H., B. Harrington, M. Bisesi, and S. Khuder. 2001. Comparisons of microbiological evaluations of selected kitchen areas with visual inspections for preventing potential risk of foodborne outbreaks in food service operations. *J. Food Prot.* 64:509–513.
13. Marples, R. R., and A. G. Towers. 1979. A laboratory model for the investigation of contact transfer of microorganisms. *J. Hyg.* 82:237–248.
14. Massey, F. J. 1951. The Kolmogorov-Smirnov test for goodness of fit. *J. Am. Stat. Assoc.* 46:68–78.
15. Miles, J. A. R., M. Solberg, B. A. Prevost, and D. K. Miskimin. 1978. Foodborne pathogens and indicator tests in ready to serve and raw foods. *Microbiol. Ecol.* 4:432–435.
16. Miskimin, D. K., K. A. Berkowitz, M. Solberg, W. E. Riha, W. C. Franke, R. L. Buchanan, and V. O'Leary. 1976. Relationships between indicator organisms and specific pathogens in potentially hazardous foods. *J. Food Sci.* 41:1001–1006.
17. Setiabuhdi, M., M. Theis, and J. Norback. 1997. Integrating hazard analysis and critical control point (HACCP) and sanitation for verifiable food safety. *J. Am. Diet. Assoc.* 97:889–891.
18. Solberg, M., J. J. Buckalew, C. W. Chen, D. W. Schaffner, K. O'Neil, J. McDowell, L. S. Post, and M. Boderck. 1990. Microbial safety assurance system for foodservice facilities. *Food Technol.* 44:68–73.
19. Solberg, M., D. K. Miskimin, R. Kramer, W. E. Riha, W. C. Franke, R. L. Buchanan, V. O'Leary, and K. Berkowitz. 1976. Assurance of microbiological safety in a university feeding system. *J. Milk Food Technol.* 39:200–205.
20. Solberg, M., D. K. Miskimin, B. A. Martin, G. Page, S. Goldner, and M. Libfeld. 1976. What do microbiological indicator tests tell us about the safety of foods? *Food Prod. Dev.* 10:72.
21. Tessi, M. A., E. E. Aringoli, M. E. Pirovani, A. Z. Vincenzini, N. G. Sabbag, S. C. Costa, C. C. Garcia, M. S. Zannier, E. R. Silva, and M. A. Moguilevsky. 2002. Microbiological quality and safety of ready-to-eat cooked foods from a centralized school kitchen in Argentina. *J. Food Prot.* 65:636–642.