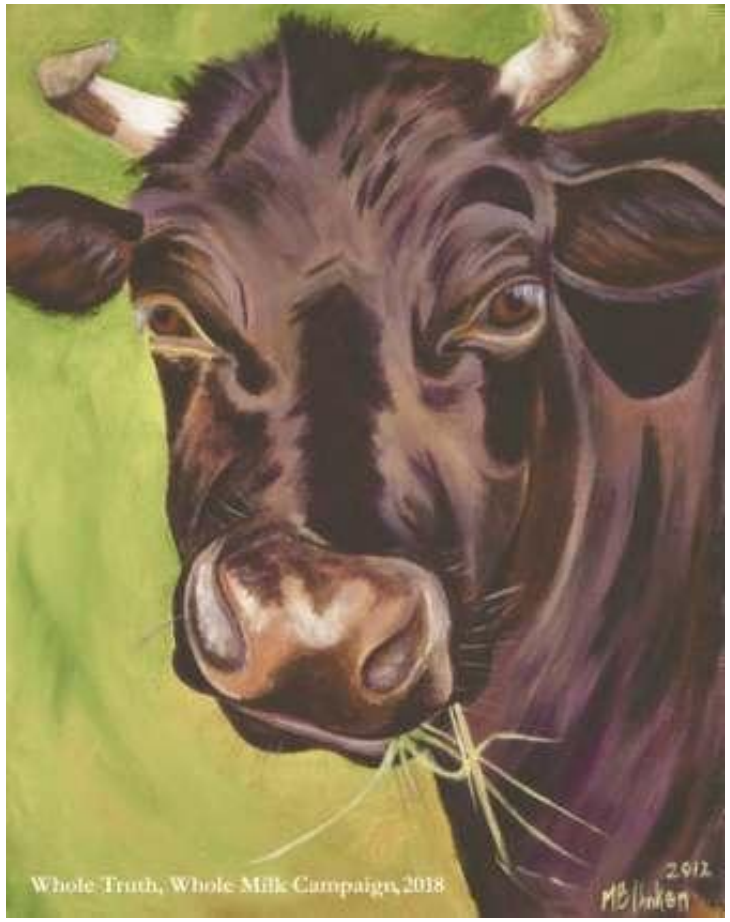


FRAMING EVIDENCE FOR SALMONELLOSIS BURDEN OF ILLNESS:

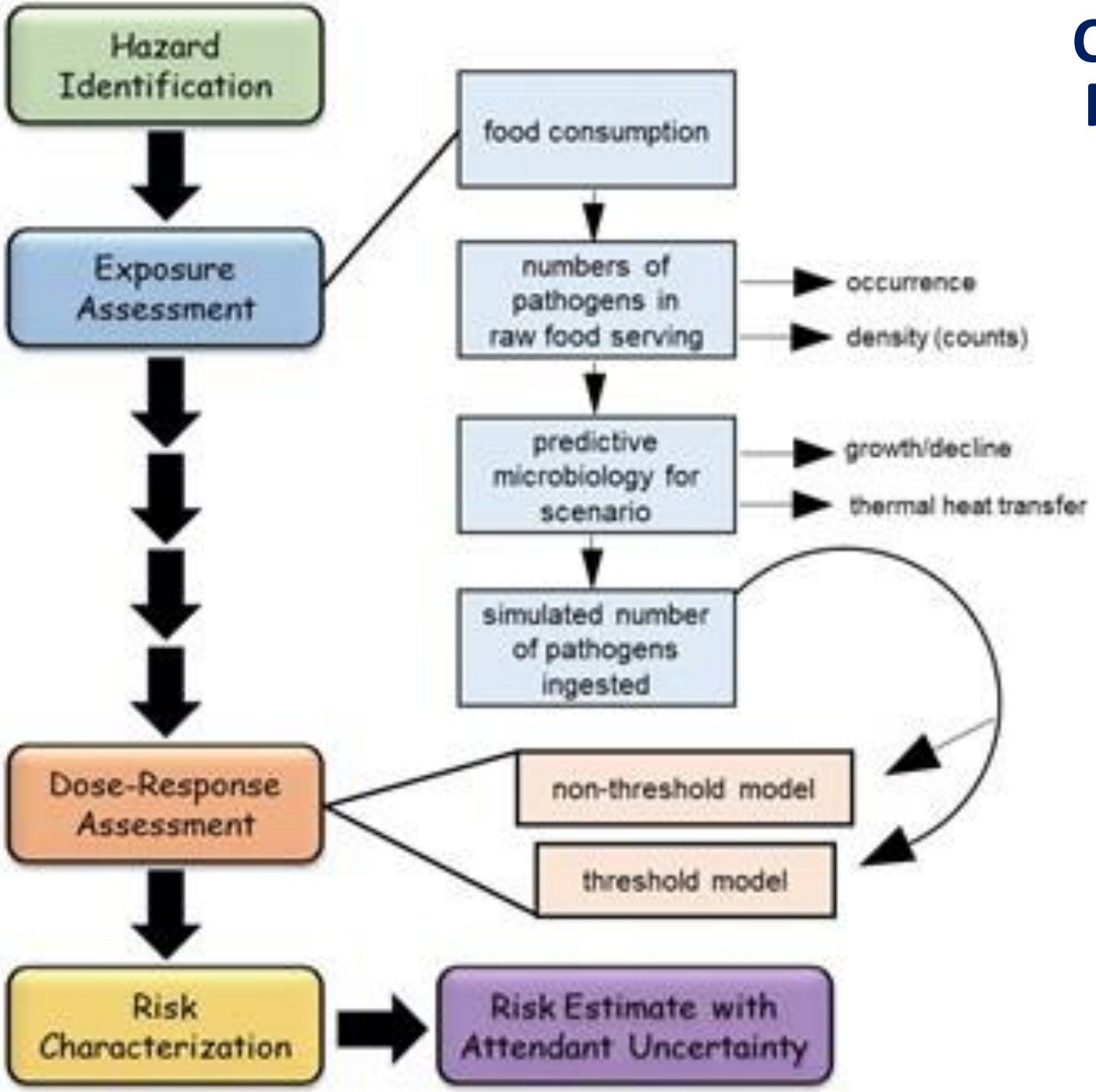
HAZARD IDENTIFICATION, EXPOSURE ASSESSMENT, MICROBIAL RISK ASSESSMENT

Peg Coleman, Medical Microbiologist/Risk Analyst
Fellow, Past Councilor of the Society for Risk Analysis

COLEMAN SCIENTIFIC CONSULTING

19 June 2025

CONSENSUS FRAMEWORK FOR MICROBIAL RISK ASSESSMENT
(Marks et al., 1998; CAC, 1999)



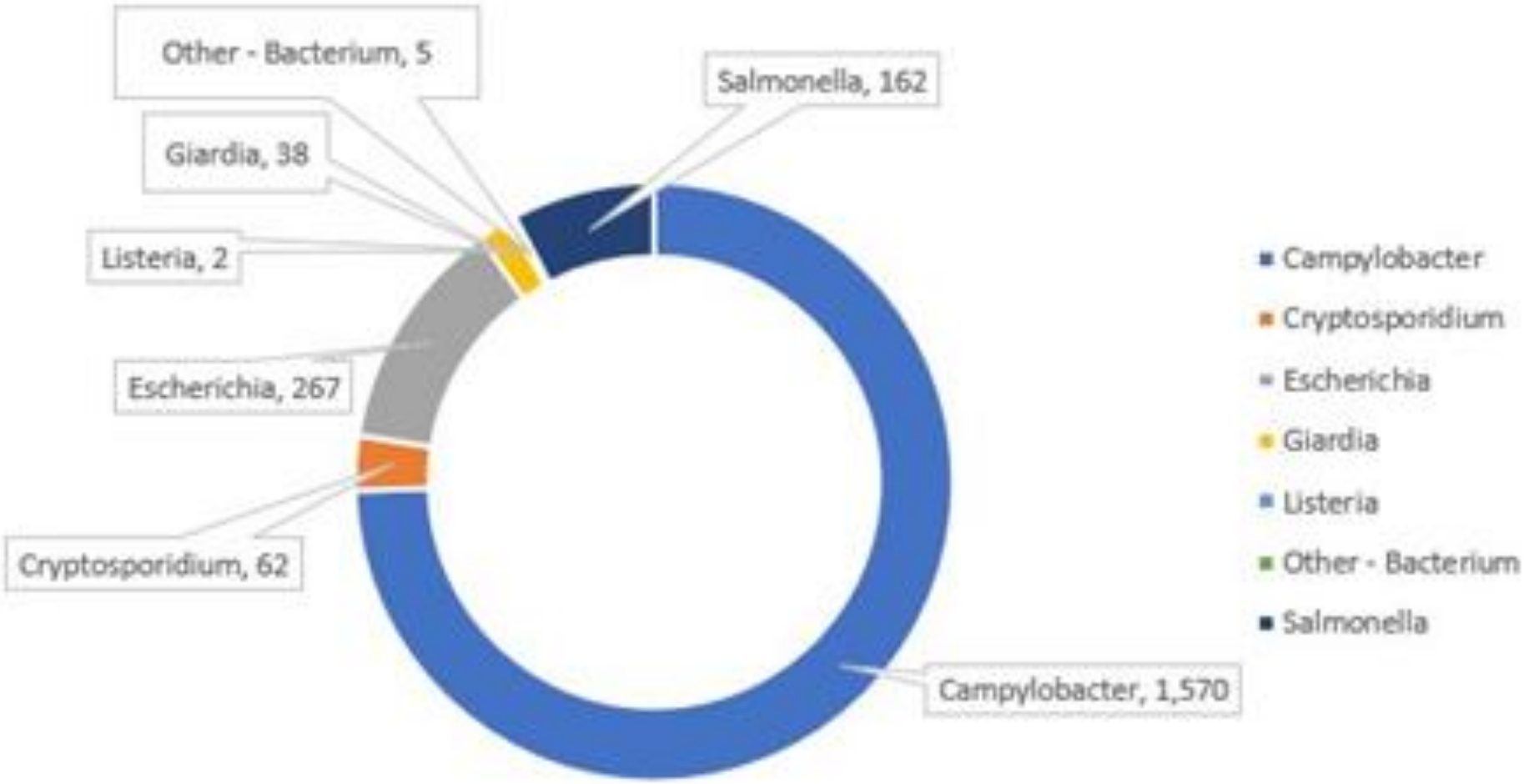
- **Where does epidemiologic evidence fit in this framework?**

  Hazard Identification primarily

- **How is epidemiologic evidence applied?**

  Document burden of illness for food-pathogen pairs

HAZARD IDENTIFICATION FOR RAW MILK
(CDC NORS, 2005-2020; Stephenson et al., 2024)



HAZARD IDENTIFICATION: FOODBORNE DISEASE BURDENS

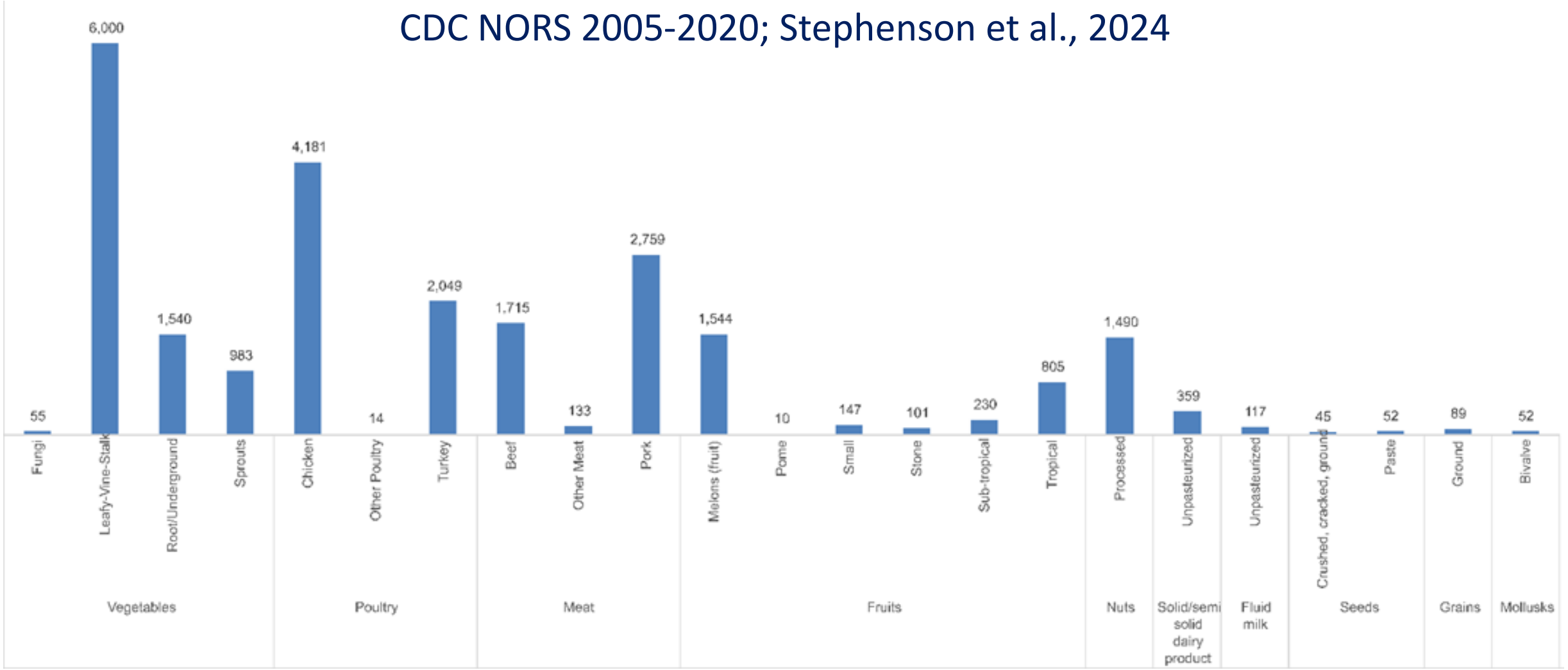
CDC NORS 2005-2020; **Stephenson** et al. (2024)

	Pathogens (numbers ill by pathogen)	Illnesses	Deaths
Leafy Greens	Norovirus, *E. coli* STEC, *Cyclospora*, *Salmonella*	**16,434**	23
Oysters	Norovirus, *Vibrio*, *Campylobacter*, *E. coli* STEC, *Salmonella*, *Giardia*, Hepatitis, Sapovirus, *Staphylococcus*	**2,408**	**2**
Pasteurized Milk	***Campylobacter* (1,873),** *Yersinia* (125), Norovirus (33), *Salmonella* (24), *L. monocytogenes* (5), *E. coli* STEC (3), other hazards (48)	**2,111**	4
Raw Milk	***Campylobacter* (1,570),** *E. coli* STEC (267), *Salmonella* (162), *Cryptosporidium* (35)	**1,696**	1 confirmed

Sebastianski et al. (2022) systematic review on listeriosis:

higher likelihood and **severity** (premature delivery, miscarriage, fetal deaths/stillbirths) for **pasteurized milk**

HAZARD IDENTIFICATION:
SALMONELLOSIS DISEASE BURDENS
CDC NORS 2005-2020; Stephenson et al., 2024



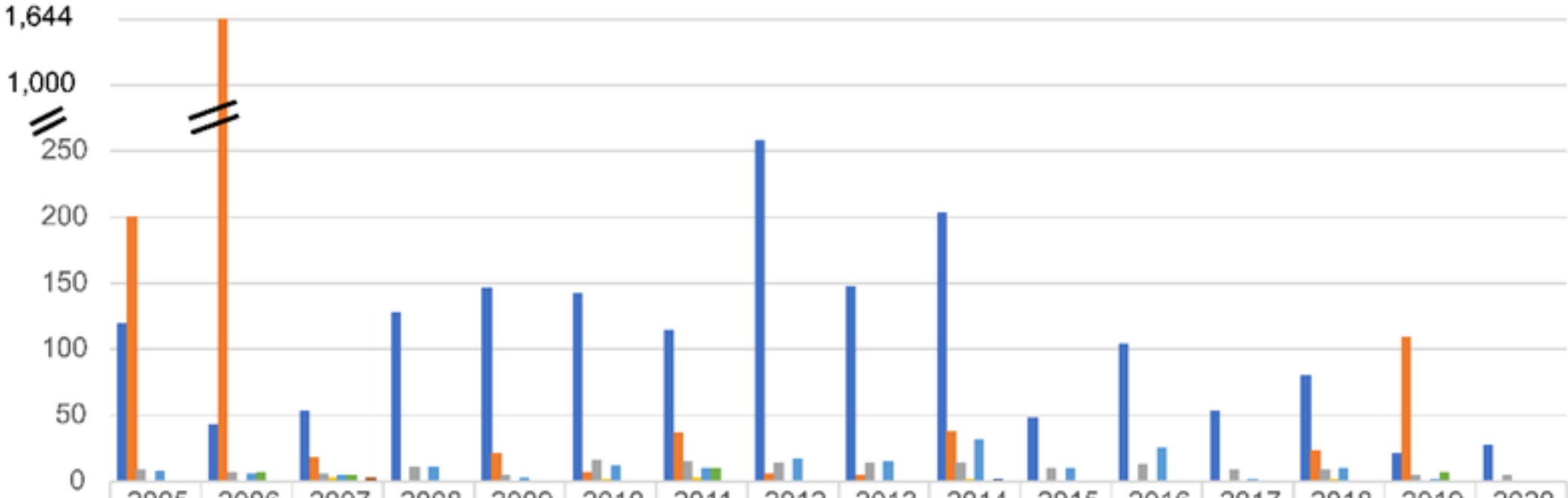
Raw milk contributed to **less than 1%** of **23,066 salmonellosis cases** for predominant foods above from 2005-2020.

Invalid Assumptions about *Salmonella* Genus

1. Presence of any *Salmonella* in raw milk is sufficient to predict risk to humans
   - **The International consensus framework requires not just Hazard Identification but Exposure Assessment, Dose-Response Assessment, and Risk Characterization (Marks et al., 1998; CAC, 1999)**
2. All 2,600+ *Salmonella* serotypes are equivalent in causing human disease
   - **Public health and academic scientists now agree that less than 10 highly infectious serotypes at high ingested doses cause most human salmonellosis disease burden; many less infective, lower virulence serotypes (e.g., Cerro, Kentucky) pose low or negligible risks to humans (CDC NORS, 2005-2020; FoodNet, 2010-2022; Fenske et al., 2023; Katz et al., 2024; Marshall et al., 2024; Venu et al, 2024a,b)**
3. Predominant *Salmonella* serotypes in raw milk (Cerro and Kentucky) cause human disease burden for salmonellosis
   - **These serotypes were not associated with human disease (Sonnier et al., 2018; CDC NORS, 2005-2020)**

NO INCREASING TRENDS IN MILKBORNE ILLNESS

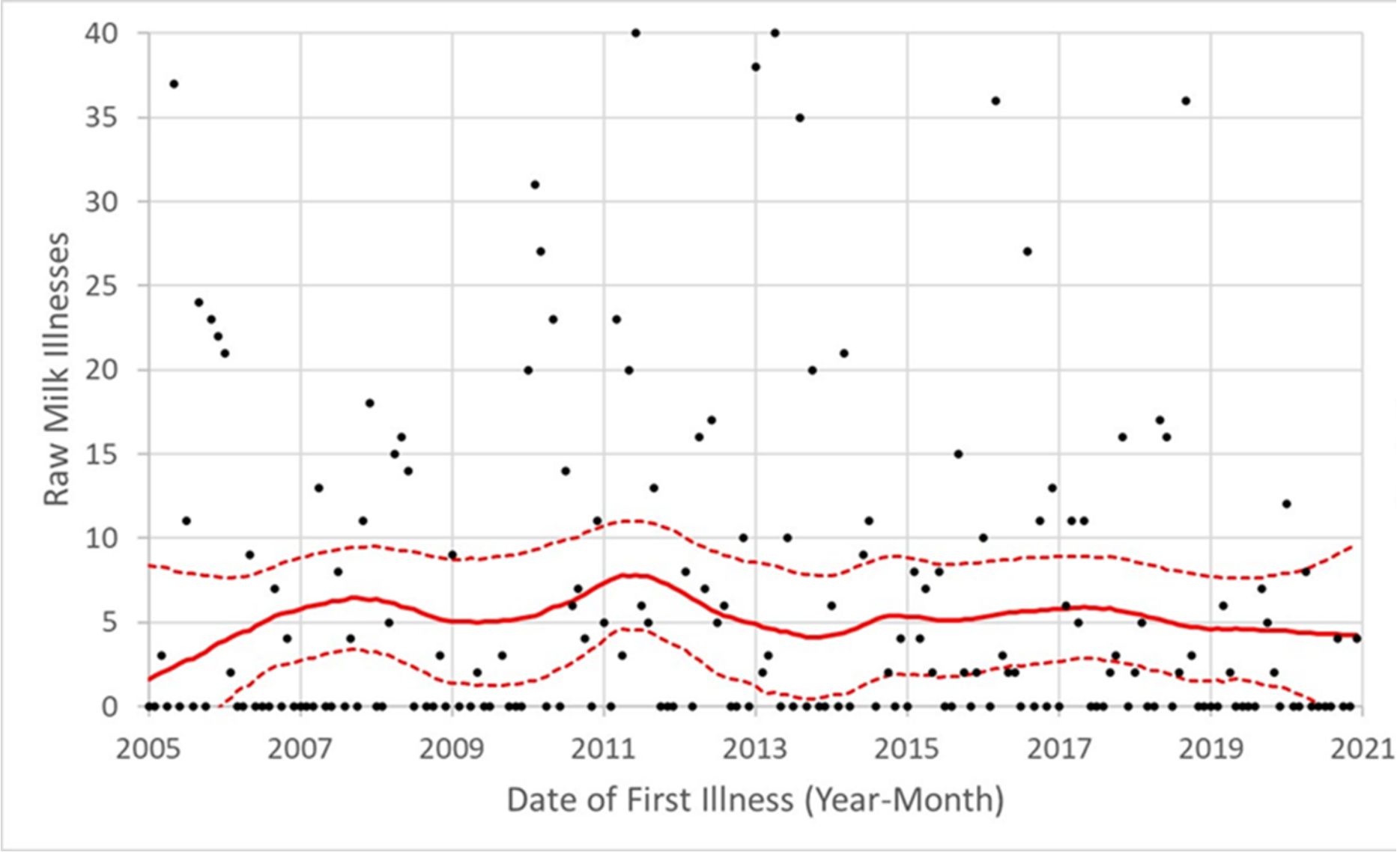
CDC Dataset for 2005-2020; Stephenson et al., 2024



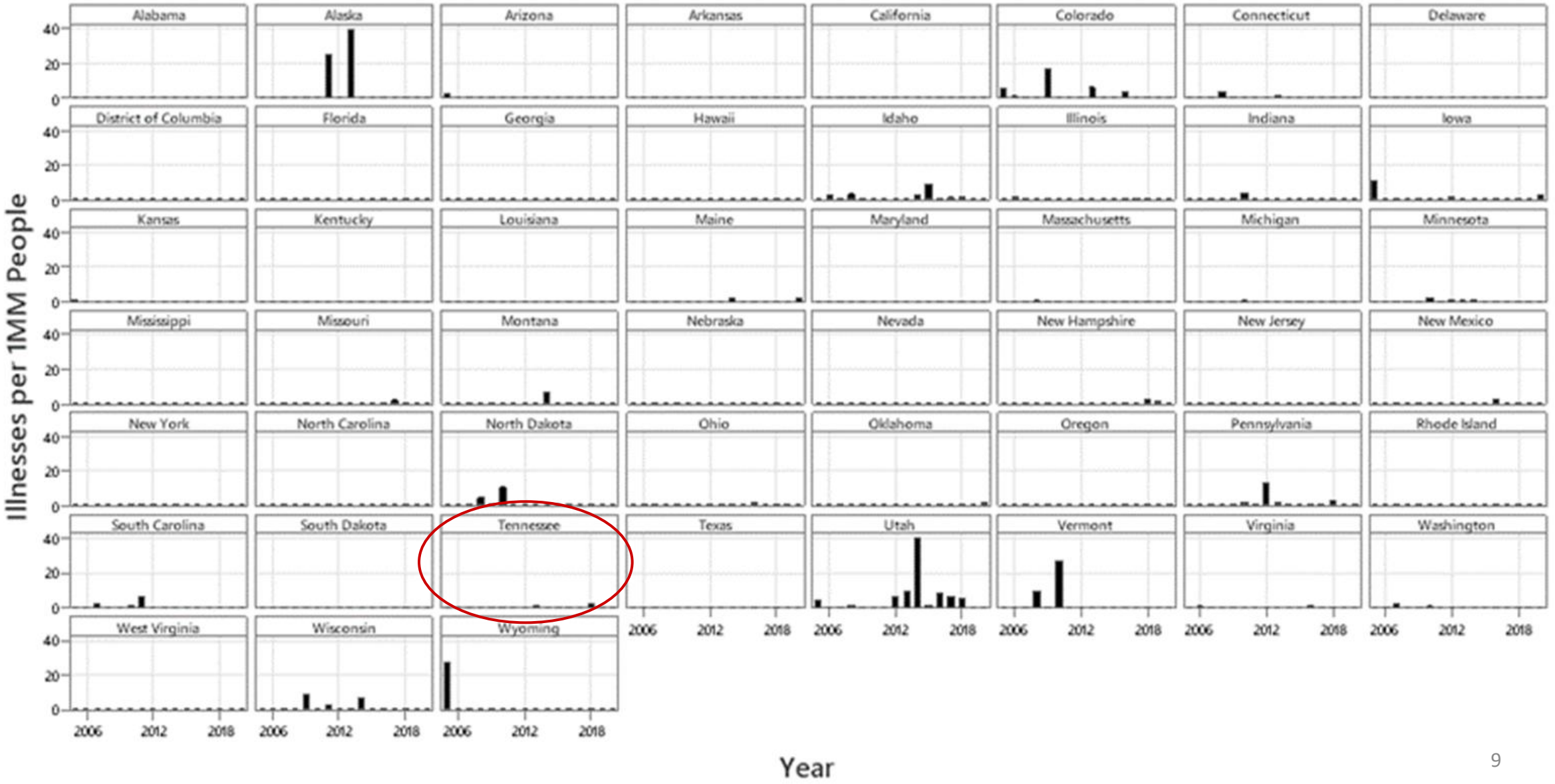
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Illness - unpasteurized	120	43	54	128	147	143	115	258	148	203	48	104	54	81	22	28
Illness - pasteurized	200	1644	19	0	22	7	37	6	5	38	0	0	0	24	109	0

NO INCREASING TRENDS IN RAW MILK ILLNESS

CDC Dataset for 2005-2020; Stephenson et al., 2024



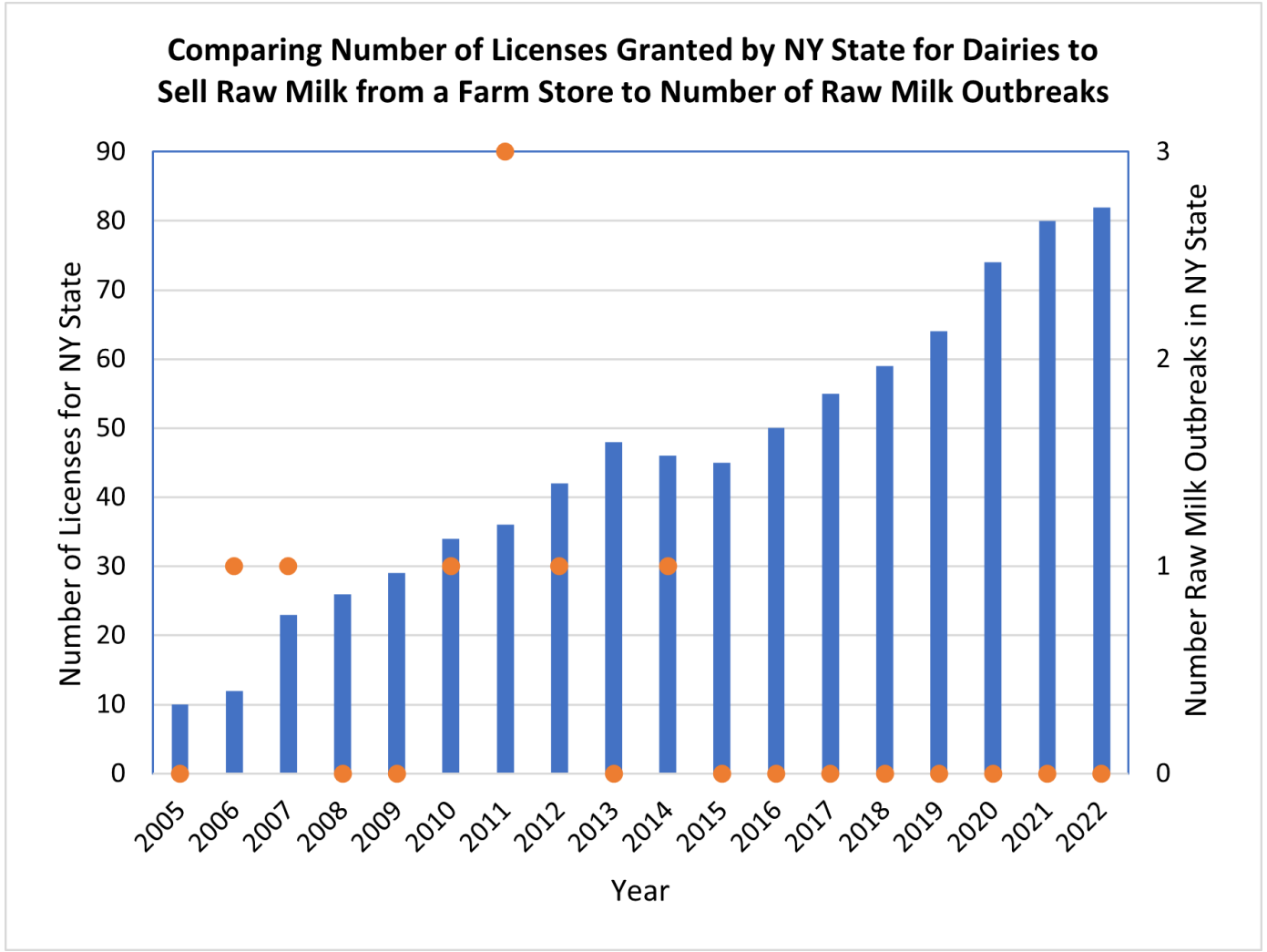
RATES OF RAW MILK ILLNESS BY STATE NOT INCREASING



NY STATE LICENSED RAW MILK DAIRIES AND CDC EPIDEMIOLOGIC DATA FOR NY

- Increasing numbers of licenses for NY farms legally selling raw milk - blue bars, left axis label (2005-2022, data obtained by FOIA)

- US CDC NORS outbreak illness reports associated with raw milk - orange symbol, right axis label
  - Eight **campylobacteriosis** outbreaks in NY state over 16 years (2005-2020)
    - 58 illnesses and 4 hospitalizations
  - One **campylobacteriosis** outbreak (2023)
    - 4 ill, no hospitalizations
  - **Zero deaths**
  - **Pathogens NOT associated with NY state outbreaks** (since at least 1998):
    - *Listeria monocytogenes*
    - Pathogenic *E. coli* (EHEC/STEC/VTEC)
    - *Salmonella* spp.
    - *Staphylococcus aureus*



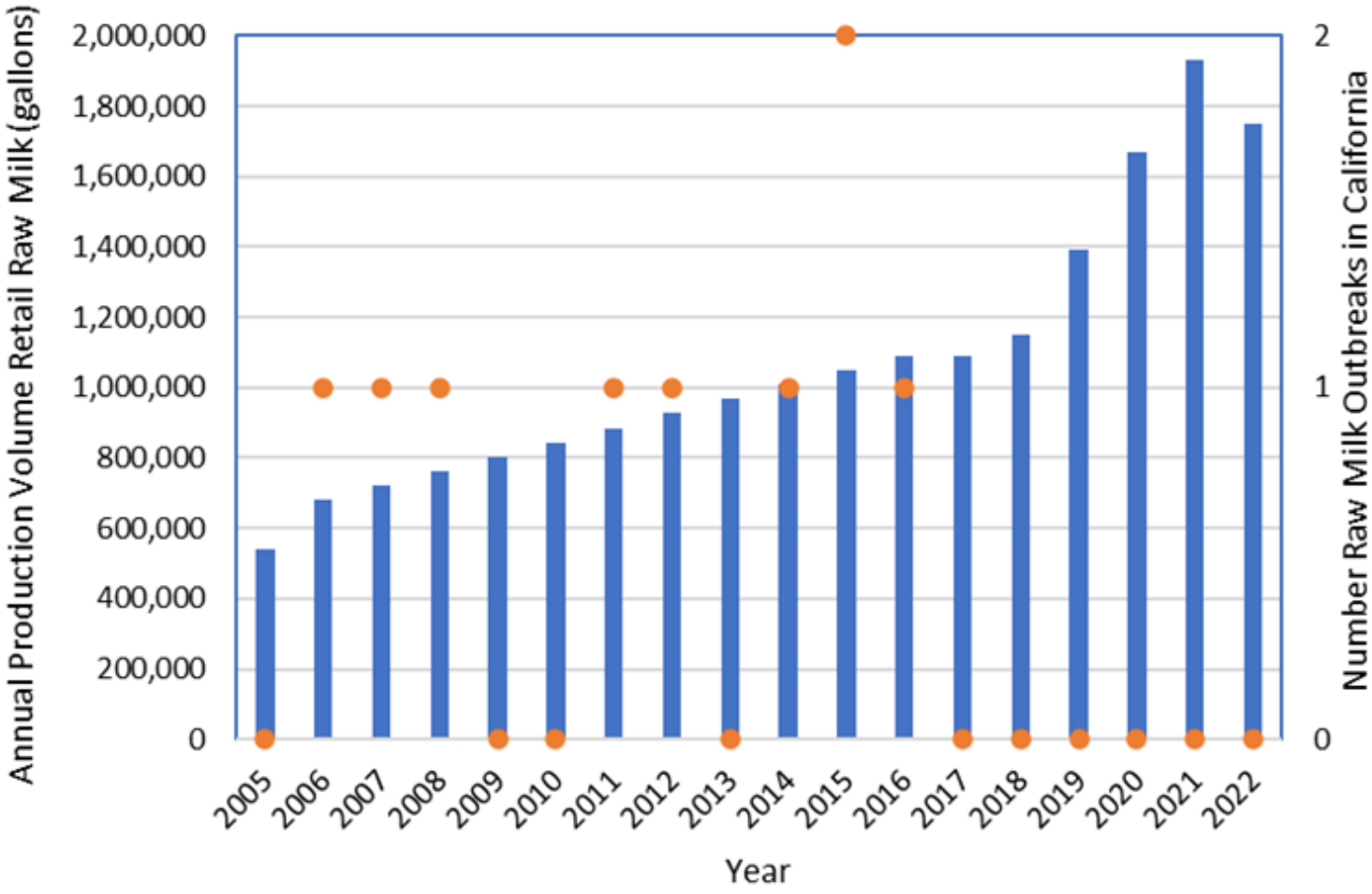
RETAIL RAW MILK PRODUCTION AND CDC EPIDEMIOLOGIC DATA FOR CALIFORNIA

- Retail raw milk sales – blue bars, left axis (2005-2022)

- US CDC NORS outbreaks – orange symbol, right axis (2005-2020)
  - 9 CA outbreaks in 16 years
    - **99 illnesses** (73 campylobacterosis, 21 O157:H7, 5 salmonellosis)
    - **16 hospitalizations** (10 campylobacteriosis, 5 O157:H7, 1 salmonellosis)
    - **Zero deaths**
  - **Pathogen NOT associated with CA outbreaks** (since at least 1998):
    - *Listeria monocytogenes*
  - **No raw milk outbreaks** reported in CA since **2016** despite increasing production

- **Less than one illness** in **~20 million servings** for CA retail raw milk consumers for 2018-2020

- **Less than one influenza illness** in **4.6 million servings** in CA retail market, November 2024



EXPOSURE ASSESSMENT: QUESTIONS, STUDIES

1. Is a pathogen **detected** in serving of food? — Dietert et al., 2022
2. How many **servings consumed**? — insufficient data (4.4%)
3. How **many counts per serving** if detected? — insufficient data
4. Does pathogen **grow** (or survive) in food? — Coleman et al., 2023
   - If yes, **how fast** (or how long)
   - Growth depends on **temperature, time,** AND **competing food microbiota**
5. How **many** pathogens (AND beneficial microbiota) are in **simulated serving (DOSE ingested)** at consumption? — insufficient data

Q1: EXTREMELY LOW PERCENTAGE OF PATHOGEN POSITIVES

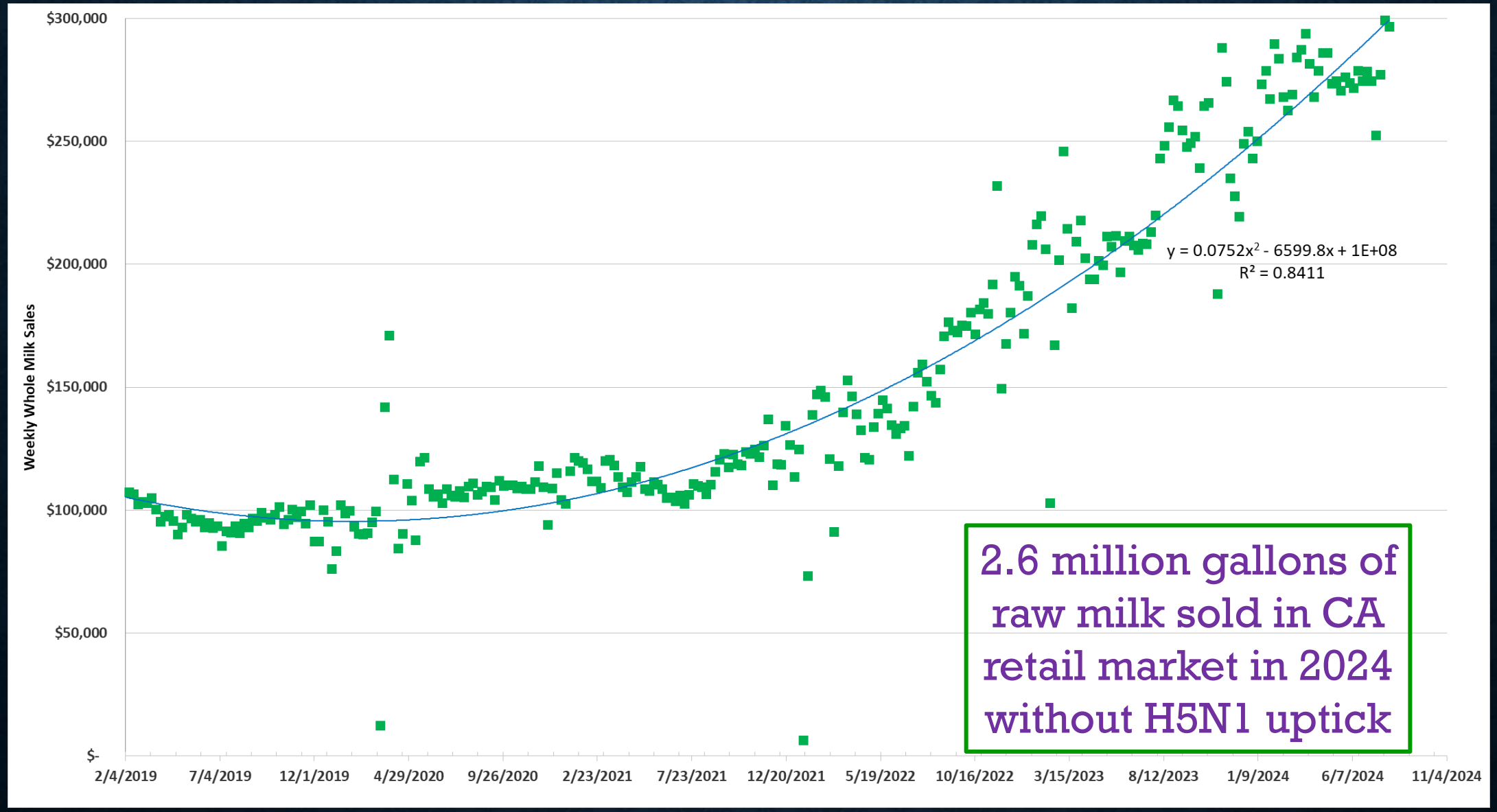
RESULTS RAW MILK PRODUCED FOR DIRECT HUMAN CONSUMPTION COMPILED FROM MONITORING PROGRAMS IN US (2009-2015) AND AROUND THE WORLD (2001-2021)

Raw Milk Monitoring: Canada, Finland, Germany, Poland, UK, US	*Campylobacter*	*E. coli* O157:H7 or EHECs	*L. monocytogenes*	*Salmonella*
OVERALL PERCENTAGE POSITIVE	93/9,740 (0.9%)	26/10,934 (0.2%)	40/9,118 (0.4%)	14/7,976 (0.2%)

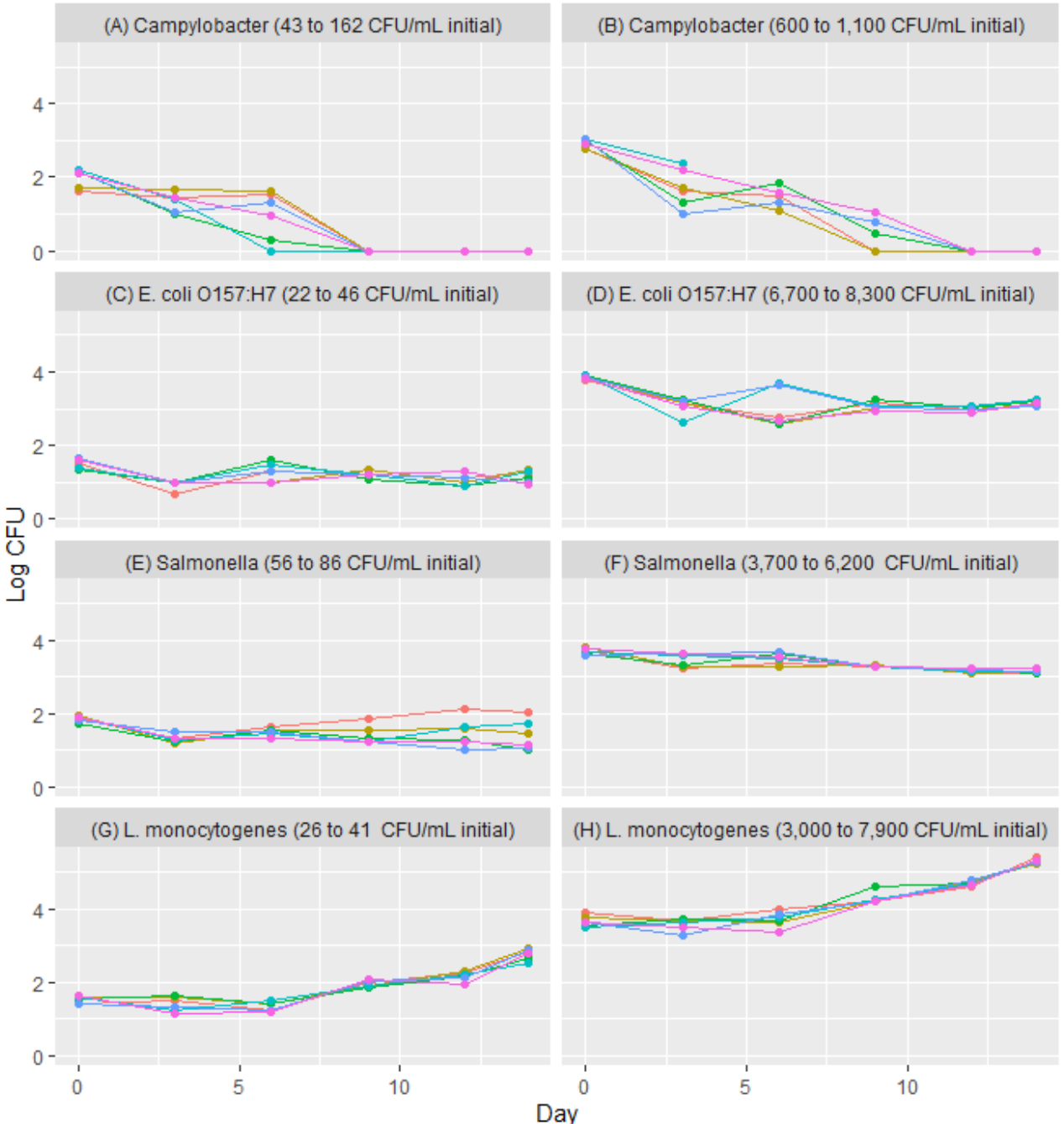
Extracted from detailed table in Dietert et al. (2022); see backup slides

State	*C. jejeuni/coli*	*E. coli* O157:H7/STECs	*L. monocytogenes*	*Salmonella* spp.
CA	0/122	0/122	0/122	0/122
NY	7/1,118 (0.6%)	2/1,118 (0.2%)	4/1,118 (0.4%)	0/1,118
TX	4/601	0/596	4/596	11/606
WA	0/974	0/988	0/991	0/973

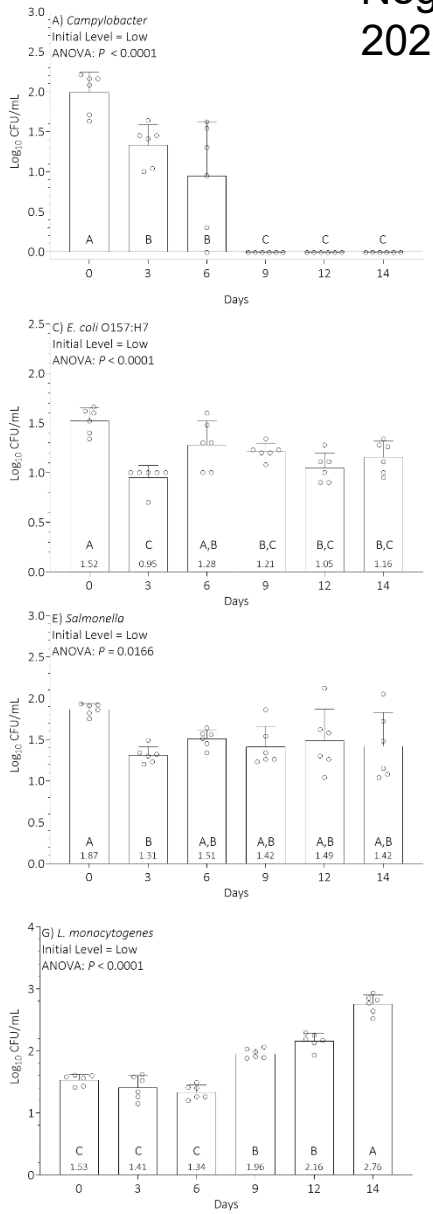
Q2: WEEKLY RETAIL SALES OF FLUID RAW MILK
RAW FARM, CALIFORNIA (2019-2024)



Q4: REFRIGERATED RAW MILK (MICROBIOTA) SUPPRESSES PATHOGEN GROWTH



(Coleman, Oscar, Negley, Stephenson, 2023. PLOS ONE)



Backup Slides

Authors (Date)	Manuscript Title	Manuscript Link
Coleman, Elkins, Gutting, Walls (2018)	Microbiota and Dose-Response: Evolving Paradigm of Health Triangle	**chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.researchgate.net/profile/Margaret-Coleman/publication/325654121_Microbiota_and_Dose-Response_Evolving_Paradigm_of_Health_Triangle/links/67ab6f8b4c479b26c9ddd2c3/Microbiota-and-Dose-Response-Evolving-Paradigm-of-Health-Triangle.pdf**
Coleman, Dietert, North, Stephenson (2021)	Enhancing Human Superorganism Ecosystem Resilience by Holistically 'Managing Our Microbes'	https://doi.org/10.3390/applmicrobiol1030031
Coleman, North, Dietert, Stephenson (2021)	Examining Evidence of Benefits and Risks for Pasteurizing Donor Breastmilk	https://doi.org/10.3390/applmicrobiol1030027
Dietert, Coleman, North, Stephenson (2022)	Nourishing the Human Holobiont to Reduce the Risk of Non-Communicable Diseases: A Cow's Milk Evidence Map Example	https://doi.org/10.3390/applmicrobiol2010003
North, Coleman, Hull (2022)	Need for International Workshops to Deliberate Evidence of Benefits and Risks of Raw Milks	https://www.corpuspublishers.com/assets/articles/cjdvs-v3--22-1031.pdf
Coleman, North (2023)	Revisioning Small Family Dairy Farms that Apply One Health Approaches	https://lupinepublishers.com/dairy-veterinary-science-journal/pdf/CDVS.MS.ID.000216.pdf
Coleman, Oscar, Negley, Stephenson (2023)	Suppression of Pathogens in Properly Refrigerated Raw Milk	https://doi.org/10.1371/journal.pone.0289249
Stephenson, Coleman, Azzolina (2024)	Trends in Burdens of Disease by Transmission Source (USA, 2005–2020) and Hazard Identification for Foods: Focus on Milkborne Disease	https://doi.org/10.1007/s44197-024-00216-6
Waller, Coleman, Denard, Soane (2024)	Lessons identified from applications of the Risk Analysis QualityTest Release 1.0	https://onlinelibrary.wiley.com/doi/epdf/10.1111/risa.14292
Coleman (2025)	Deliberating the Scientific Evidence Base for Influenza Transmission to Raw Milk Consumers	Accepted for publication in *Risk Analysis* , 24 June 2025

Complex Relationships with Microbes:

Presence Alone Insufficient to Predict Risk or Health

- **Probiotics:** Live microorganisms which, **when administered in adequate amounts**, confer a **health benefit** on the host (FAO/WHO, 2002)

- **Pathogens:** Live microorganisms which, **when administered in adequate amounts**, **cause disease** in the host

- **Commensals:** Live microorganisms which benefit by relationship with host but **do not harm or provide known benefits to host**
  - Commensal ***Staphylococcus aureus*** can become an **opportunistic pathogen** causing **skin/respiratory/wound infections, foodborne illness,** and **mastitis at high doses** e.g., above limit or threshold for toxin production (**100,000 bacteria per mL food**) controlled genetically (quorum sensing)

Dose Matters for both Health and Disease

18

ADVANCING KNOWLEDGE OF MAMMALIAN MILK MICROBIOTA

Shared Microbes in Breastmilk and Ruminant Milks, NOT Fecal Contamination

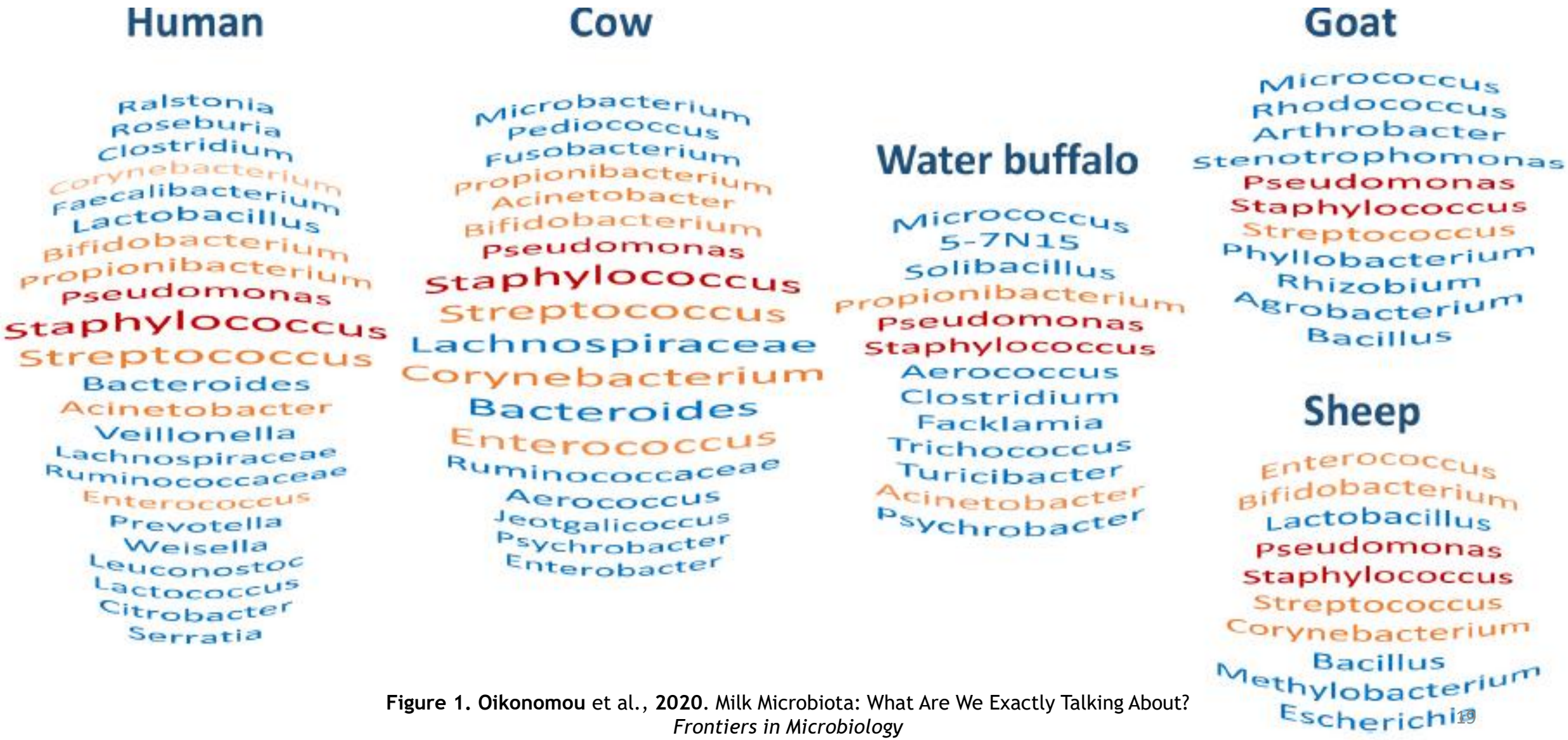


Figure 1. Oikonomou et al., **2020.** Milk Microbiota: What Are We Exactly Talking About?
Frontiers in Microbiology

NY State data for confirmed raw milk outbreaks from CDC, 1998-2023

Year	Month	Etiology	Illnesses	Hospitalizations	Deaths	Food Vehicle
2023	9	Campylobacter jejuni	4	0	0	Raw Milk
2014	7	Campylobacter jejuni	8	0	0	Raw Milk
2012	1	Campylobacter jejuni	6	2	0	Raw Milk
2011	6	Campylobacter jejuni	4	0	0	Raw Milk
2011	7	Campylobacter jejuni	3	0	0	Raw Milk
2011	9	Campylobacter jejuni	13	0	0	Raw Milk
2010	1	Campylobacter jejuni	20	1	0	Raw Milk
2007	4	Campylobacter unknown	2	1	0	Raw Milk
2006	2	Campylobacter unknown	2	0	0	Raw Milk
2000	9	Campylobacter jejuni	39	0	0	Raw Milk
1998	7	Campylobacter unknown	3	0	0	Raw Milk
Total Raw Milk Illnesses for Period			**104**	**4**	**0**	

NY State data from CDC 1971-2023

Illnesses	Hospitalizations	Deaths	Sources
2	0	0	ANIMAL CONTACT
20,278	694	17	FOOD
69,345	28	0	PERSON TO PERSON
16,943	432	49	WATER
106,568	1,154	66	ALL SOURCES NY STATE 1971-2023
			suspected and confirmed
104	4	0	RAW MILK
0.513%	0.576%	-	compared ALL FOODS
0.098%	0.347%	-	compared ALL SOURCES

Global Data on Raw Milk Monitoring Programs (Dietert et al, 2022)

Table 1. Detection of Potential Pathogens in Raw Milk from Recent Studies and Monitoring Programs.

Country (Reference)	Dates (State if US)	*Campylobacter*	*E. coli* O157:H7 or EHECs	*L. monocytogenes*	*Salmonella*
Canada (BCHA, 2021; website listed above)	2015–2021	0/192	0/192	0/192	0/192
Poland (Andrzejewska et al., 2019 [87])	2014–2018	0/113 vending machines; 26/221 (12%) *C. jejuni*, directly from farmers	Not Tested	Not Tested	Not Tested
UK (McLauchlin et al., 2020 [88])	2017–2019	18/635 (2.8%)	0/58 O157; 3/304 EHEC (0%, 1%)	1/642 (0.2%)	3/622 (0.5%)
UK (Willis et al., 2018 [89])	2014–2016 (routine monitoring)	2/770 (<0.01%)	2/770 (<0.01%)	2/770 >100 cfu/mL (<0.01%)	0/770
US State Monitoring (database of FOIA source data from licensed farms; Stephenson and Coleman, 2021 [90])	2009–2014 (CA)	0/61	0/61	0/61	0/61
	2009–2014 (NY)	6/783 (0.7%)	0/782	1/781 (0.1%)	0/780
	2009–2014 (TX)	4/601 (0.7%)	0/596	4/596 (0.7%)	11/606 (1.8%)
	2012–2015 (WA)	0/497	0/502 2/501 (0.4%)	0/502	0/494
Germany (Berge & Baars, 2020 [84])	2001–2015 (VZM)	7/2352 (0.3%)	17/2737 (0.7%)	30/2999 (1%)	0/3367
Germany (Berge & Baars, 2020 [84])	2001–2015 (not for direct consumption raw, pre-pasteurized)	17/2258 (0.8%)	82/5433 (1.5%)	52/2355 (2.2%)	0/1084
Finland (Castro et al., 2017 [91])	2013–2015	Not Tested	Not Tested	5/105 retail bottles (4.8%) 2/115 bulk tanks (1.7%)	Not Tested
Finland (Jaakkonen et al., 2019 [92])	2014–2015	0/789	0/789 O157:H7; 2/789 O121:H19 (<1%)	Not Tested	Not Tested
US (Del Collo et al., 2017, [93])	2014 (17 states)	13/234 culture; 27/234 PCR (6%; 12%)	Not Tested	Not Tested	Not Tested
OVERALL PERCENTAGE POSITIVE		93/9740 (0.01%)	26/10,934 (<0.01%)	40/9118 (<0.01%)	14/7976 (<0.01%)

FDA/FSIS LISTERIOSIS PREDICTIONS FOR MILK

Perception: FDA Division Plant & Dairy Food Safety
Raw milk is **poison**, consuming is **playing Russian roulette** with your health

Estimates: FDA Risk Assessment Division (2003), with USDA/FSIS

- US consumers **exposed regularly** to **low to moderate levels** of *Listeria monocytogenes* in foods (23 categories investigated)
- Exposure and Dose-Response models **overpredict** risk

Pasteurized Milk

- 90.8 deaths per year (**high** risk)
- 10^{-9} per serving or 1 fatal case in 1,000,000,000 exposures at selected doses (**moderate** risk)

Unpasteurized Milk

- 3.1 deaths per year (**moderate** risk)
- $7x10^{-9}$ per serving or 7 fatal cases in 1,000,000,000 exposures at selected doses (**high** risk)

Fatal cases predicted, but not observed in decades!

Summary Table 1, Predicted Median Listeriosis Cases per Serving and per Annum (FDA/FSIS, 2003)

- Agencies announced intent to conduct a listeriosis risk assessment in 1999
- Tremendous level of effort compiling, generating, and incorporating data for 23 foods/food groups (outbreak-associated)
- Multiple public meetings, expert consultations, and 6-month public comment period for 2001 drafts: assessment, risk management action plan (backup slide)
- Documentation of evidence and parameters used to estimate risks
- Simulated servings containing **>10,000 Lm** drove relative risk estimates

Relative Risk Ranking	Predicted Median Cases of Listeriosis for 23 Food Categories					
	Per Serving Basis[a]			Per Annum Basis[b]		
		Food	Cases		Food	Cases
1	High Risk	Deli Meats	7.7×10^{-8}	Very High	Deli Meats	1598.7
2	High Risk	Frankfurters, not reheated	6.5×10^{-8}	High Risk	Pasteurized Fluid Milk	90.8
3	High Risk	Pâté and Meat Spreads	3.2×10^{-8}	High Risk	High Fat and Other Dairy Products	56.4
4	High Risk	Unpasteurized Fluid Milk	7.1×10^{-9}	High Risk	Frankfurters, not reheated	30.5
5	High Risk	Smoked Seafood	6.2×10^{-9}	Moderate Risk	Soft Unripened Cheese	7.7
6	High Risk	Cooked Ready-to-Eat Crustaceans	5.1×10^{-9}	Moderate Risk	Pâté and Meat Spreads	3.8
7	Moderate Risk	High Fat and Other Dairy Products	2.7×10^{-9}	Moderate Risk	Unpasteurized Fluid Milk	3.1
8	Moderate Risk	Soft Unripened Cheese	1.8×10^{-9}	Moderate Risk	Cooked Ready-to-Eat Crustaceans	2.8
9	Moderate Risk	Pasteurized Fluid Milk	1.0×10^{-9}	Moderate Risk	Smoked Seafood	1.3
10	Low Risk	Fresh Soft Cheese	1.7×10^{-10}	Low Risk	Fruits	0.9
11	Low Risk	Frankfurters, reheated	6.3×10^{-11}	Low Risk	Frankfurters, reheated	0.4
12	Low Risk	Preserved Fish	2.3×10^{-11}	Low Risk	Vegetables	0.2
13	Low Risk	Raw Seafood	2.0×10^{-11}	Low Risk	Dry/Semi-dry Fermented Sausages	<0.1
14	Low Risk	Fruits	1.9×10^{-11}	Low Risk	Fresh Soft Cheese	<0.1
15	Low Risk	Dry/Semi-dry Fermented Sausages	1.7×10^{-11}	Low Risk	Semi-soft Cheese	<0.1
16	Low Risk	Semi-soft Cheese	6.5×10^{-12}	Low Risk	Soft Ripened Cheese	<0.1
17	Low Risk	Soft Ripened Cheese	5.1×10^{-12}	Low Risk	Deli-type Salads	<0.1
18	Low Risk	Vegetables	2.8×10^{-12}	Low Risk	Raw Seafood	<0.1
19	Low Risk	Deli-type Salads	5.6×10^{-13}	Low Risk	Preserved Fish	<0.1
20	Low Risk	Ice Cream and Other Frozen Dairy Products	4.9×10^{-14}	Low Risk	Ice Cream and Other Frozen Dairy Products	<0.1
21	Low Risk	Processed Cheese	4.2×10^{-14}	Low Risk	Processed Cheese	<0.1
22	Low Risk	Cultured Milk Products	3.2×10^{-14}	Low Risk	Cultured Milk Products	<0.1
23	Low Risk	Hard Cheese	4.5×10^{-15}	Low Risk	Hard Cheese	<0.1

EVIDENCE FOR THRESHOLDS FOR HUMAN ILLNESS

Healthy people have **innate resistance to** many pathogens **particularly at low doses**.

Salmonellosis cases observed at doses greater than 10^9 or **1,000,000,000** ingested bacteria for *Salmonella* Pullorum

Coleman & Marks, 2000; Coleman et al., 2017

Tularemia cases observed at ingested doses greater than 10^6 or **1 million** ingested bacteria Thran, 2015

Listeriosis cases not simulated at doses less than $3x10^5$ or **300,000** ingested bacteria for *Listeria monocytogenes*, thresholds likely

FDA, 2008; Buchanan, 2017; Collineau, 2019

Staphylococcus aureus carried by ~30% of US population but can be opportunistic pathogen; incapable of forming toxin until densities greater than 10^5 or **100,000** bacteria; typically causing person-to-person skin infections, no milkborne illnesses 2005-2020

FDA Bad Bug Book, 2012; Esfahanian et al., 2019; Chandrasekaran & Jiang, 2021; Stephenson et al., 2024