Incorporating Superorganisms in One Health Approaches

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and

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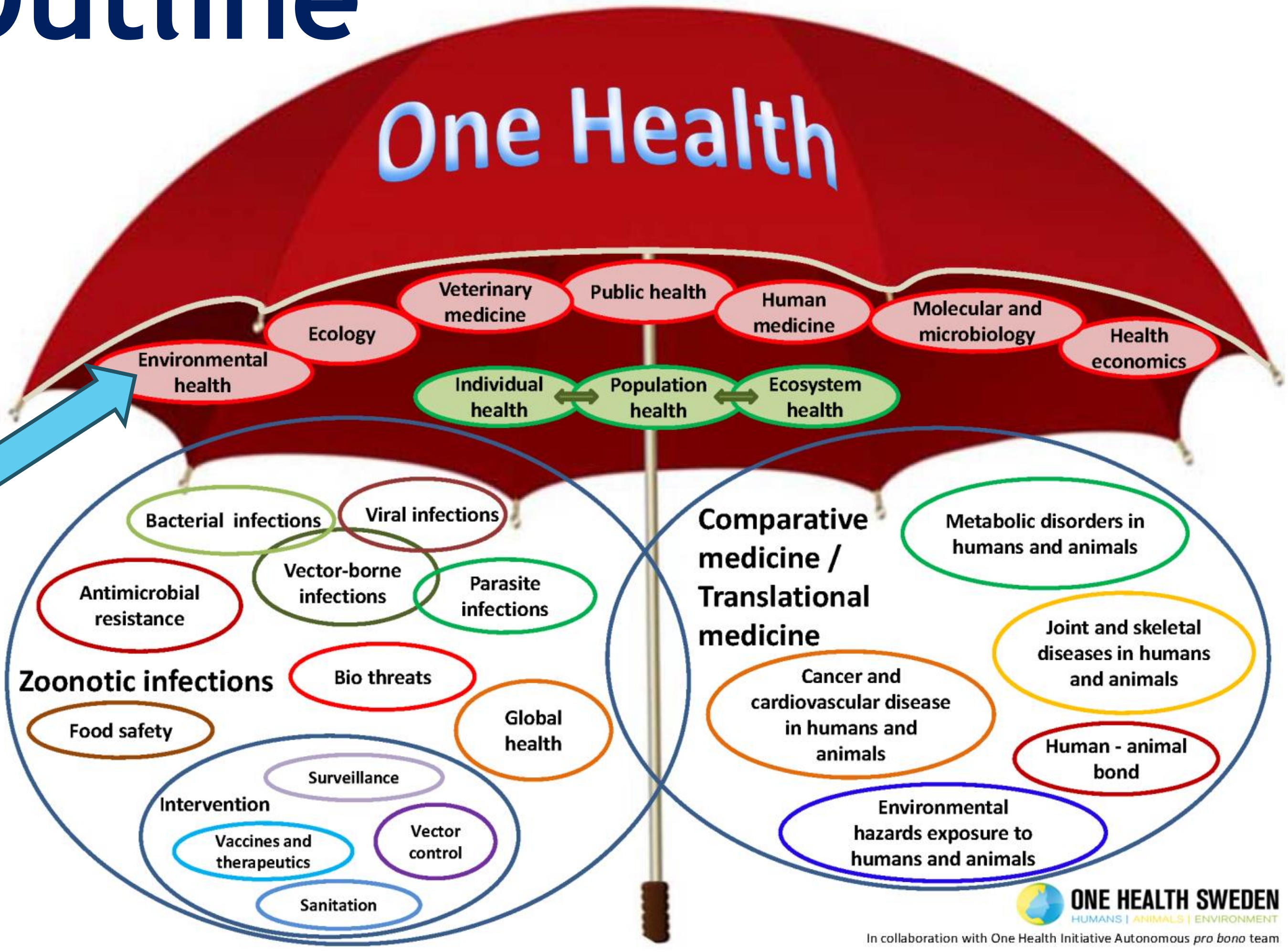
Outline

- One Health AND:
  - Epidemiologic Trends/Hazard ID
  - Microbiology/Microbiota and Ecosystem Management

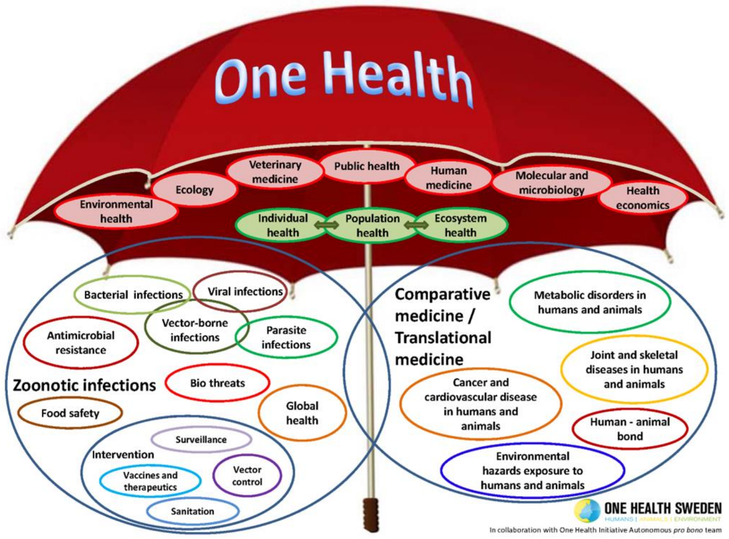


- Call to Re-Vision Agriculture

Assess and balance benefits and risks, risk-risk tradeoffs, for human and ecosystem health by aligning One Health and Risk Analysis

Connecting One Health and Risk Analysis

- Global recognition of need for multi-sector, trans-disciplinary collaborations, **building unifying** and **transparent processes** with policy makers, scientists, stakeholders, communities
  - “No one person, organization, or sector can address issues at the animal-human-environment interface [associated with One Health approaches] alone.” (US CDC)
- **Social, political, cultural construction** of **outbreaks** can **oversimplify** problems, **falling short** of identifying **root causes** and **preventing future outbreaks**
  - Essential to address **ecosystem complexities and interdependencies** for **farm-to-fork risks** can be effectively managed to prevent or minimize harm
- Target research supporting healthy **superorganisms** (animals and plants with microbial partners) and **multi-hurdle risk management and food safety**
- Connect One Health and Risk Analysis to **build resilience and sustainability** in local and global agricultural systems that balance benefits and risks for human and ecosystem health



Epidemiologic Trends/Hazard ID

US Centers for Disease Control and Prevention (CDC) Access® Database for 2005-2020
(Data from CDC, 2021; Figures from Stephenson et al., in preparation)

Acknowledge colleagues Michele Stephenson for work with the database and both she and statistician Nick Azzolina for work on the figures from the manuscript ready to submit

Hazard Identification (1 of 2)

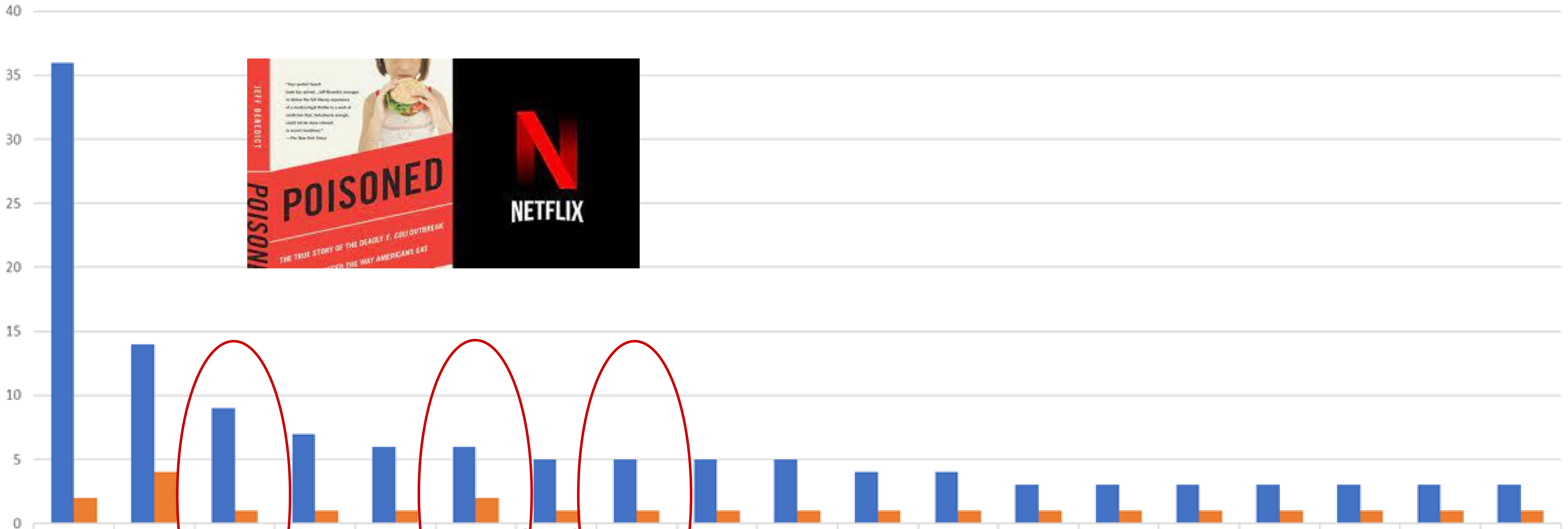
Bacterial Pathogen	Food	Number of Illnesses Reported (2005-2020)
Campylobacter spp.	**Pasteurized fluid milk**	**1,873**
	Raw fluid milk	**1,570**
	Poultry	603
	Mollusks	408
	Homemade raw cheese	126
	Cheese (unspecified or pasteurized)	18
Listeria monocytogenes	**Melons**	**153**
	Cheese (unspecified or pasteurized)	**143**
	Pome, stone, and sub-tropical fruits	**54**
	Deli meats	**49**
	Leafy-vine-stalk vegetables	**48**
	Fungi	41
	Raw cheese	37
	Ice cream from pasteurized milk	10
	Pasteurized milk	5
	Raw milk	2

Hazard Identification (2 of 2)

Bacterial Pathogen	Food	Number of Illnesses Reported (2005-2020)
Salmonella (non-typhoidal)	**Poultry**	**6,244**
	Leafy-vine-stalk vegetables	**6,000**
	Pork	**2,759**
	Beef	**1,715**
	Melons	**1,544**
	Root/underground vegetables	**1,540**
	Processed nuts	**1,490**
	Sprouts	983
	Raw cheese	301
	Cheese (unspecified or pasteurized)	181
	Raw milk	162
	Pasteurized milk	24
STEC	**Leafy-vine-stalk vegetables**	**2,221**
	Beef	**1,485**
	Raw milk	267
	Cheese (unspecified or pasteurized)	135
	Raw cheese	15
	Pasteurized milk	3

Foods Causing More than 2 Deaths (2005-2020)

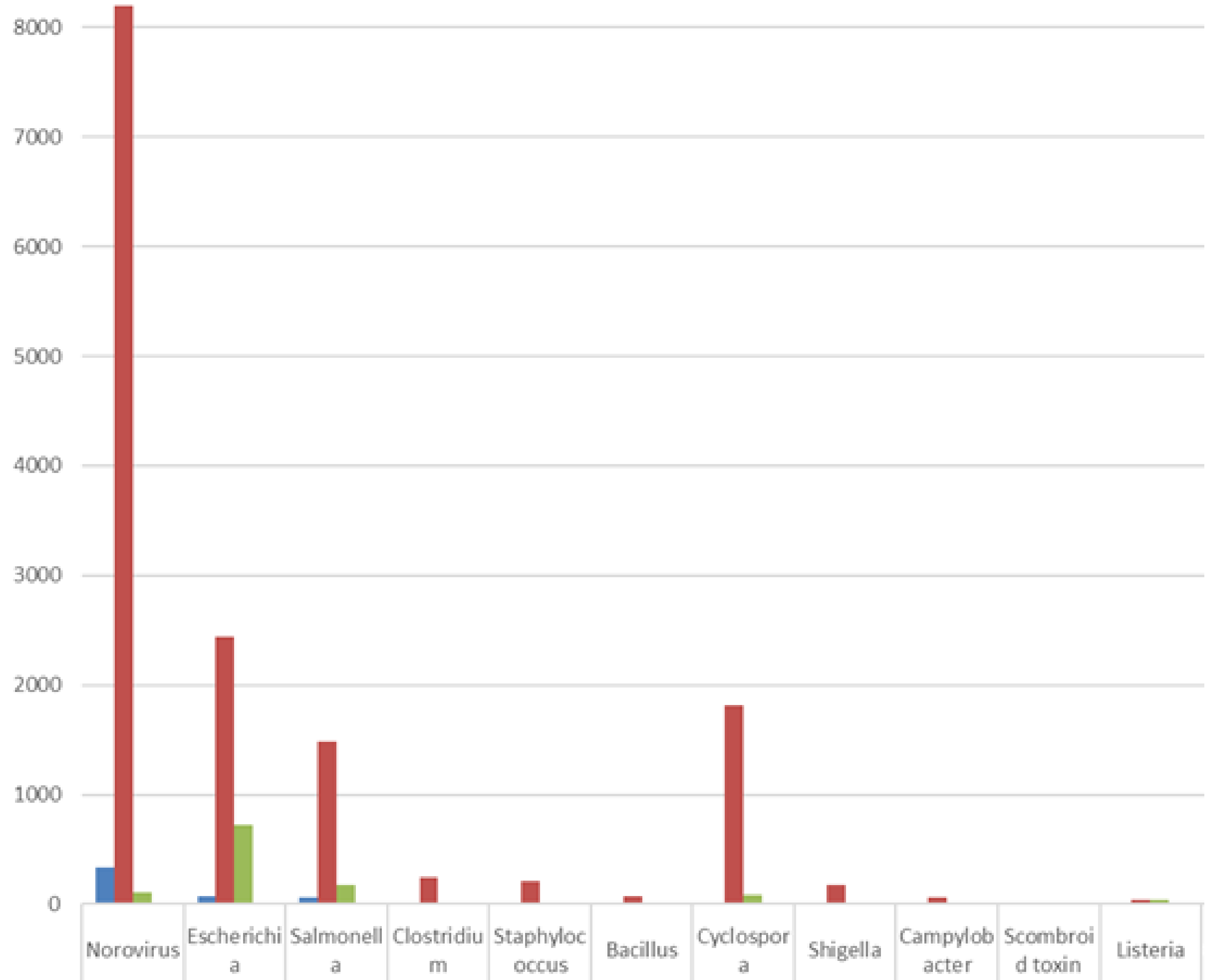
Fruits, Peanut Butter, Leafy Greens, Pasteurized Milk, Pasteurized Ice Cream



	cantaloupe	unknown	peanut butter	caramel apple	cucumber	prepackaged leafy greens	ricotta salata cheese, pasteurized	romaine lettuce	celery, unspecified	spinach	soup, mushroom	Enoki mushroom	chicken pot pie	skim milk, pasteurized	frozen vegetables	hummus	ice cream, commercial	tuna salad	turkey
Deaths	36	14	9	7	6	6	5	5	5	5	4	4	3	3	3	3	3	3	3
Outbreaks	2	4	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1

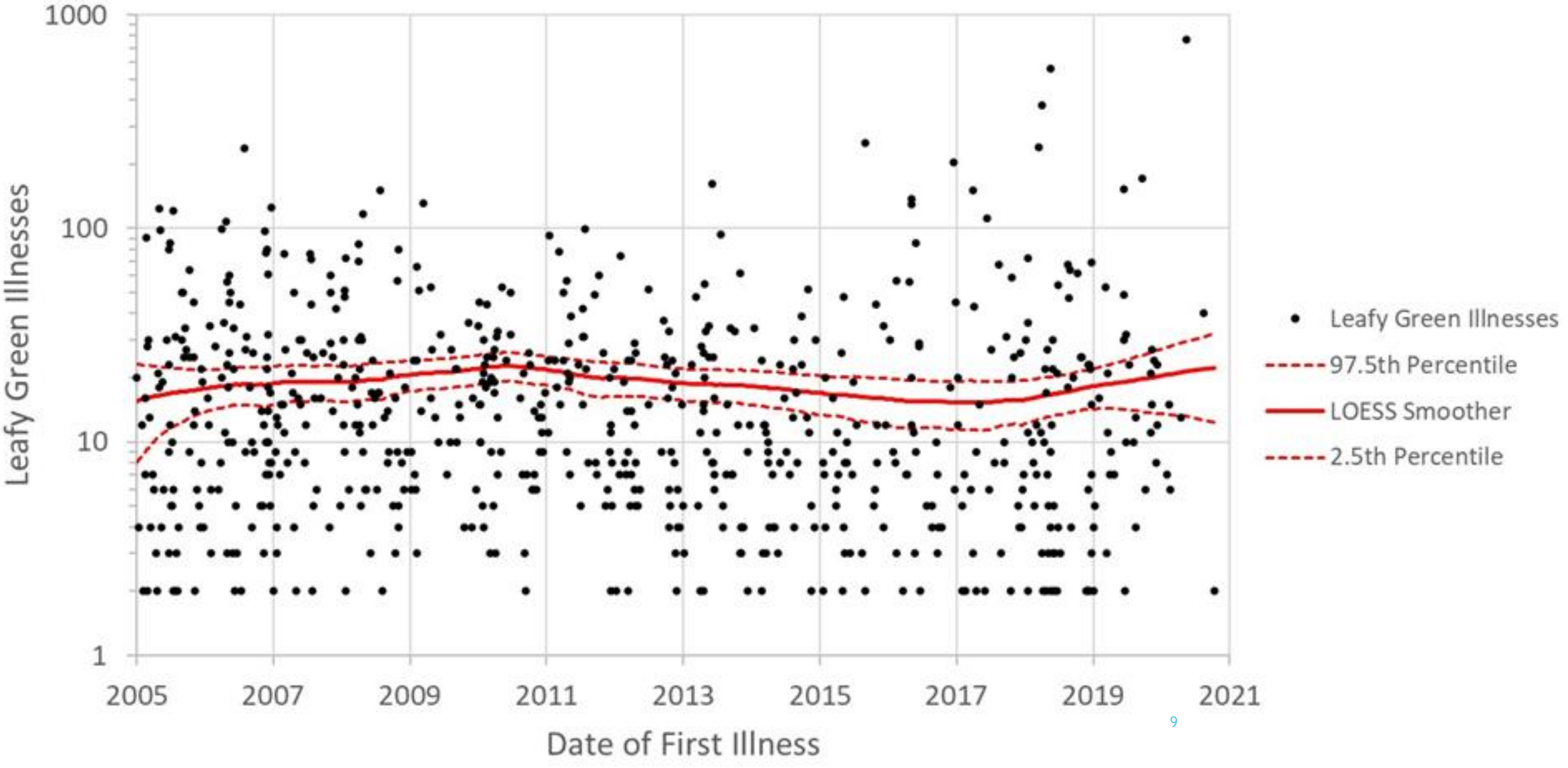
Predominant Hazards Associated with Leafy Green Illnesses

- **Leafy greens** contributed to **16,434 illnesses,**
  671 outbreaks,
  1,250 hospitalizations, and
  23 deaths in US over 16 years
  - Norovirus: 8,199
  - Pathogenic *E. coli*: 2,442
  - *Cyclospora*: 1,819
  - *Salmonella*: 1,489
  - *L. monocytogenes* 40
- **Overall trends on next chart NOT decreasing!**

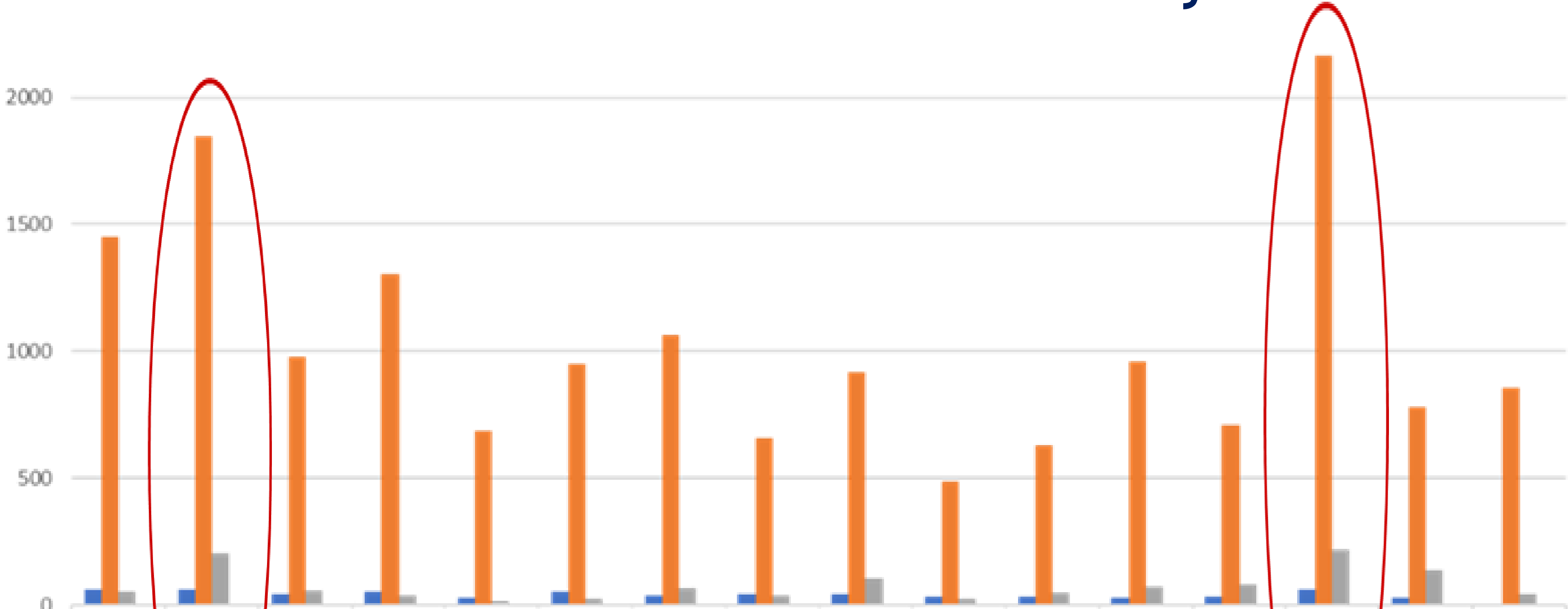


	Norovirus	Escherichia	Salmonella	Clostridium	Staphylococcus	Bacillus	Cyclospora	Shigella	Campylobacter	Scombroid toxin	Listeria
Outbreaks	340	76	66	16	15	13	9	8	7	5	4
Illnesses	8,199	2,442	1,489	250	207	72	8 1,819	181	59	16	40
Hospitalizations	110	728	174	4	4	1	84	22	4	1	35
Deaths	2	14	0	0	0	0	0	0	0	0	7

Trends of Leafy Green Illnesses Per Outbreak



Trends for Annual Burden of Illness for Leafy Greens



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Outbreaks	62	64	45	53	30	54	41	45	44	36	34	32	33	61	30	7
Illnesses	1,450	1,848	979	1,302	684	949	1,064	657	917	486	628	961	709	2,165	781	854
Hospitalizations	55	204	57	40	18	27	68	40	106	25	51	73	82	219	139	46
Deaths	0	5	1	1	0	0	0	1	1	4	1	0	4	5	0	0

Q: Does the industrial scale of farming contribute to scale of the burden and severity of illness?

- Consider scale in production, processing, transportation

Burden of Milkborne Illness: Pasteurized and Raw

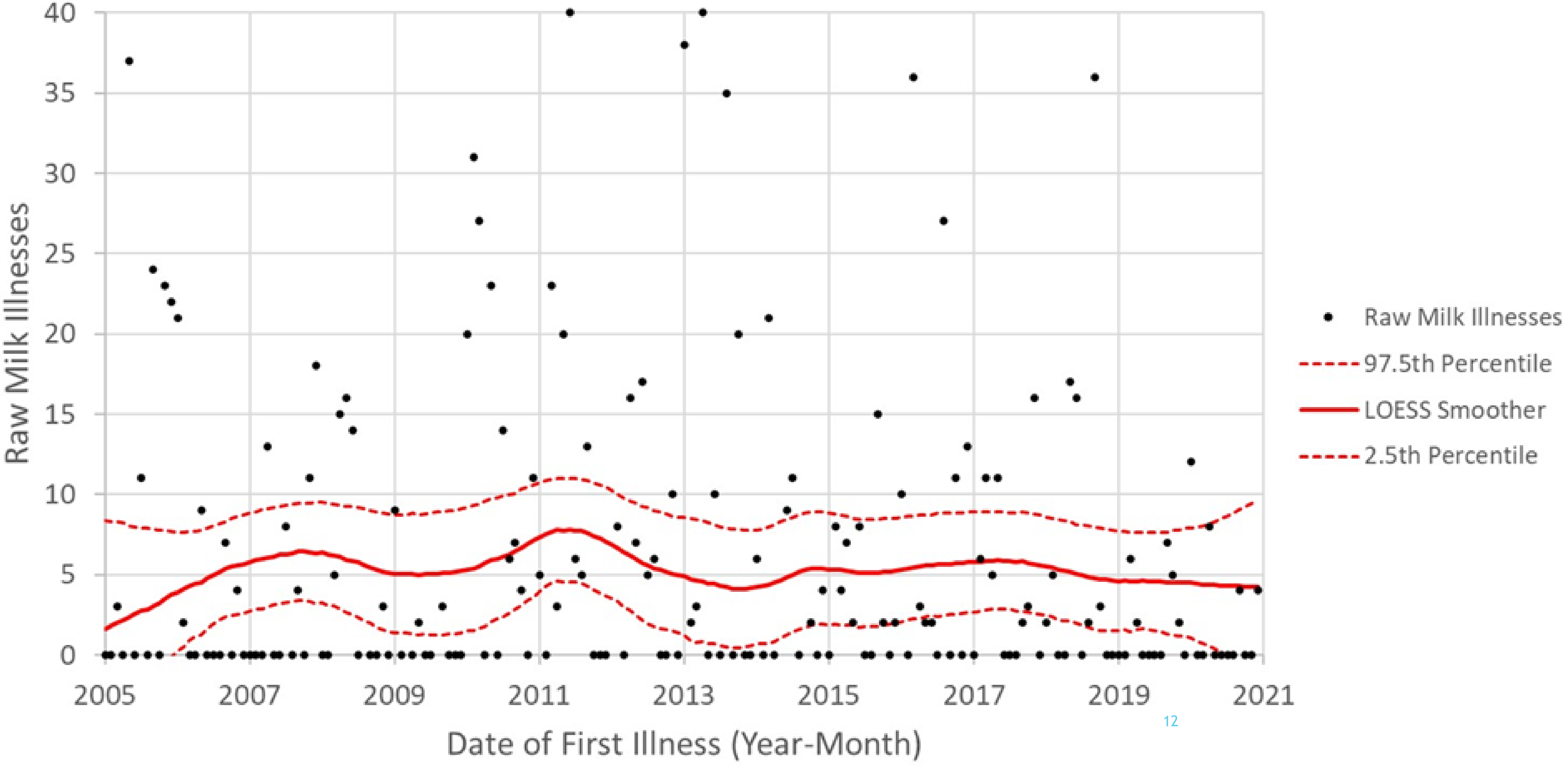
- **Fluid milk** contributed to burden of illness in US over this 16-year period:
  3,807 illnesses
  180 outbreaks
  202 hospitalizations
  6 deaths

	Pasteurized Milk	Raw Milk
Illnesses	2,111	1,570
Outbreaks	18	162
Hospitalizations	32	170
Deaths	4	2

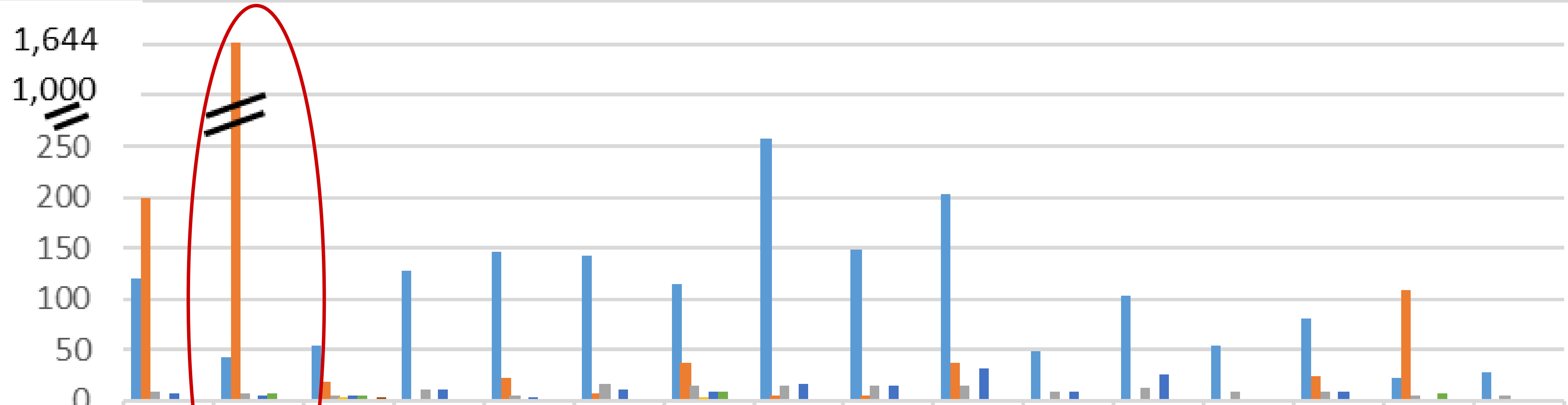
- **Campylobacteriosis** accounted for 3,443 of fluid milkborne illnesses (54% pasteurized milk)

- **Listeriosis** accounted for 5 illnesses in pasteurized milk, 2 illnesses in raw milk, 37 illnesses in raw solid milk products, 143 illnesses from pasteurized solid milk products; a recent systematic review reported higher risk for pasteurized milk (Sebastianski et al., 2022)

Trends of Raw Milk Illnesses Per Outbreak



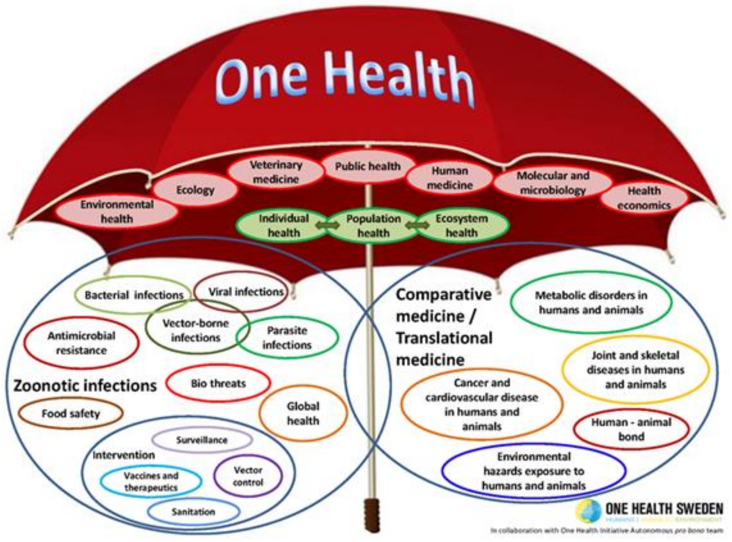
Trends of Annual Milkborne Illness: Pasteurized and Raw



	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		22	7	37	6	5	38				24	109	
Outbreaks - unpasteurized	9	7	6	11	5	16	15	14	14	14	10	13	9	9	5	5
Outbreaks - pasteurized	1	1	3		1	2	3	1	1	2				2	1	
Hospitalizations - unpasteurized	8	6	5	11	3	12	10	17	15	32	10	26	2	10	2	1
Hospitalizations - pasteurized	1	7	5		0	0	10	0	1	0				1	7	
Deaths - unpasteurized	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Deaths - pasteurized	0	0	3		0	0	1	0	0	0				0	0	

Q: Does the industrial scale of dairy farming contribute to scale of the burden of illness?

- Consider industrial scale in production, processing, transportation



Microbiology/Microbiota and Ecosystem Management

Ecosystem Problem 1: 2006 Spinach Outbreak with 5 Deaths

- Politicized outbreak investigation in 2006 **failed to identify root causes** and **ignored processing failures**, blamed farmers, and **further consolidated industrial-scale** production for North America in AZ and CA deserts (Meagher et al., 2022)

- Continuing outbreaks point to **need for holistic reforms of scale** and **practice** in both production and processing industries to **maximize food safety and food security** (Meagher et al., 2022) and **minimize waste** (Duret et al., 2019)

Future 'intelligent' applications of **combinations of multiple hurdles** by growers, packers, and consumers to reduce burden of illness (Mogren et al., 2018) would require:

- **reliable scientific evidence** for assessing benefits and risks
- hygienic **criteria** for **assessing and validating risk reductions** for chemical, physical, microbial interventions
- **robust holistic risk analysis** including **stakeholders**

Potential Root Causes for Leafy Green Outbreaks

- **Irrigation** water and **soil amendments**
- Proximity to animals, particularly **feedlots**
- **Workers' health** and training for hygienic harvesting
- **Temperature** post-harvest
- **Transportation** conditions (hygiene, times and temperatures)
- Load of pathogens and natural microbiota
- Plant damage

Ecosystem Problem 2: 2018 Romaine Outbreak with 5 Deaths

Yuma AZ Romaine Fields Separated from Adjacent CAFO Feedlot by Irrigation Canal

FDA, 2018. Memorandum to the File on the Environmental Assessment; Yuma 2018 E. coli O157:H7 Outbreak Associated with Romaine Lettuce. Figure 1.

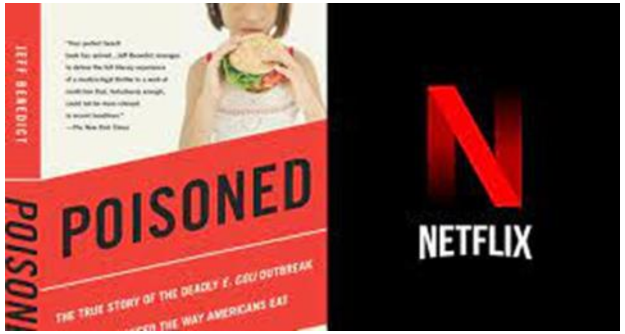
Figure 1. *Wellton Irrigation Canal. This Google Earth view depicts a section of the Wellton main canal adjacent to a CAFO and locations of three outbreak-pathogen-positive irrigation water samples.*

CAFO: Concentrated Animal Feeding Operation;

Industrial scale requiring waste management practices overseen by states and US Environmental Protection Agency;

Such large CAFOs may house **700** to **tens of thousands** of animals (steers) confined on **compacted manure** and sandy soil.

Solutions Offered by NYU Emerita Prof Marion Nestle?



- Grow your own leafy greens
- Buy local
- Avoid packaged leafy greens from industrial scale operations

Attorney and Advocate Bill Marler reportedly unaware of evidence of outbreaks associated with foods from US farmers' markets

UC Cooperative Extension (2023): ~$17,000 costs per acre to produce and harvest romaine heart lettuce in CA (Table 1a)

UC Cooperative Extension, UC Davis (2023)

UC COOPERATIVE EXTENSION – UC DAVIS AGRICULTURAL AND RESOURCE ECONOMICS

TABLE 1. COSTS PER ACRE TO PRODUCE AND HARVEST ROMAINE HEARTS LETTUCE

Operation	Operation Time (Hrs/A)	Cash and Labor Costs per Acre: Labor Cost	Fuel	Lube &Repairs	Material Cost	Custom/ Rent	Total Cost
Cultural:							
Soil Samples (12 per 250 Ac)	0.00	0	0	0	0	9	9
Disc & Roll 6X	1.73	61	122	66	0	0	249
Sub-Soil 2X	1.02	36	72	39	0	0	148
Land Plane (1X per 2 Crops)	0.18	7	13	5	0	0	25
Laser Level (1X per 2 Crops)	0.00	0	0	0	0	93	93
Chisel 4X	1.42	50	100	53	0	0	204
List Beds 3-Row	0.00	0	0	0	0	26	26
Cultivate-Lilliston 2X	0.40	14	17	9	0	0	40
Power Mulch/Shape Beds	0.48	17	25	8	0	0	50
Fertilizer (Potassium Sulfate)	0.00	0	0	0	137	30	167
Plant/Fertilize (7-0-0-7)	0.57	20	30	21	543	0	615
Herbicide Application	0.00	0	0	0	80	30	110
Sprinkler Setup/Irrigate	5.00	125	0	0	106	0	231
Thin Stand-Automated/Fertilize	0.00	0	0	0	0	300	300
Disease/Insect Management	0.00	0	0	0	850	140	990
Cultivate-Break Bottoms	0.32	11	13	6	0	0	31
Hand Weed 2X	12.00	284	0	0	0	0	284
Drip Setup/Irrigate	1.32	247	60	30	476	0	813
Fertigate (20-0-0-5) 2X	0.00	0	0	0	151	0	151
Vertebrate Pest Management	0.88	20	0	0	0	0	20
PCA/CCA Fee	0.00	0	0	0	0	39	39
Pickup-3/4 Ton Farm Use	1.00	36	9	6	0	0	50
TOTAL CULTURAL COSTS	26.32	929	461	242	2,343	666	4,642
Harvest:							
Harvest/Field Pack	0.00	0	0	0	0	6,800	6,800
Cool/Palletize	0.00	0	0	0	0	1,445	1,445
Market/Sales Fee	0.00	0	0	0	0	1,148	1,148
TOTAL HARVEST COSTS	0.00	0	0	0	0	9,393	9,393
Interest on Operating Capital at 7.00%							145
TOTAL OPERATING COSTS/ACRE	26	929	461	242	2,343	10,059	14,179

Leafy Green Microbiota and Effects of Competitors

Microbial Genera Detected in Leafy Greens

(dense, diverse microbiota: $8x10^3$ - $6x10^8$ counts/g;
Mogren et al., 2018; Leonard et al., 2021)

- *Pseudomonas*
- *Rhodococcus*
- *Chryseobacterium*
- *Pantoea*
- *Flavobacterium*
- *Ralstonia*
- *Stenotrophomonas*
- *Erwinia*
- *Xanthomonas*
- *Serratia*
- *Enterobacter*
- *Bacillus*
- *Staphylococcus*
- *Acinetobacter*
- *Alkanindiges*
- *Comamonas*
- *Limnobacter*
- *Pelomonas*

Evidence of Protection: bacterial competition for nutrients after seed inoculation of baby spinach reduced counts of inoculated *E. coli* O157:H7 in greenhouse experitments

- *Pseudomonas* (phylum Proteobacteria)
- *Rhodococcus* (phylum Actinobacteria)
- Combined treatments (Karlsson et al., 2022)

Whereas, no evidence of significant antagonism by metabolites of competitors, leaf sprays of competitors, field testing under experimental conditions of Karlsson

Other Evidence of Competition against Pathogens

- Bacteriophage spray lettuce and spray of 15 bacterial genera cocktail from spinach microbiota effective in suppressing *E. coli* O157:H7 *in vitro* (cited by Mogren et al., 2018)
- *Lactobacillus* inactivation of pathogenic *E. coli* pathovars *in vitro* (Karimi et al., 2018)

Considering Leafy Green Benefits and Risks

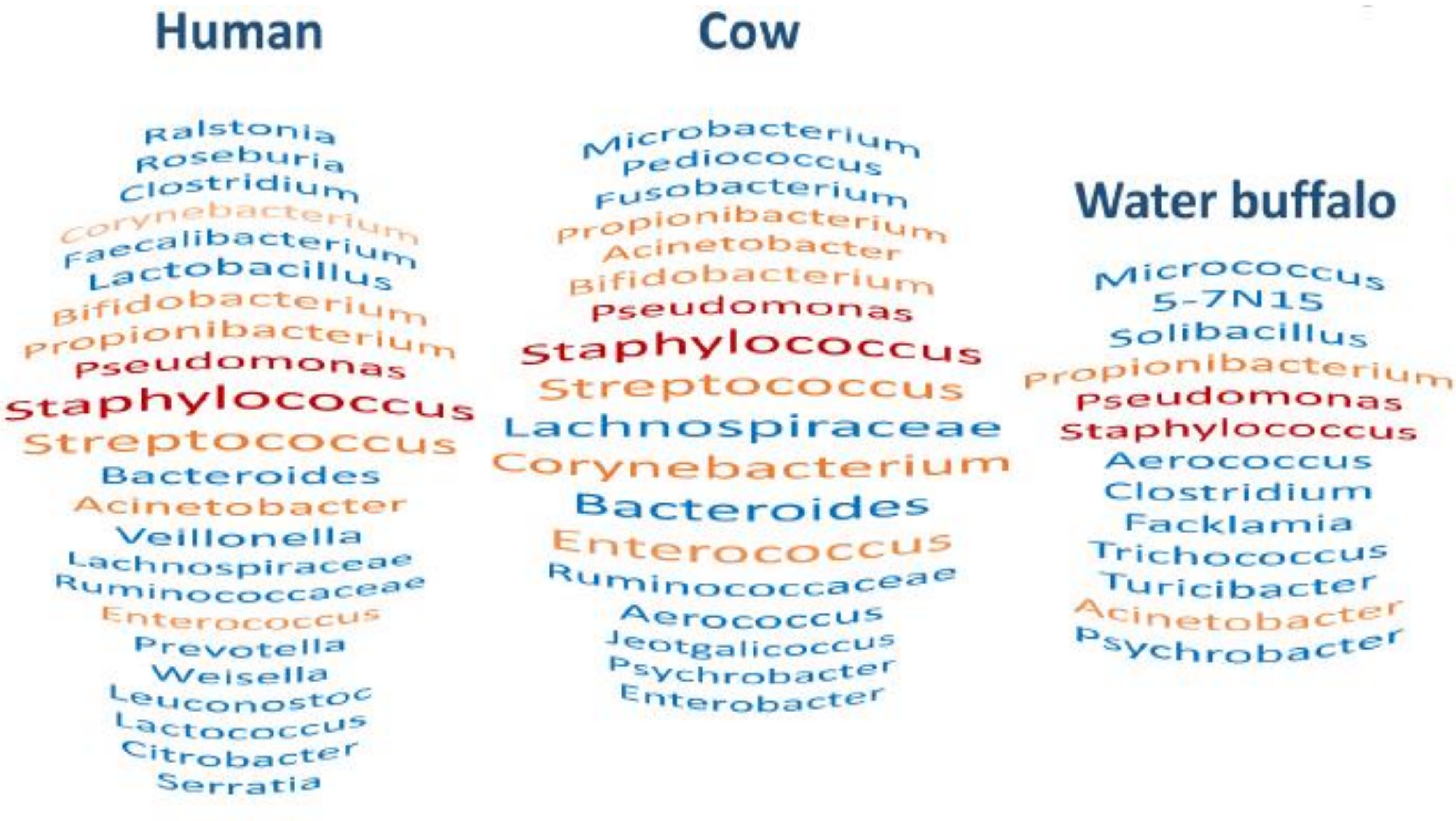
Q: Is adequate evidence available for assessing nutritional and health benefits and risks, and risk-risk tradeoffs, for leafy greens and other foods???

- **High variability** in **dietary studies**, foods, preparation, and consumer health; **many confounders**
- Leafy greens **broad group** with **high variability** in **nutrient density** and **bioavailability**; **many confounders**
- Dietary sources of **oxygenated carotenoids** (lutein plus zeaxanthin): **leafy greens**, orange and yellow fruits and vegetables, eggs, broccoli/dark green vegetables and herbs, milk (Mares, 2016; Eisenhauer et al., 2017; Giordano and Quadro, 2018; Saini et al., 2022) beneficial
  - **Additional Potential Benefits of Leafy Greens**: may protect against oxidative stress and inflammation, some chronic diseases (diabetes, cardiovascular disease, obesity, some cancers); may enhance cell-cell communication, homeostasis, membrane fluidity, eye and skin health; modulate visual and cognitive development in children

Consider Leafy Green Net Value = (Expected $ Nutritional Benefits - Expected $ Foodborne Disease) / Price of Leafy Greens

Williams R (2023). Public Health Without Politics: The Sabermetrics of Lettuce. 31 August. Available at: https://open.substack.com/pub/fixingfood/p/the-sabermetrics-of-lettuce?r=2p4y6p&utm_campaign=post&utm_medium=email

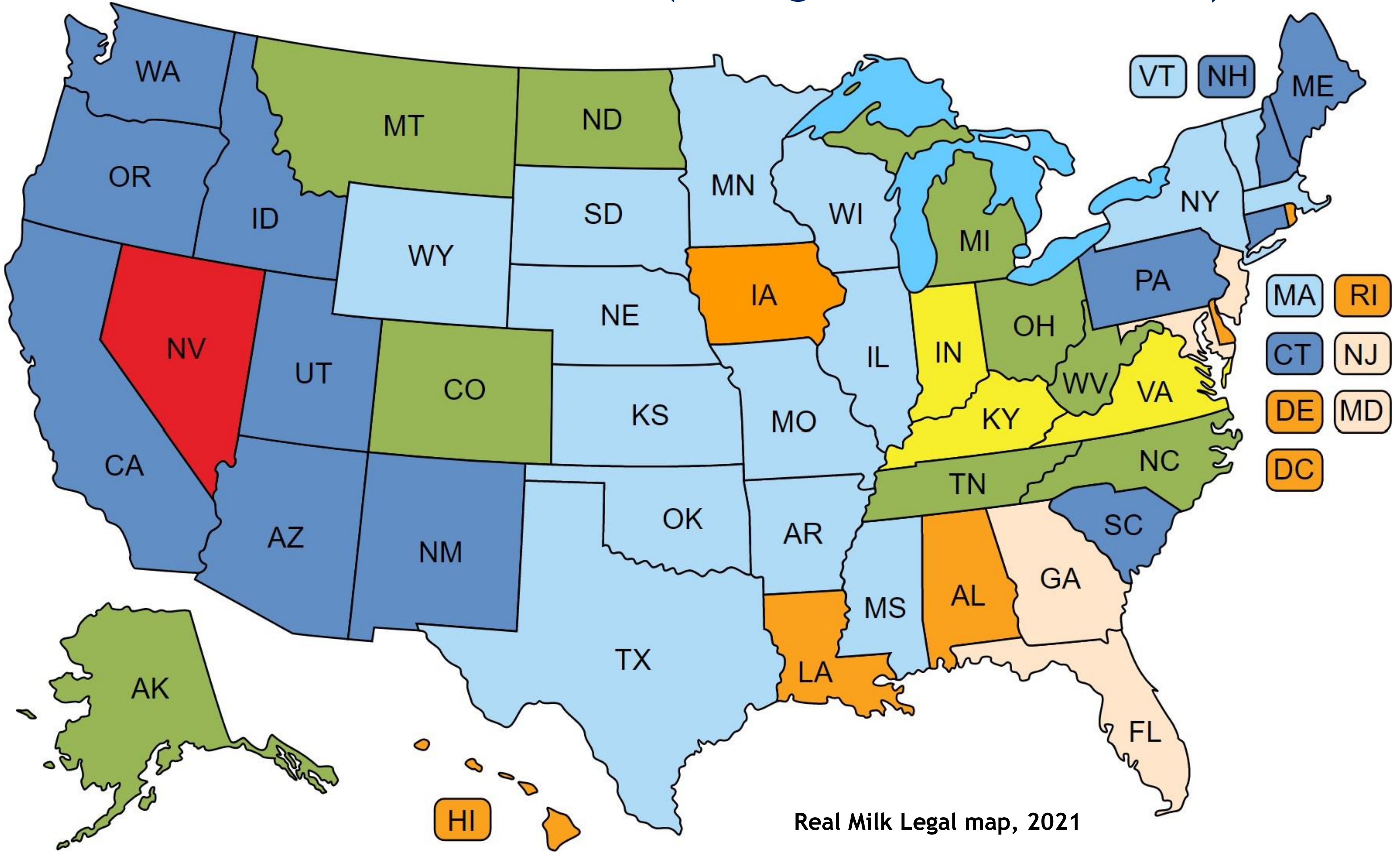
Recent Milk Microbiota Comparison



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

Many States Permit Local Access to Raw Milk at the Farm Gate (24 Light Blue and Green)

Wider Access in 12 States Permitting Retail Sale
(Dark Blue)

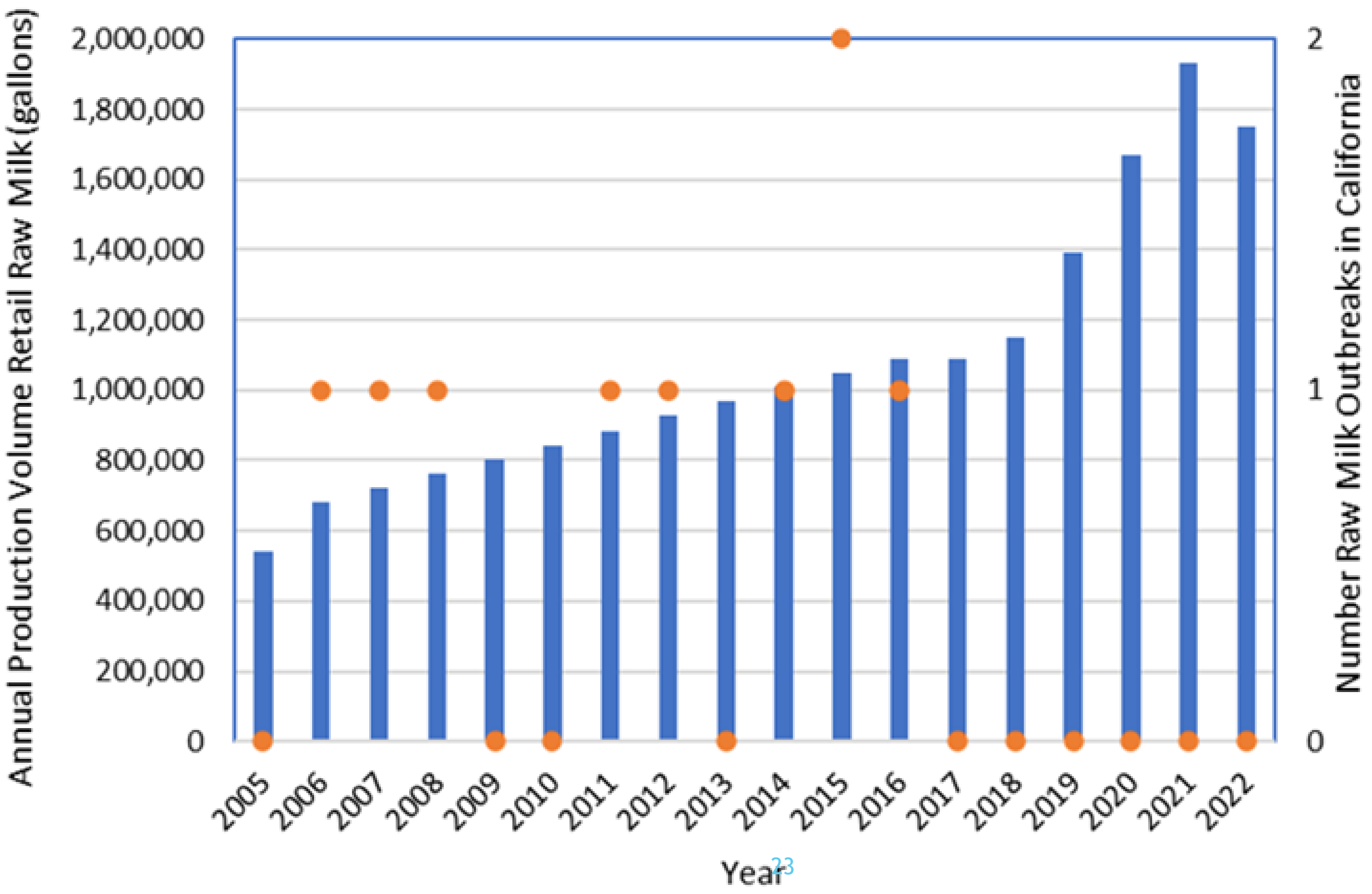


Real Milk Legal map, 2021

For a Grass-Fed CA Dairy Farm, Wider Access at Retail Not Necessarily Predict Higher Risk

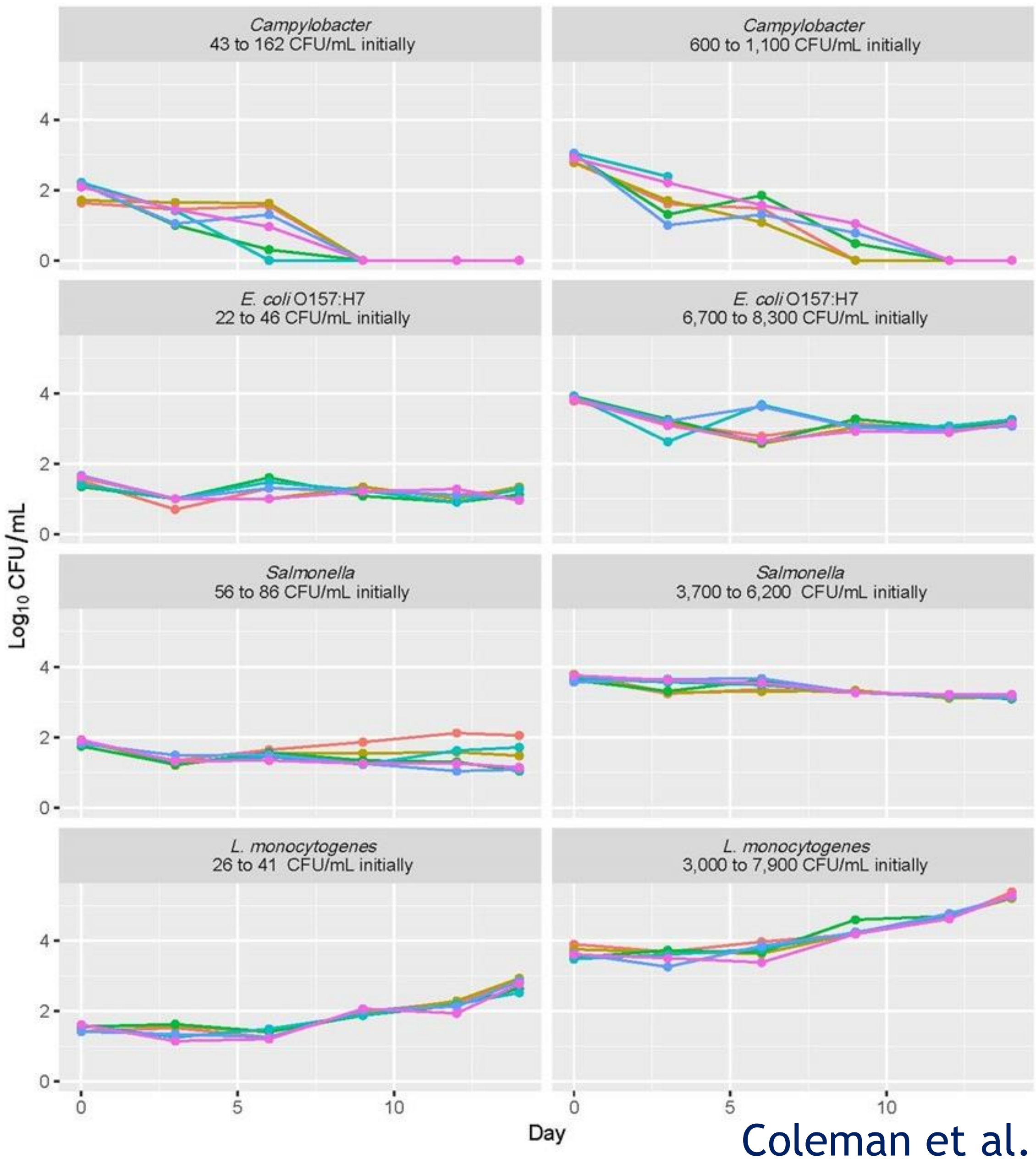
Coleman and North, 2023

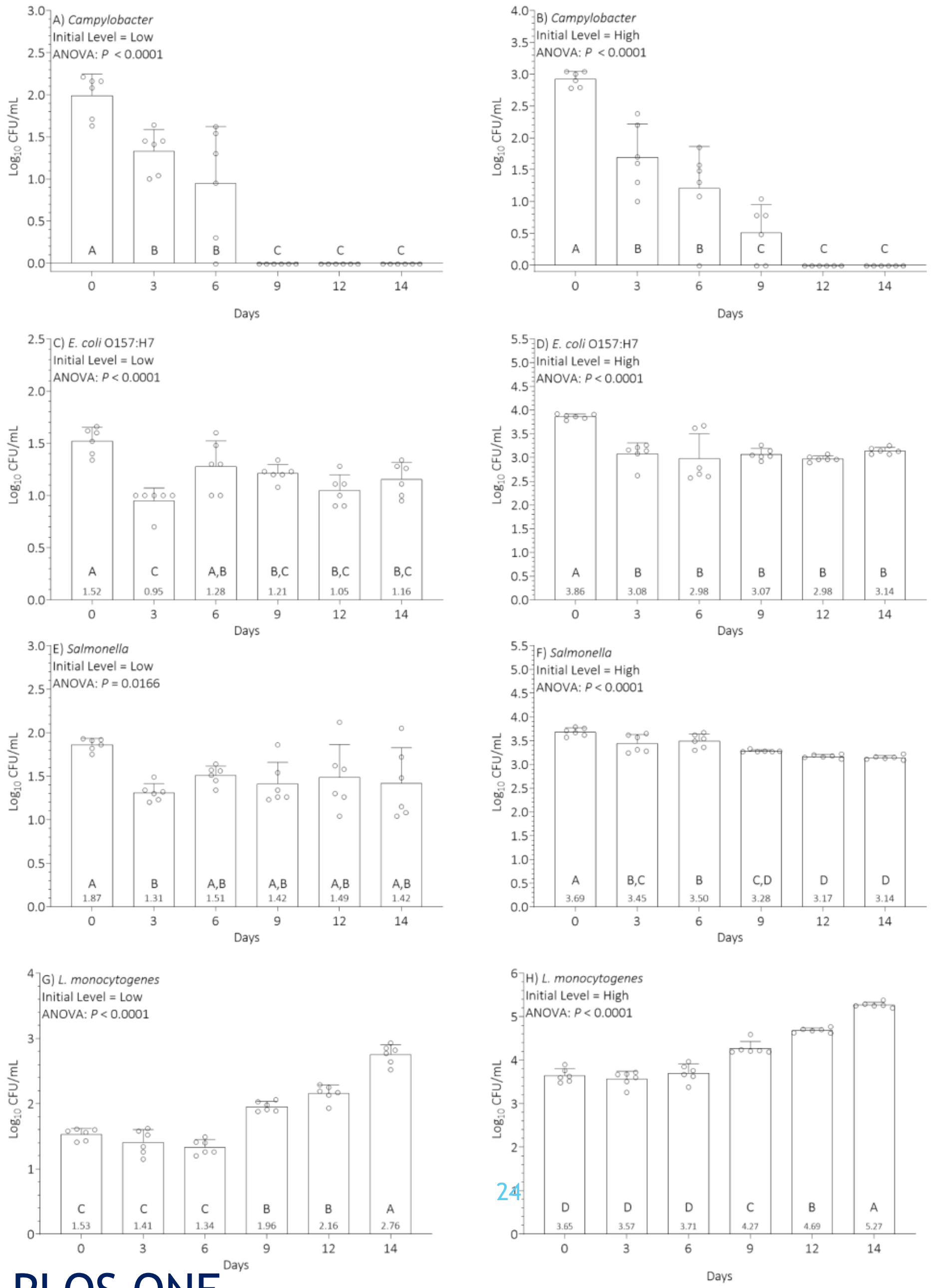
1. Production from one CA dairy **≥1.4 million gallons (5.3 million liters)** of raw milk supplied to CA retail markets recent years (blue bars)
2. No CA outbreaks since **2016** (orange dots in figure), 6 outbreaks prior, 83 illnesses, 11 hospitalizations, no deaths
3. Nearly **9 million gallons** of retail raw milk sold from 2017 to 2022, without an outbreak reported in CA linked to raw milk consumption (risk estimate: **<1 illness in 20 million 250-mL servings**)
4. **Campylobacteriosis primary hazard** for both **raw** and **pasteurized** milks



Coleman and North, 2023

Ecological Explanation: Raw Milk Microbiota, Temperature Hurdles





Coleman et al., 2023, PLOS ONE

Call to Re-Vision Agriculture: One Health and Risk Analysis

Re-Visioning Agriculture: Align One Health AND Risk Analysis

(Coleman and North, 2023)

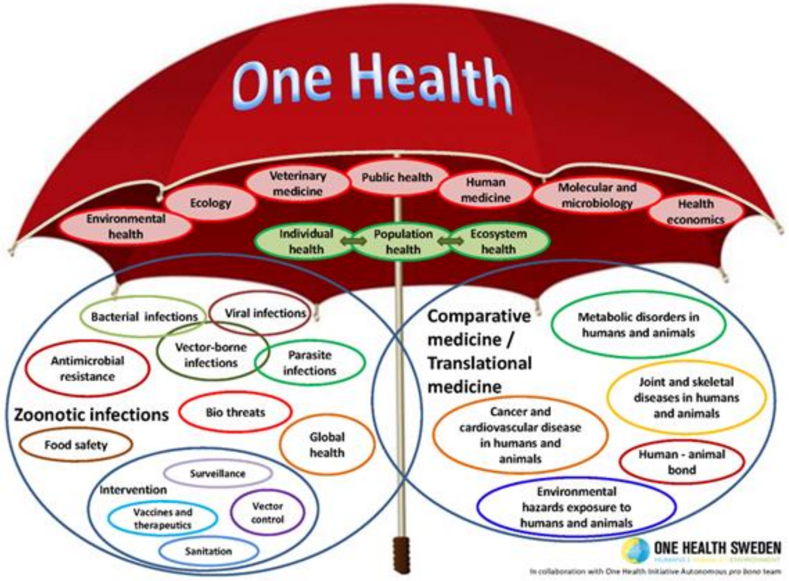
1. Food quality/safety focused on **ecosystem dependencies** (e.g., minimize irrigation and transportation for leafy greens to minimize food waste, illness; feed herbivores natural grass-based diet with rotational grazing) to maintain the quality of foods, pastures, soils, water

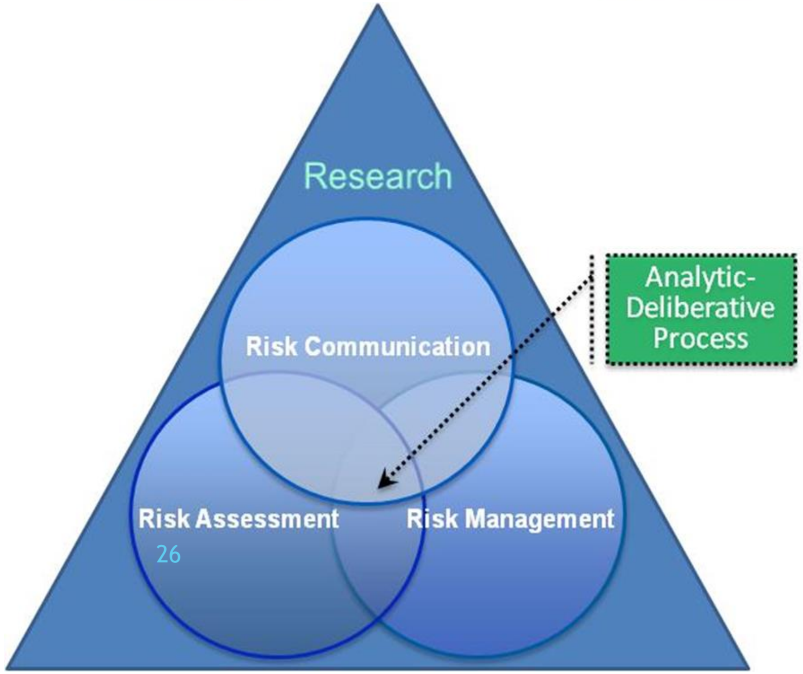
2. Address **root causes** for **complex systems**: animal and ecosystem health and welfare; rural and urban community health and wellness; local, regional, and global scales

3. Relevance of '**analytic deliberative process**' of risk analysis (NRC, 1996) to One Health: multi-sector and trans-disciplinary dialogue and collaboration; transparent, evidence-based analysis and communication

4. **Iterative cycles** of **open, transparent public discourse** including **deliberation** of **evidence and analysis** essential to developing public policies about **what types/sizes of farms** (e.g., regenerative grazing versus CAFO) most **desirable ecologically, socially, environmentally**

5. **Holistic** considerations of **cultural, environmental, nutritional, social** effects of **industrial scale agriculture** (CAFOs) for healthy communities





Questions? Comments? Interested Partners?

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11 December 2023, Society for Risk Analysis Annual Meeting, Washington, DC

Backup Slides

Presenters' Recent Collaborations in Peer-Reviewed Literature

Authors	Manuscript Title	Manuscript Link
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	accepted PLOS ONE, July 2023; not yet available online

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