SWAT-SIR Model for Predicting Fate and Transport of Manure-borne Pathogens in Fragmented Agriculture-Forest Ecosystems

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The 7th International Congress on Environmental Modelling and Software, June 15-19, San Diego, California, USA

Outline

- Pathogens transmitted by wildlife and livestock.
- Current status of modeling pathogen transmission by wildlife.
- Integrating wildlife component into Soil and Water Assessment Tool (SWAT).
- Model implementation to a fragmented agriculture-forest watershed.
- Future development.

Livestock and wildlife pathogens potentially threatening to humans

Bacteria:

- *Escherichia coli (E. coli)* O157:H7 and other shiga-toxin producing strains,
- *Salmonella* spp.,
- *Campylobacter jejuni,*
- *Yersinia enterocolitica,*
- *Shigella* sp.,
- *Listeria monocytogenes,*
- *Leptospira* spp.,
- *Aeromonas hydrophila,*
- *Clostridium perfringens,*
- *Bacillus anthraxis* (in endemic area) in mortality carcasses

Parasites:

- Giardia lamblia,
- Cryptosporidium parvum,
- Balantidium coli,
- Toxoplasma gondii,
- Ascaris suum and A. lumbricoides,
- Trichuris trichuria

Viruses:

- rotavirus,
- hepatitis E virus,
- influenza A (avian influenza virus),
- enteroviruses,
- adenoviruses,
- caliciviruses (e.g., norovirus)

Domestic and wild animals - potential pathogen transmitters

Domestic animals:

- Cattle
- Sheep
- Swine
- Goats
- Horses
- Dogs
- Cats
- Poultry

Wild animals:

- Deer
- Elks
- Buffalo
- Feral swine
- Raccoons
- Coyotes
- Foxes
- Birds
- Fish
- Flies

Current status of modeling pathogen transmission by wildlife and domestic animals

- Agricultural Runoff Management II, Animal Waste Version (ARM II) model (Overcash et al., 1983)
- Utah State (UTAH) model (Springer et al., 1983)
- MWASTE model (Moore et al., 1988)
- COLI model (Walker et al., 1990)
- Spatially Explicit Load Enrichment Calculation Tool (SELECT) (Teague et al., 2009)
- Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997, 2011)
- KINEROS2/STWIR model (Woolhiser et al., 1990; Guber et al., 2006, 2009)
- Soil and Water Assessment Tool (SWAT) (Sadeghi and Arnold, 2002; Neitsch et al., 2005; Kim et al., 2010)

Hydrological Simulation Program–FORTRAN (HSPF)
(Bicknell et al., 1997; Moyer and Hyer, 2003; Hevesi et al., 2011)

Microbial processes:

- deposition and accumulation in a surface storage by grazing animals and manure fertilization;
- die-off in the surface storage;
- wash-off from the surface storage;
- subsurface, overland and instream transport;
- instream deposition and resuspension.

Soil and Water Assessment Tool (SWAT)
(Arnold et al., 1998; Sadeghi and Arnold, 2002; Neitsch et al., 2005; Kim et al., 2010)

Microbial processes:

- deposition on soil and foliage by grazing animals and manure fertilization;
- die-off/re-growth in soil, water and on foliage;
- wash-off from soil and foliage;
- leaching from soil;
- subsurface, overland and instream transport;
- bacteria resuspension from streambed sediment.

Microorganism Transport with Infiltration and Runoff (STWIR) add-on Module for the KINEROS2 Runoff and Erosion Model (Guber et al., 2006, 2009, 2012)

Microbial processes:

- die-off in manure, soil and water;
- release from manures;
- exchange with top soil layer;
- overland transport (CDE)

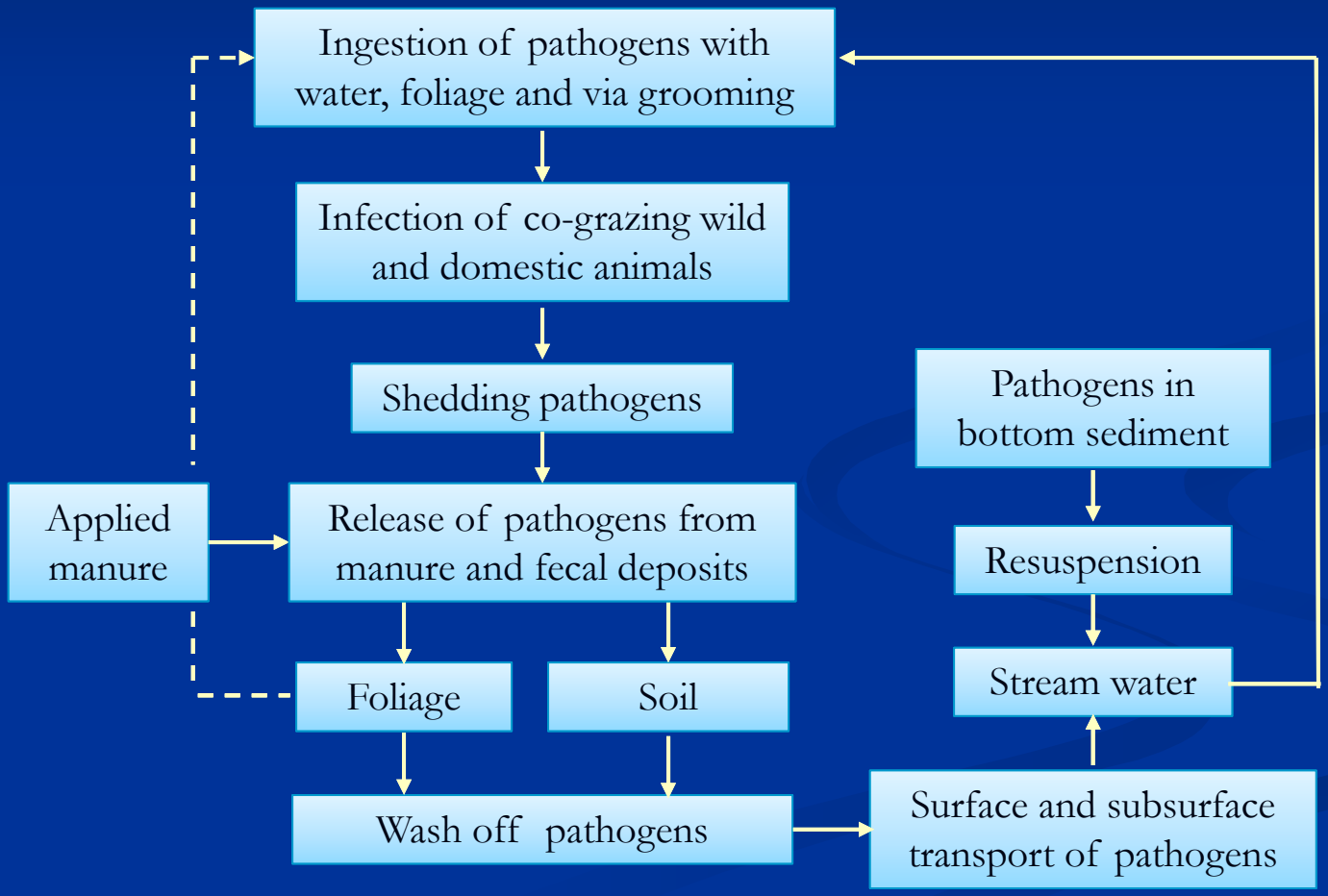
Common Limitations of Existing Models

- deposition is considered at constant rates in specified locations;
- manure phase is not considered;
- wildlife population and habitat dynamics are ignored;
- changes in foliage availability are not accounted for;
- modeling of pathogen production, transmission, and deposition by infected domestic and wildlife animals is lacking.

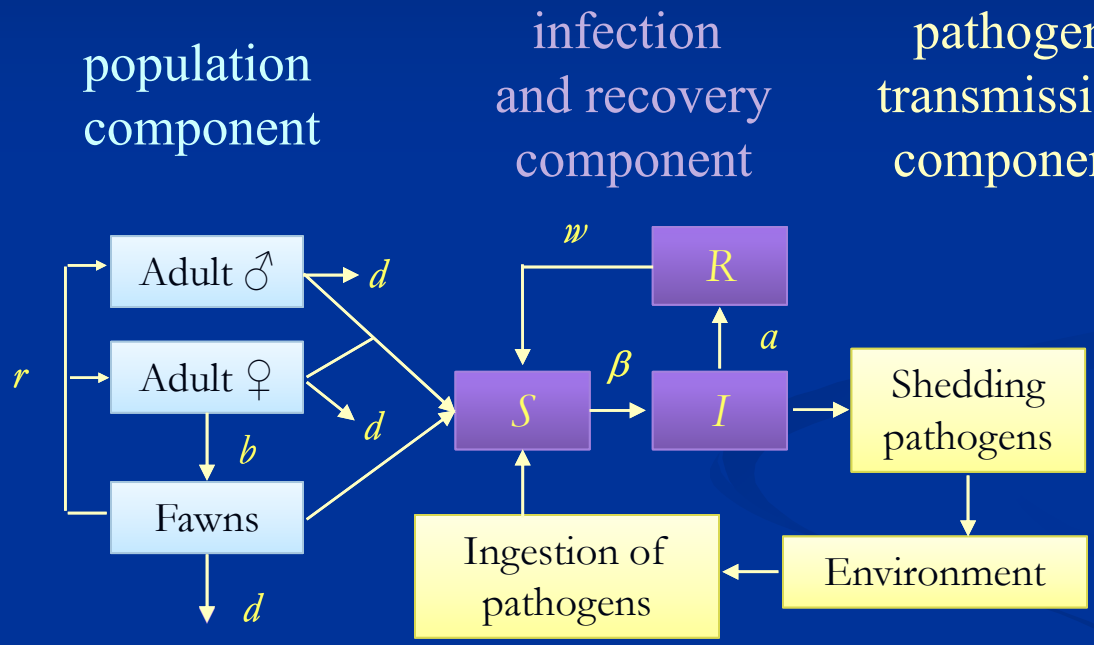
An add-on module SIR (Susceptible - Infected - Recovered) for SWAT model

- seasonal changes in wildlife population and habitat;
- resource selection and seasonal changes in foliage consumption;
- ingestion of pathogens with water, foliage, and via grooming soiled hide;
- infection and recovery of co-grazing wild and domestic animals;
- pathogen shedding by infected animals;
- survival of pathogens in manure;
- kinetic release of pathogens from applied manure and fecal material.

Pathogen cycle in SIR module



Wildlife population changes, infection and recovery in SIR add-on module



r is recruitment rate, day^{-1};
b is birth rate, day^{-1};
d is mortality rate, day^{-1}

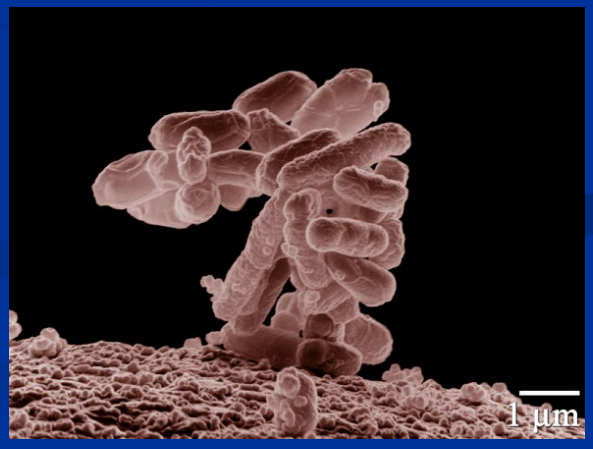
S, *I* and *R* are the abundances of susceptible, infected, and recovered animals
$1/\alpha$ is recovery period, days;
β is infection rate, day^{-1};
$1/w$ is immune period, days.

Modeled pathogen and wildlife species

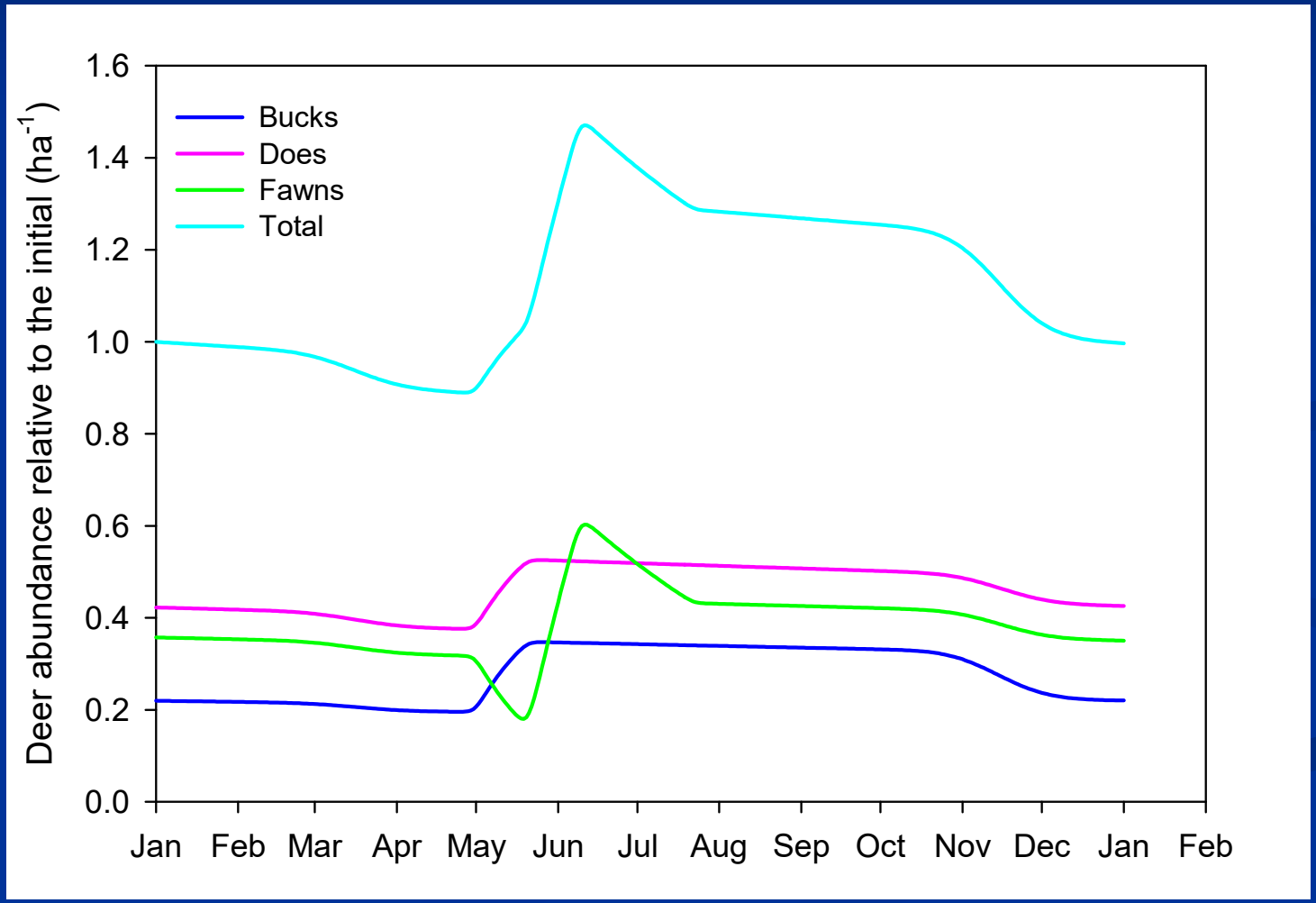
White-tailed deer (*Odocoileus virginianus*)

E.coli O157:H7

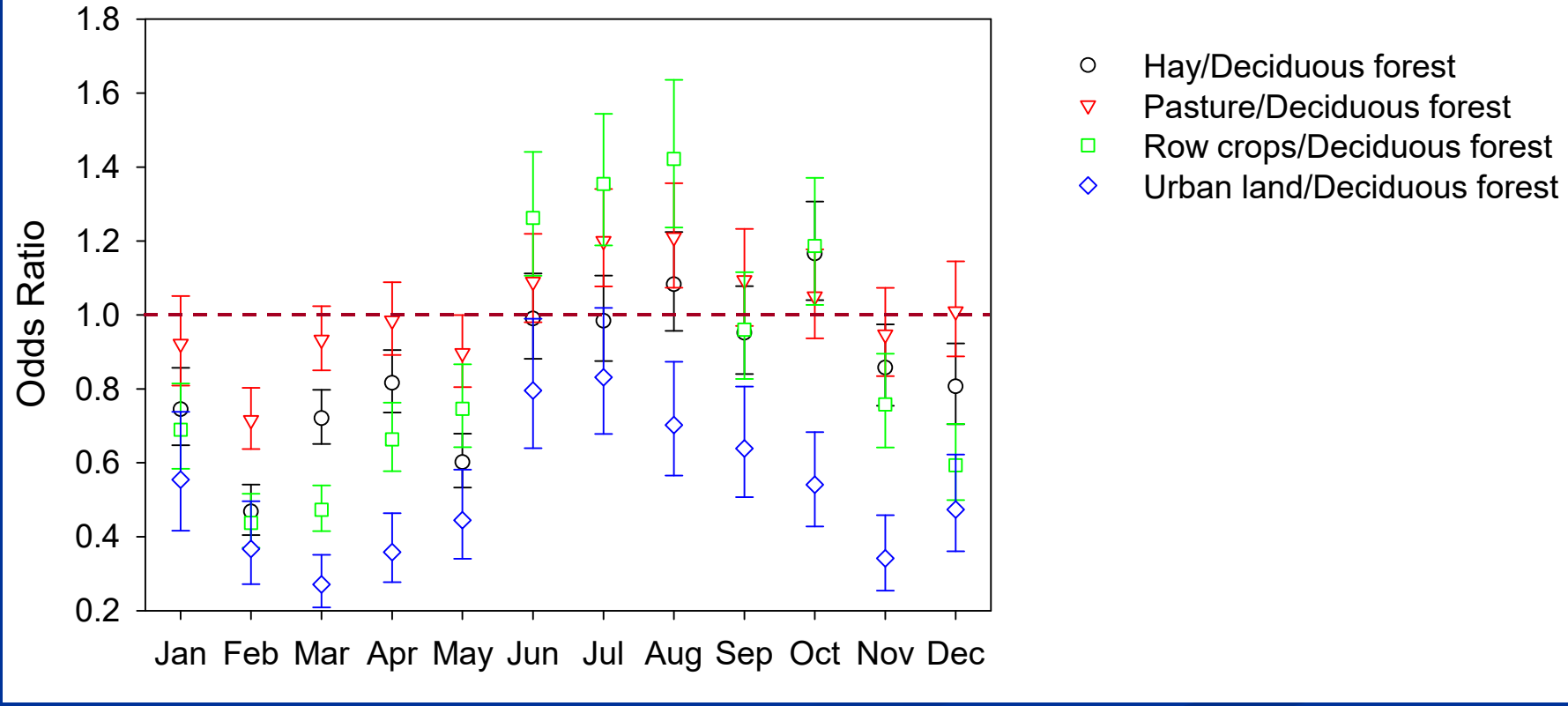
enterohemorrhagic serotype of the bacterium *Escherichia coli* and a cause of illness, typically through consumption of contaminated food. Infection may lead to hemorrhagic diarrhea, and to kidney failure.



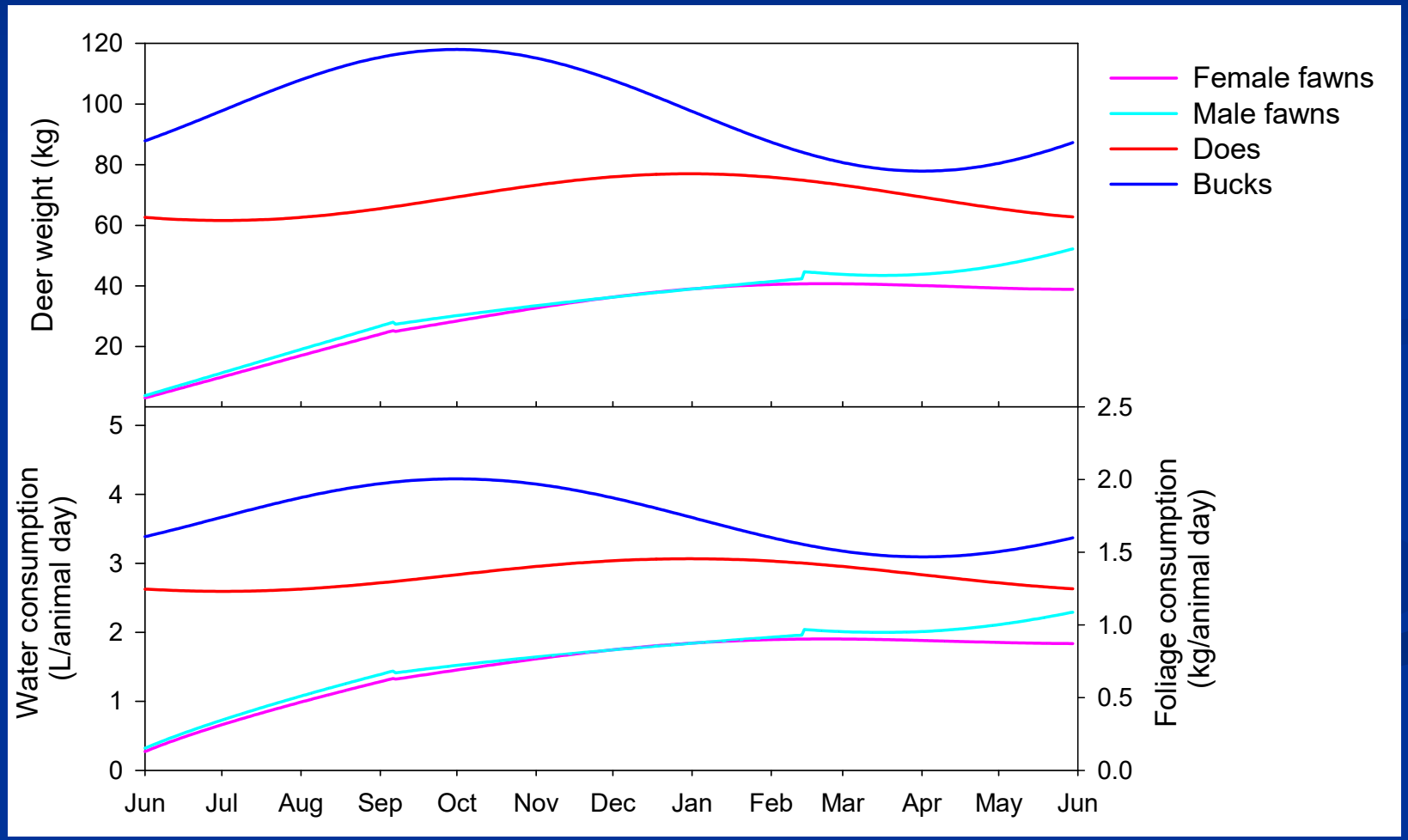
White-tailed deer population component



Resource selection component



Water and Foliage Consumption by Deer (Moen, 1978)

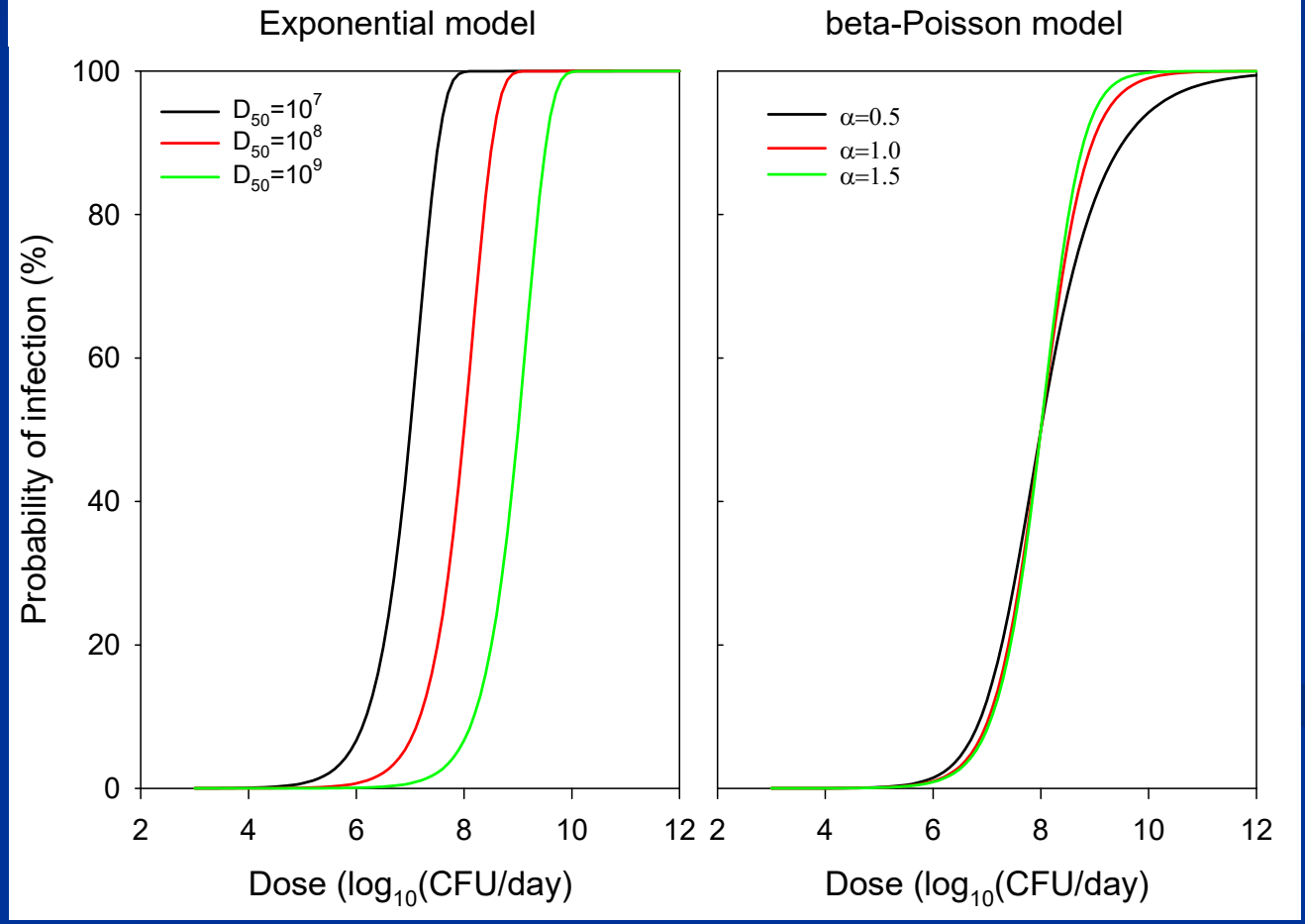


Dose-response component (Haas et al., 2000)

Daily *dose* of pathogens:

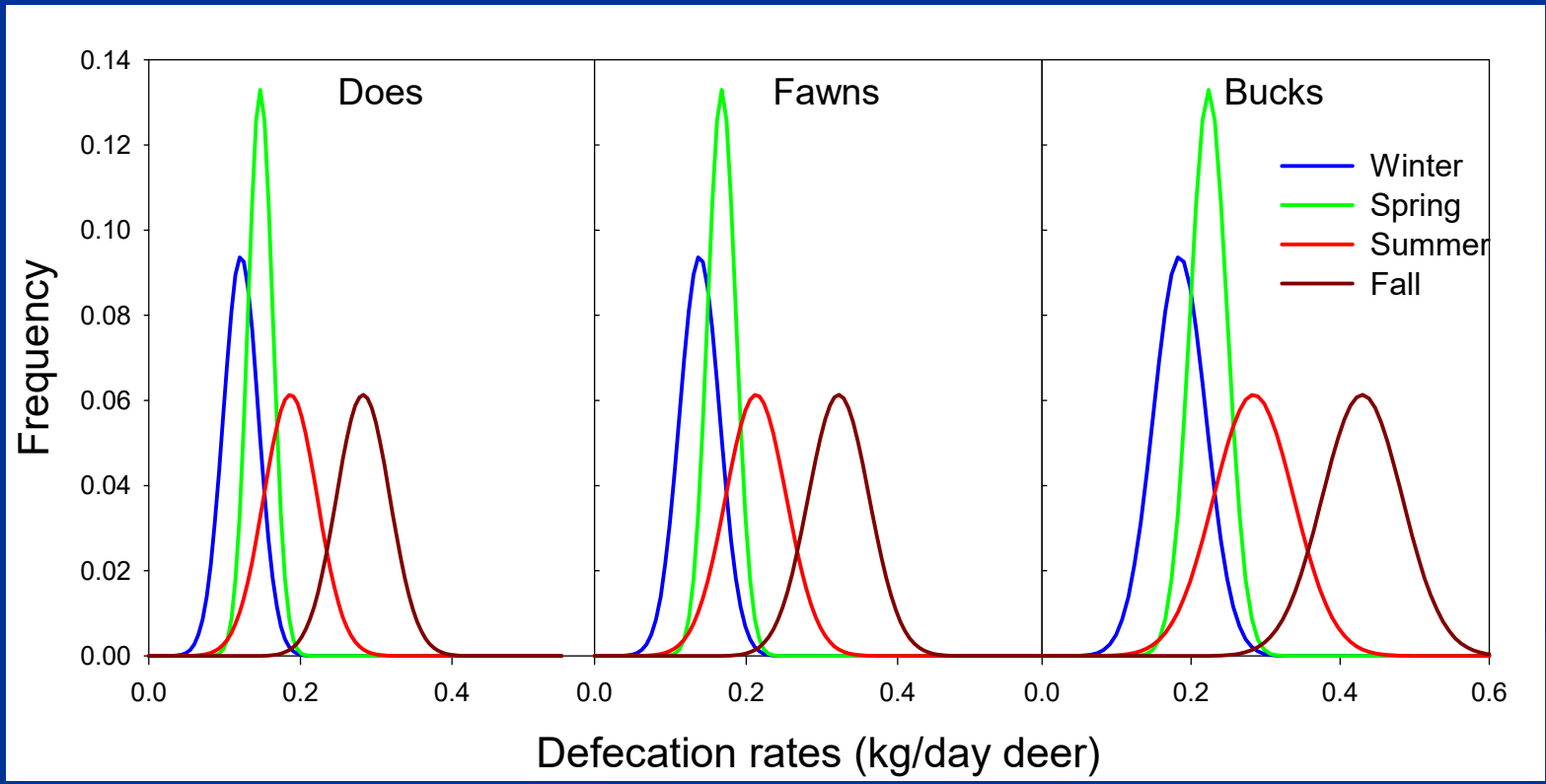
- foliage
- water
- grooming soiled hide

$$\beta = 1 - \exp(dose \cdot \ln(0.5) / D_{50}) \qquad \beta = 1 - [1 + dose\,(2^{1/\alpha} - 1) / D_{50}]^{-\alpha}$$



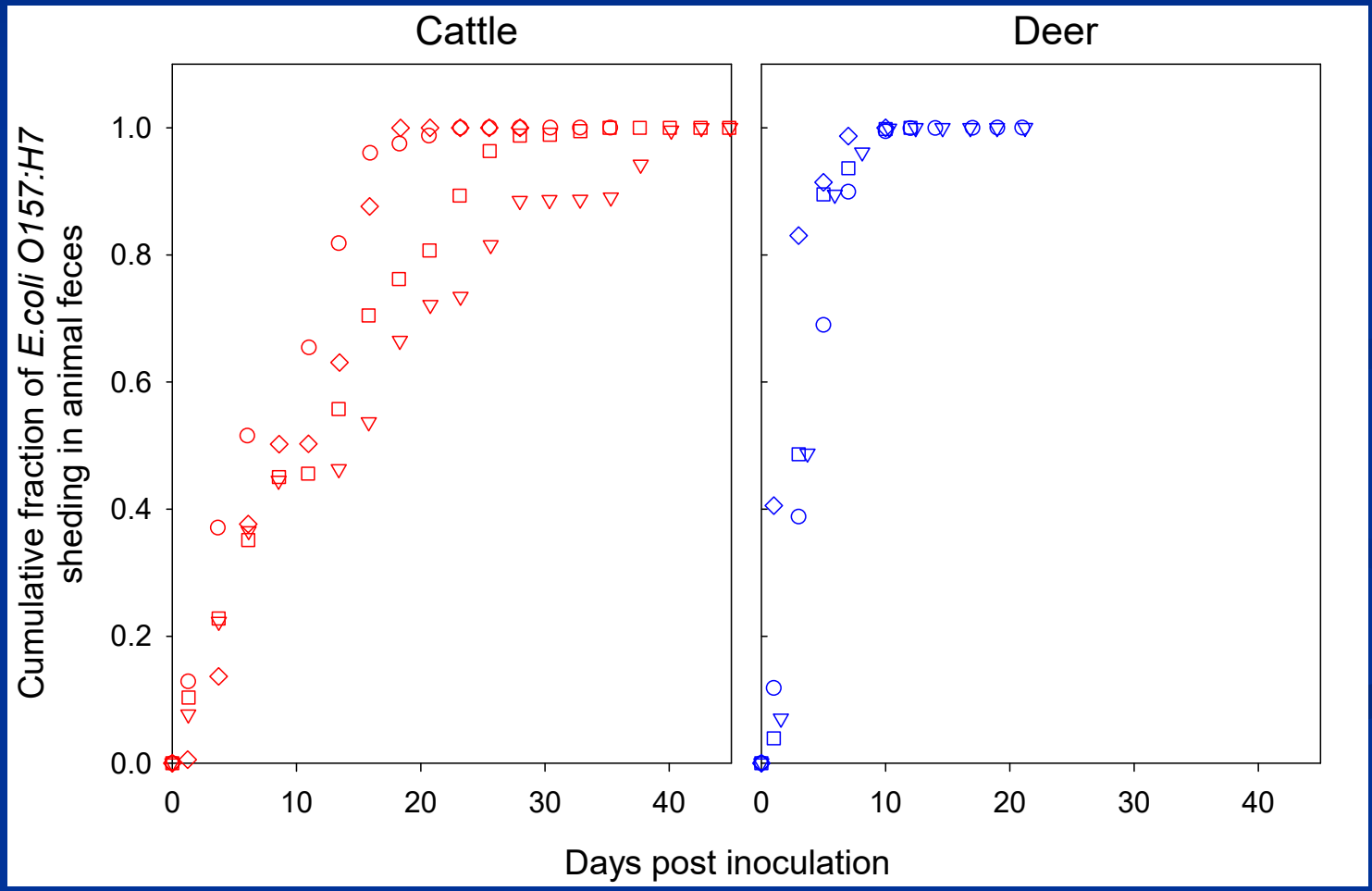
Pathogen shedding component

Seasonal changes in deer defecation rates



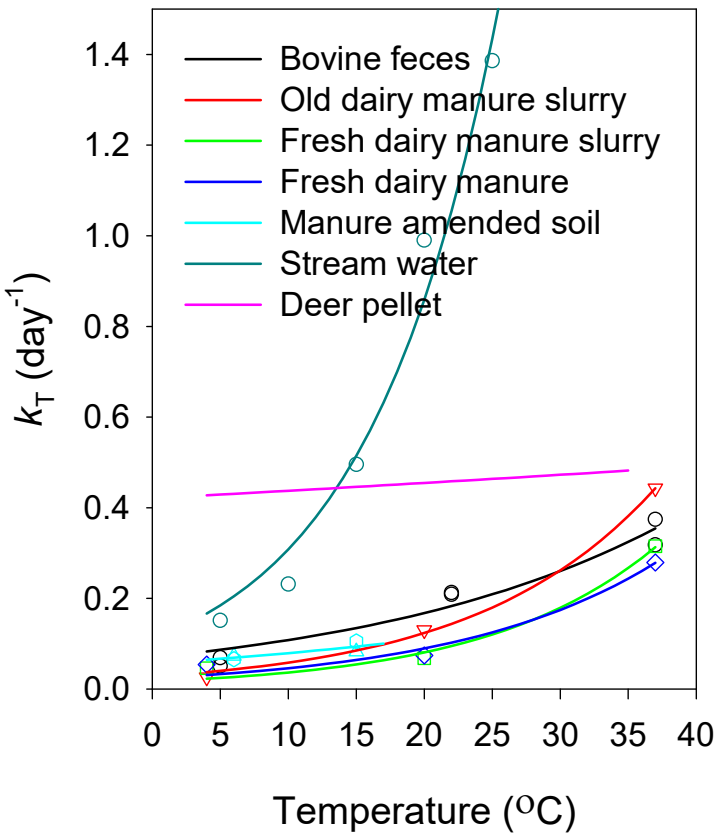
Pathogen shedding component

E.coli O157:H7 shedding by infected cattle and deer

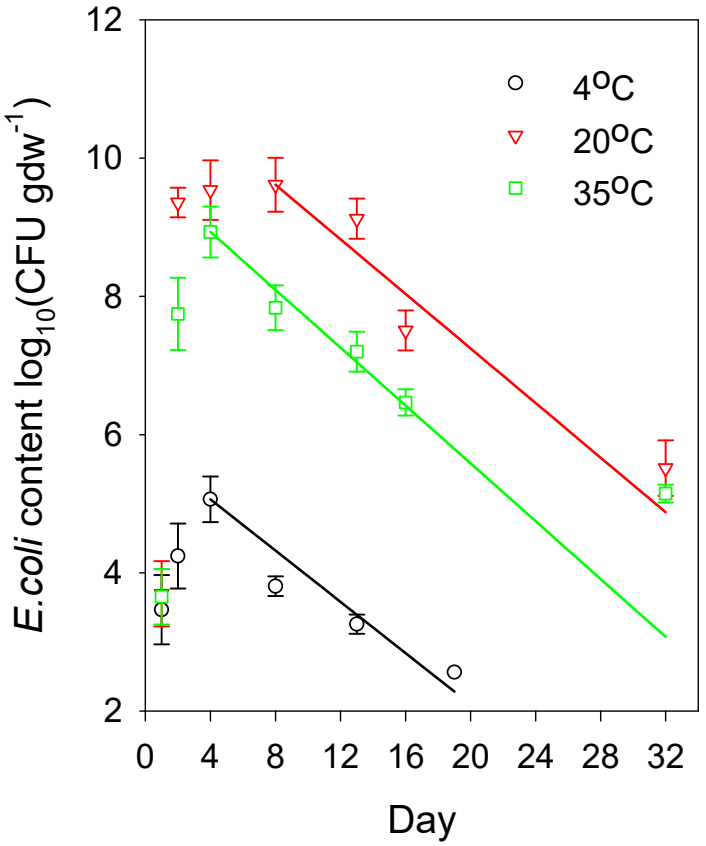


Pathogen survival component
Chick & Arrhenius equations

E.coli inactivation rates in different media

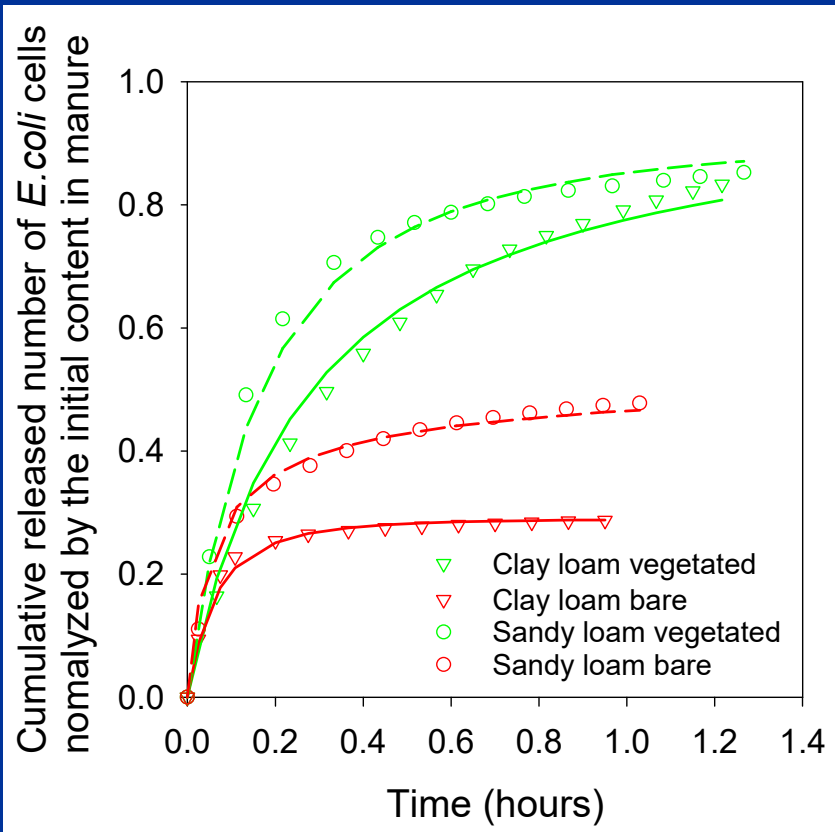


E.coli growth and die-off in deer pellet

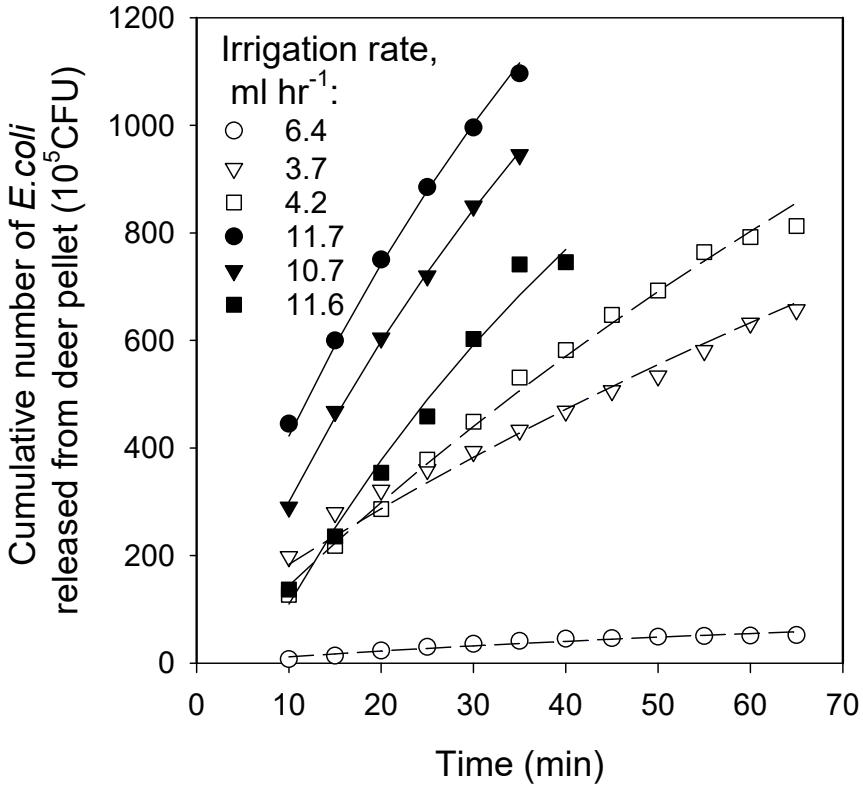


Pathogen release from fecal deposits
Bradford & Schijven (2002) model

Surface applied bovine manure



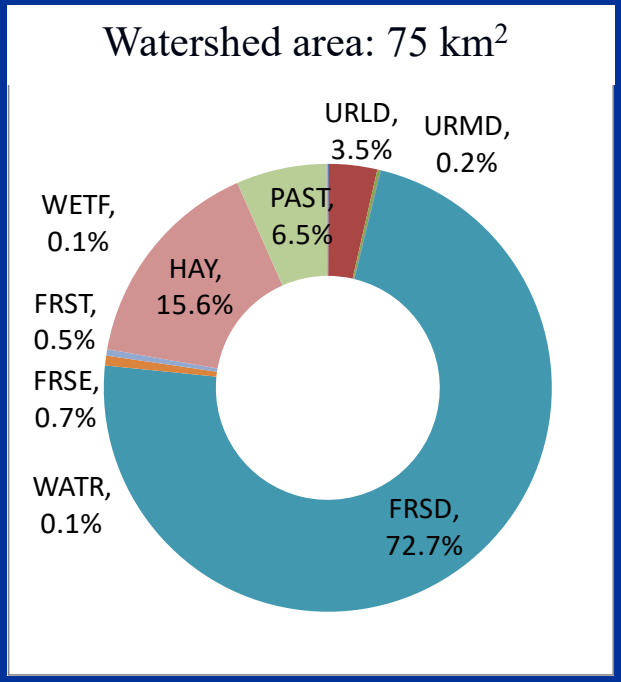
Deer pellet

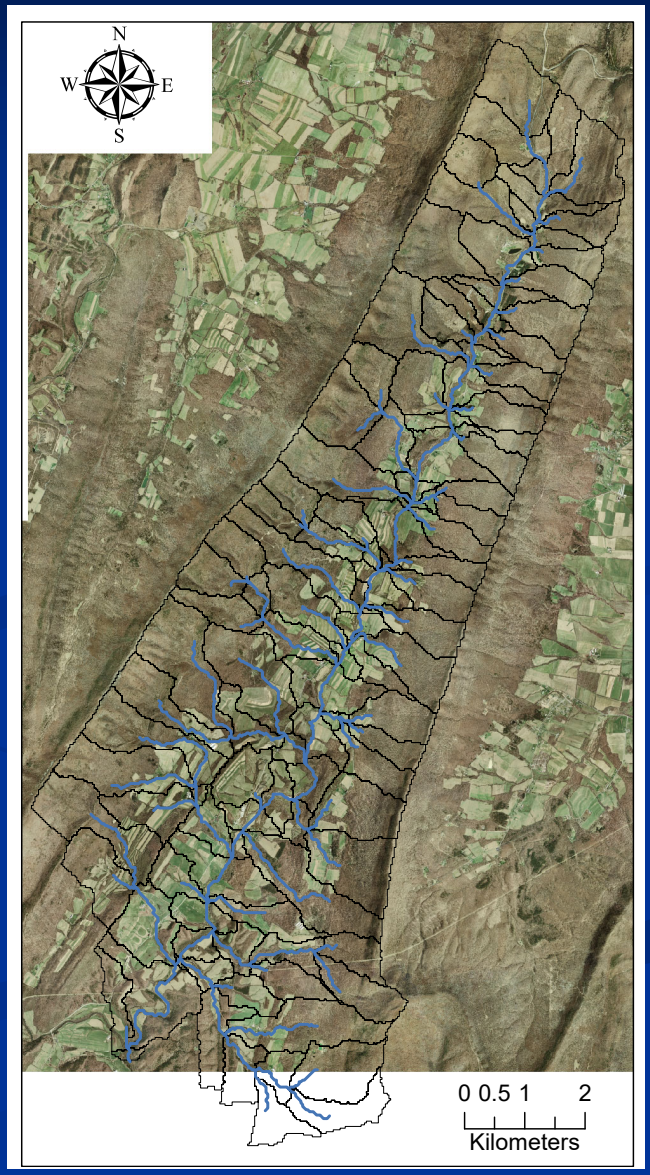


Model implementation to a fragmented agriculture-forest watershed

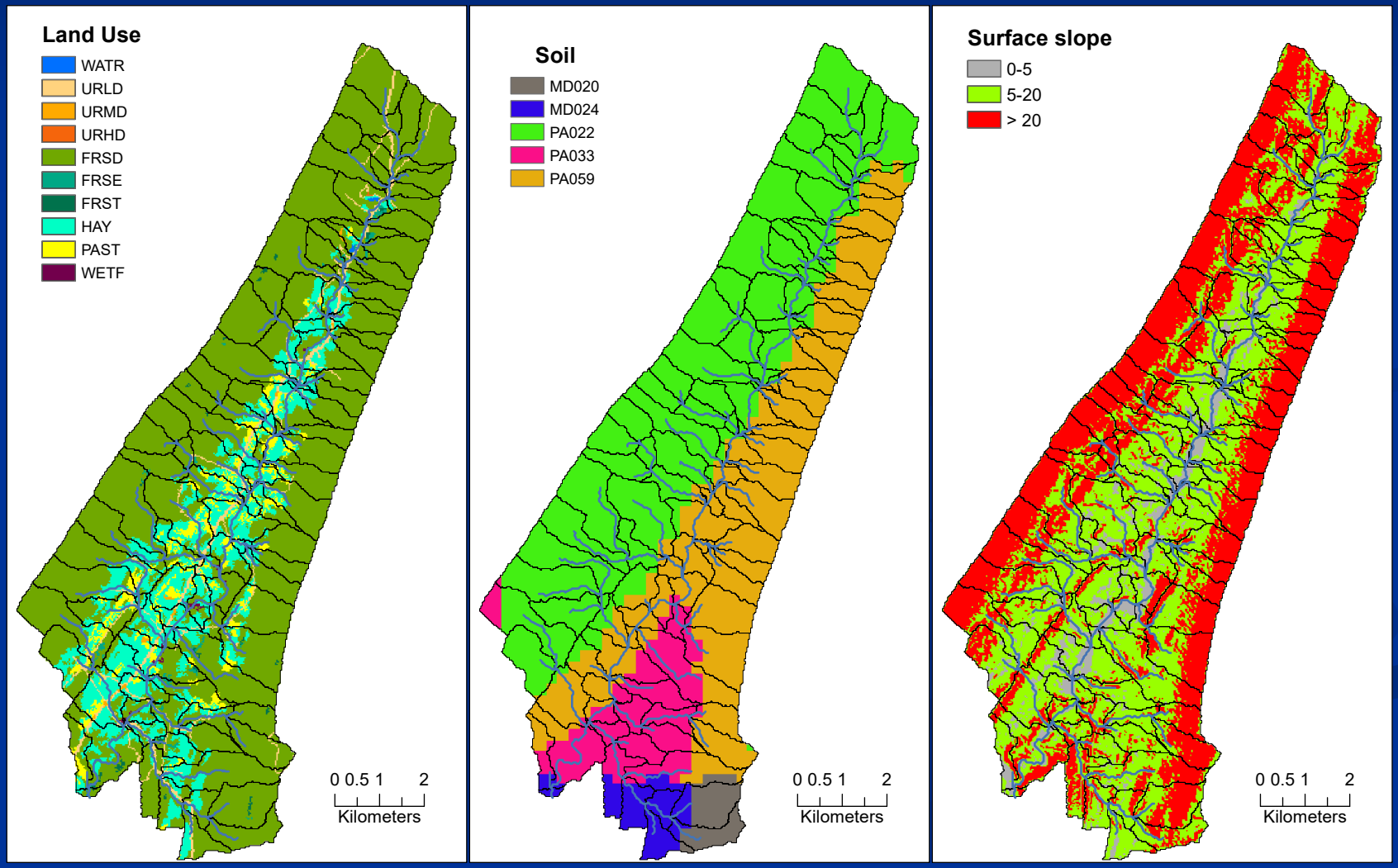
- Research area: Little Cove Creek watershed in Southern Pennsylvania
- Manure source: Livestock operations
- Manure application rates: Solid - 48 ton/ha; Liquid - 3 ton/ha
- Application time: May 12th
- Pathogen: *E.coli* O157:H7
- Fraction of *E.coli* O157:H7 in total *E.coli* content for manure: 0.01
- Abundance of white-tailed deer: 5 heads per km^2 of deciduous forest
- Density of grazing cattle: 4 head/ha
- Fraction of grazing cattle shedding *E.coli* O157:H7: 0.04
- Cattle grazing season: May 23th through October 26th

Little Cove Creek watershed (Franklin County, Southern Pennsylvania)





Characteristics of the Little Cove Creek watershed (Franklin County, Southern Pennsylvania)

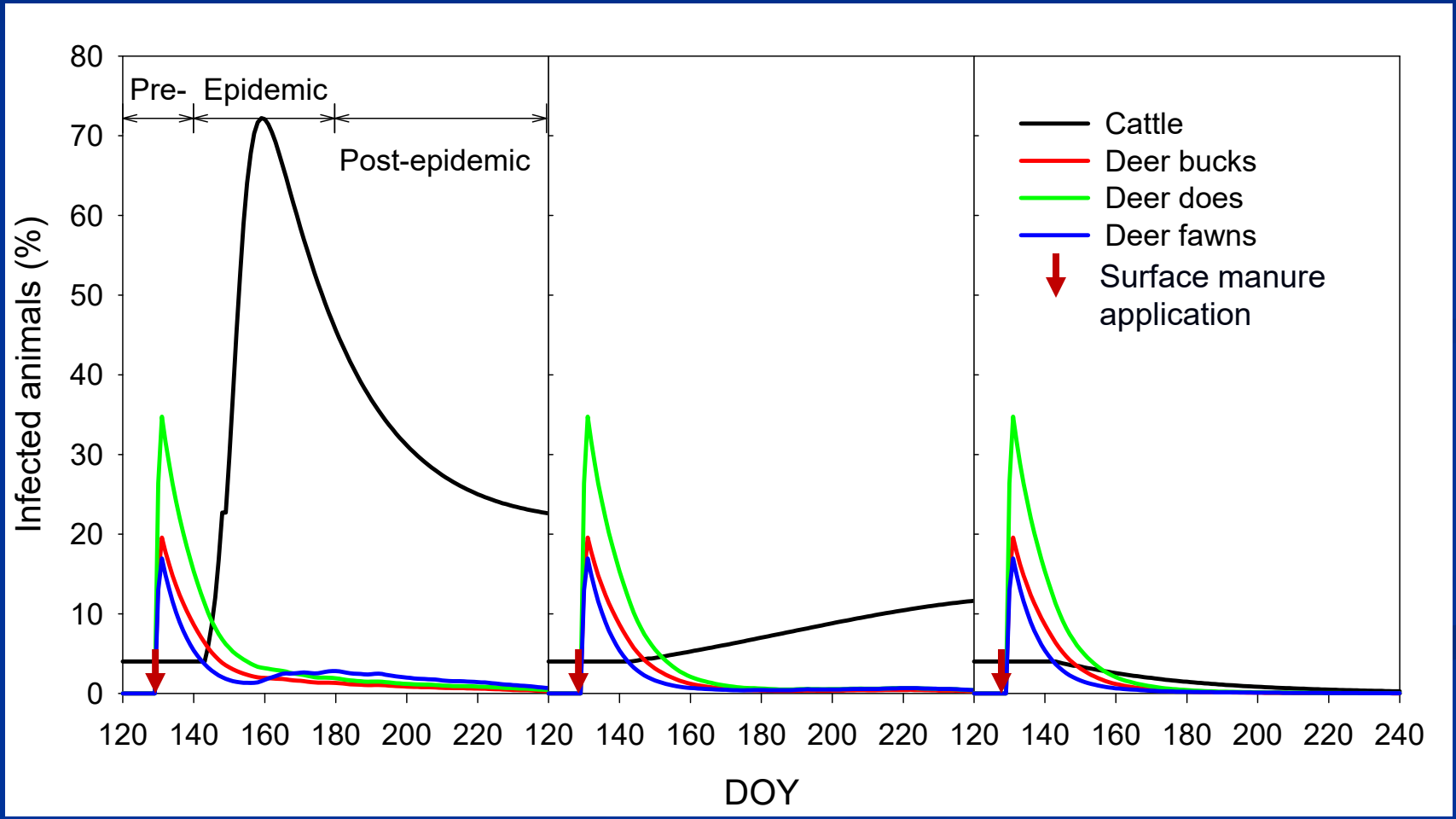


Three infection scenarios for grazing cattle

Epidemic
$D_{50}=10^{8}$ CFU/day

Gradual increase in the number of infected animals
$D_{50}=10^{9}$ CFU/day

Recovery
$D_{50}=10^{10}$ CFU/day



Daily *E.coli* O157:H7 ingestion for the three infection scenarios

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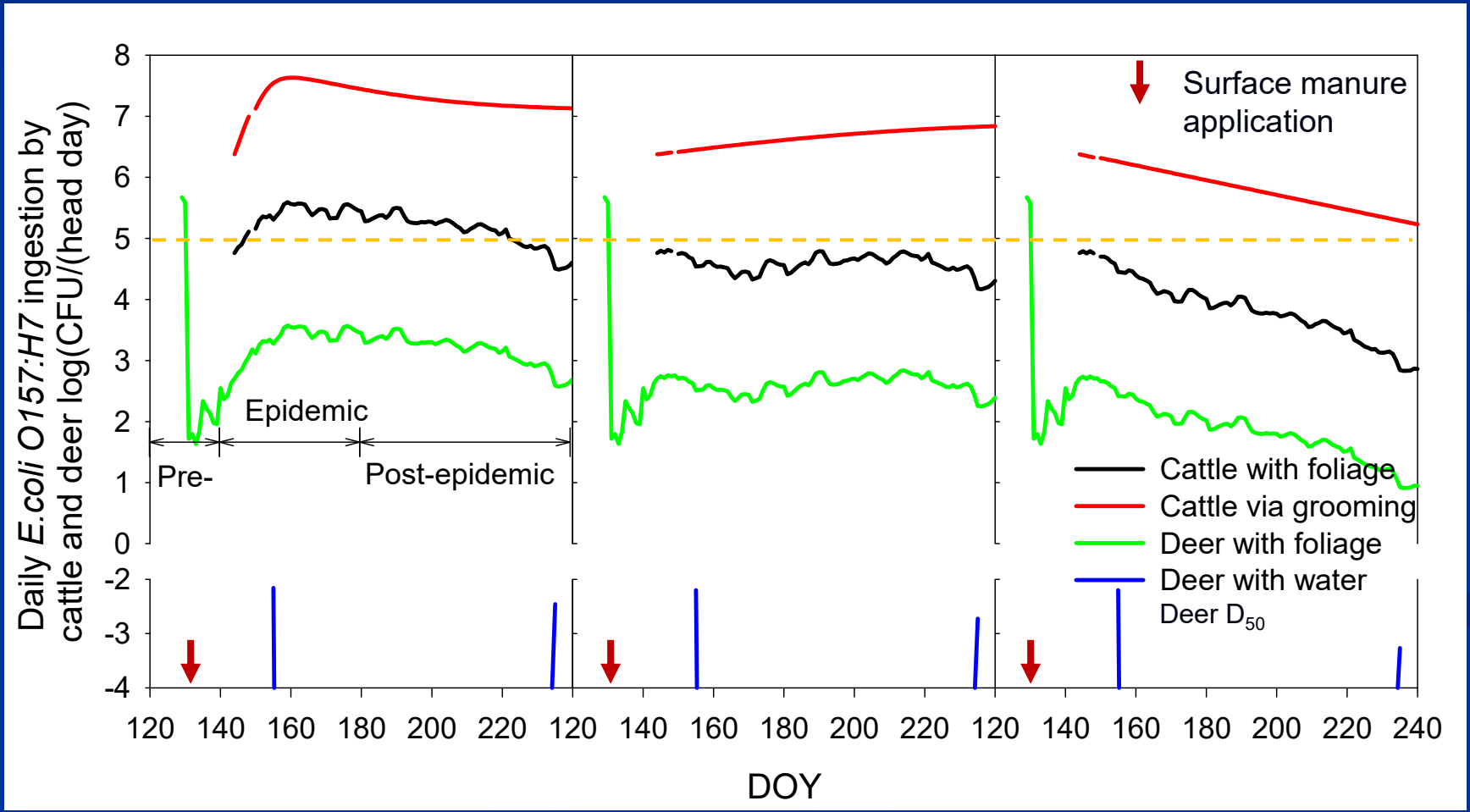

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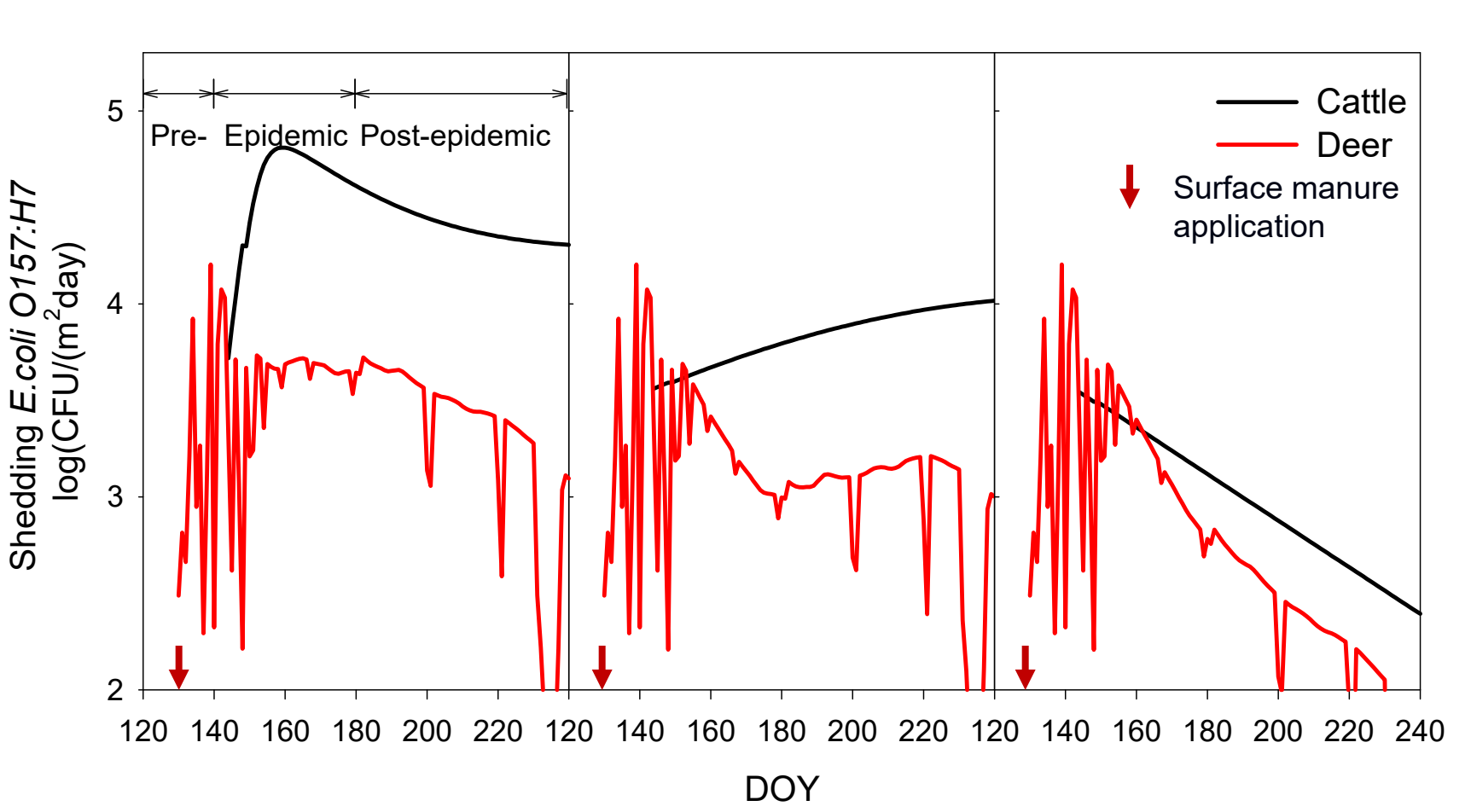
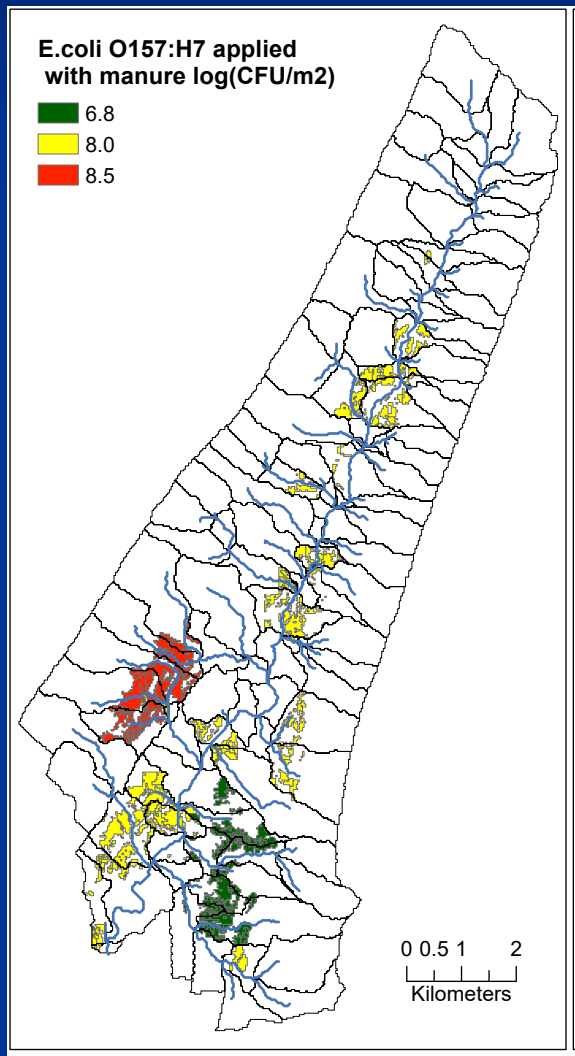
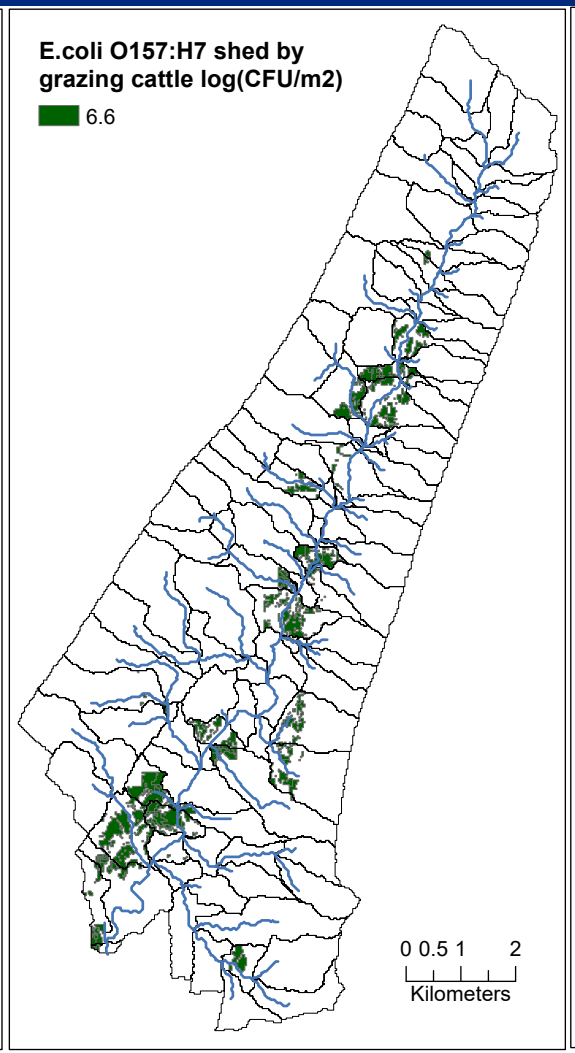


Simulated annual *E.coli* O157:H7 input with manure, cattle and deer fecal material

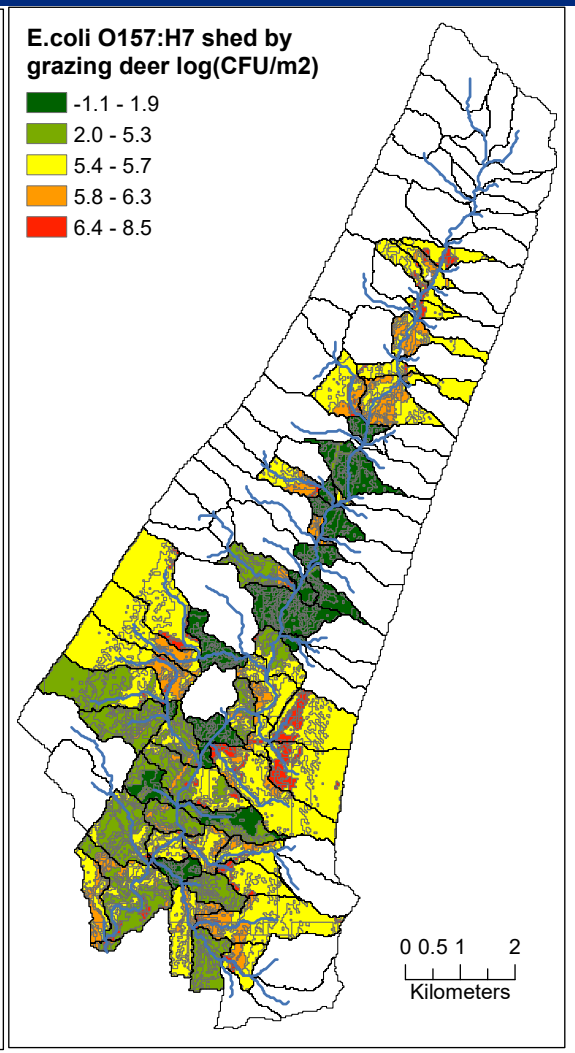
Cattle manure



Grazing cattle

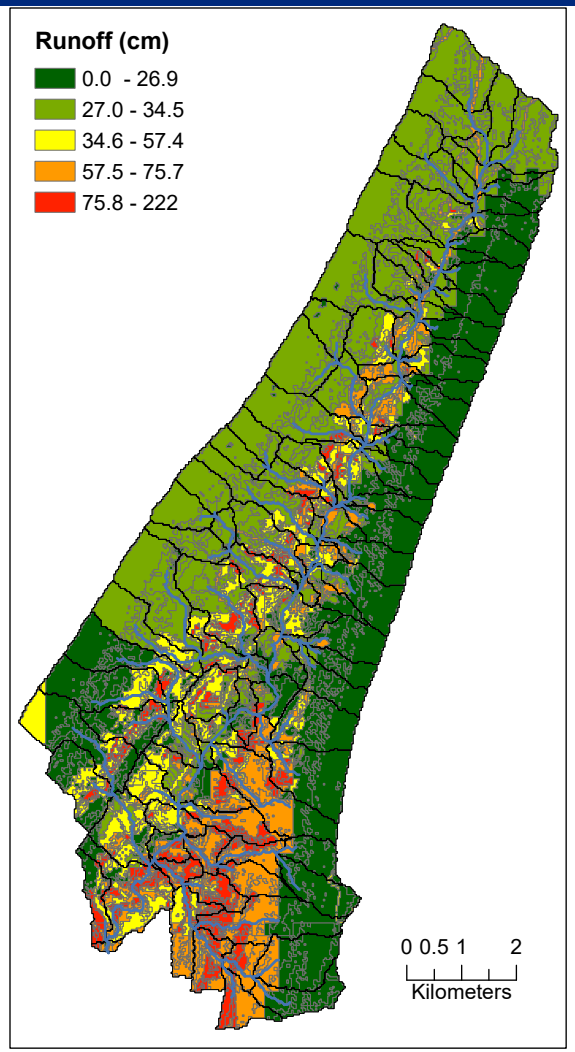


Grazing deer

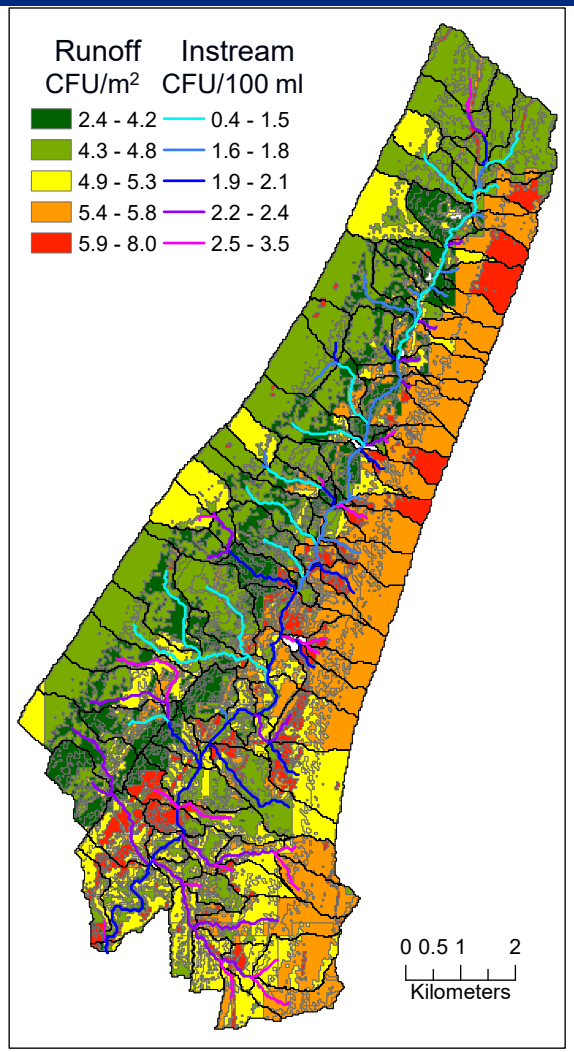


Simulated annual runoff, *E.coli*, and *E.coli* O157:H7 transport from HRUs

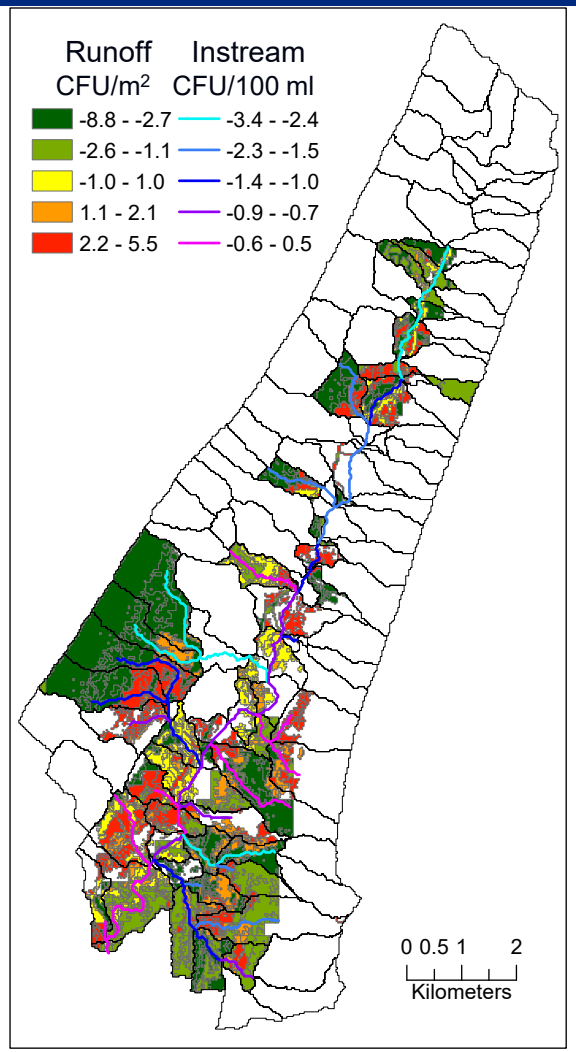
Runoff



E.coli content



E.coli O157:H7 content



Future Development

I. Impact of climate change on pathogen transmission:

- *greater probability of runoff events:* overland transport of pathogens is more probable;
- ***c**hanges in temperature:* pathogen survival;
- *changes in management practice:* wildlife habitat, foliage consumption, temporal and spatial pathogen distribution, pathogen uptake by vector.

II. Contribution of different domestic and wildlife species to the pathogen transmission, e.g. sheep, goats, elks, feral swine, rabbits, buffalo, coyotes etc.

III. Other then *E.coli* O157:H7 pathogenic microorganisms transmitted by wildlife.

IV. Contamination of leafy greens by wildlife.

ACKNOWLEDGMENTS

The work has been supported through the Water Initiative Research Grant "Multimodeling framework for predicting fate and transport of pathogens originated from wildlife and livestock interactions in fragmented agriculture-forest ecosystems" of the *Center for Water Sciences and Environmental Science and Policy Program of Michigan State University*.