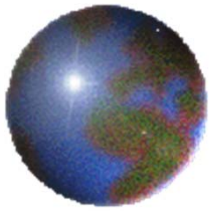

Guinea Worm Ecology Model & Simulation

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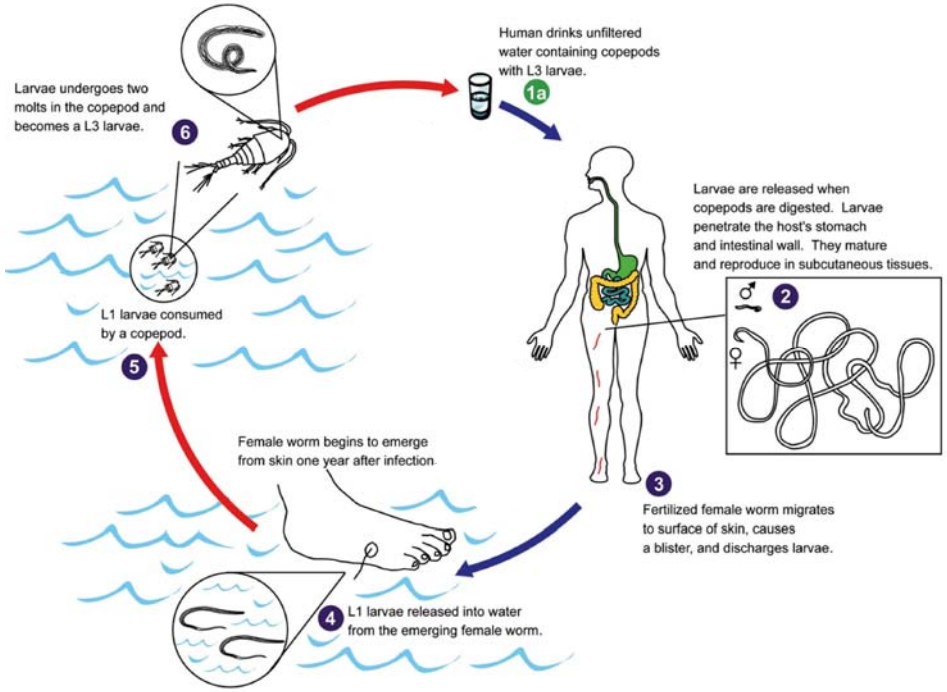
ISE EDWARD P. FITTS DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

Goals

- Goals
  - Assist in understanding Guinea Worm (GW) disease spread in Chad and evaluate the effectiveness of potential interventions
- Approach
  - Agent-based simulation model that tracks the disease spread of GW in dogs
  - Model complex interactions (e.g., humans, dogs, hosts, and water) over multiple years
  - Flexible model that can be fine tuned as more data become available

Example Life Cycle of GW with Paratenic Host



Eberhard et al, "The Peculiar Epidemiology of Dracunculiasis in Chad", Am J Trop Med (2014)

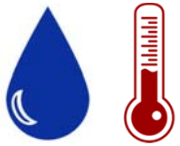
Key Assumptions

- Infections occur through water or paratenic host (e.g., fish, tadpole, frog, lizard)
- Lifetime of host and L3 larvae in host
- Timing of rainy season, link with consumption patterns of water or food, and corresponding infection rate

Disease Modeling

Today's Focus: Timing, Interventions

Worms exuded monthly



Environment (e.g., Rainfall, Temp)

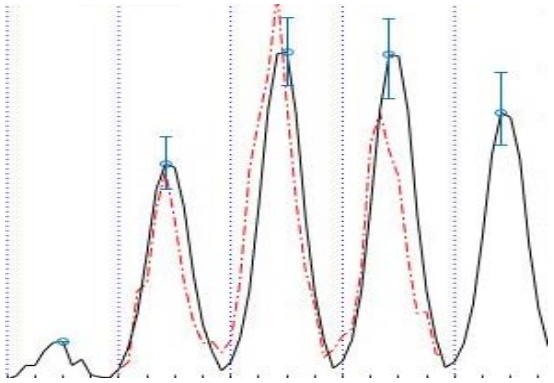
Dog population and behavior

Existing or Potential paratenic hosts

Interventions

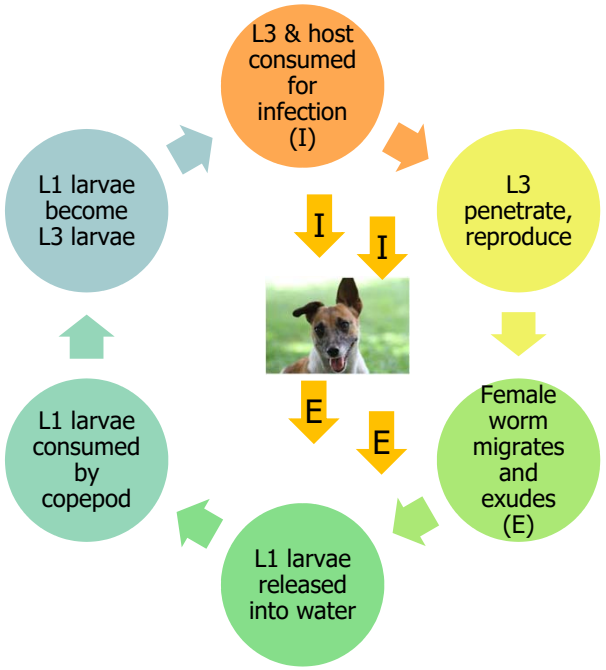
Disease Incubation (e.g., 12 months)

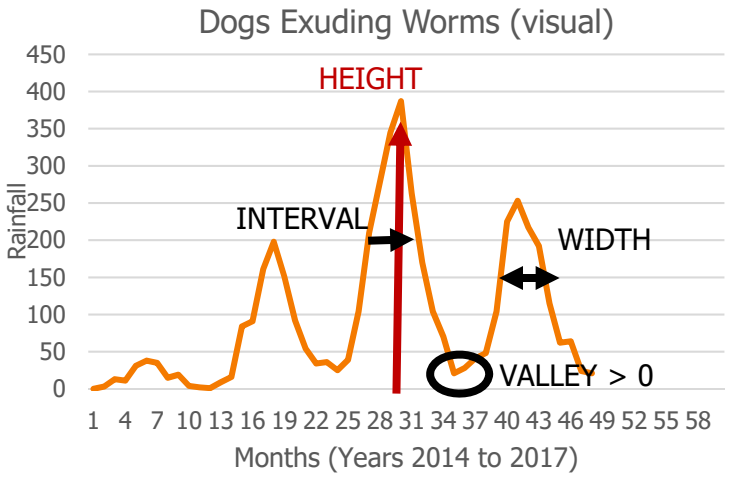
Worms exuded monthly the following year



Experiments

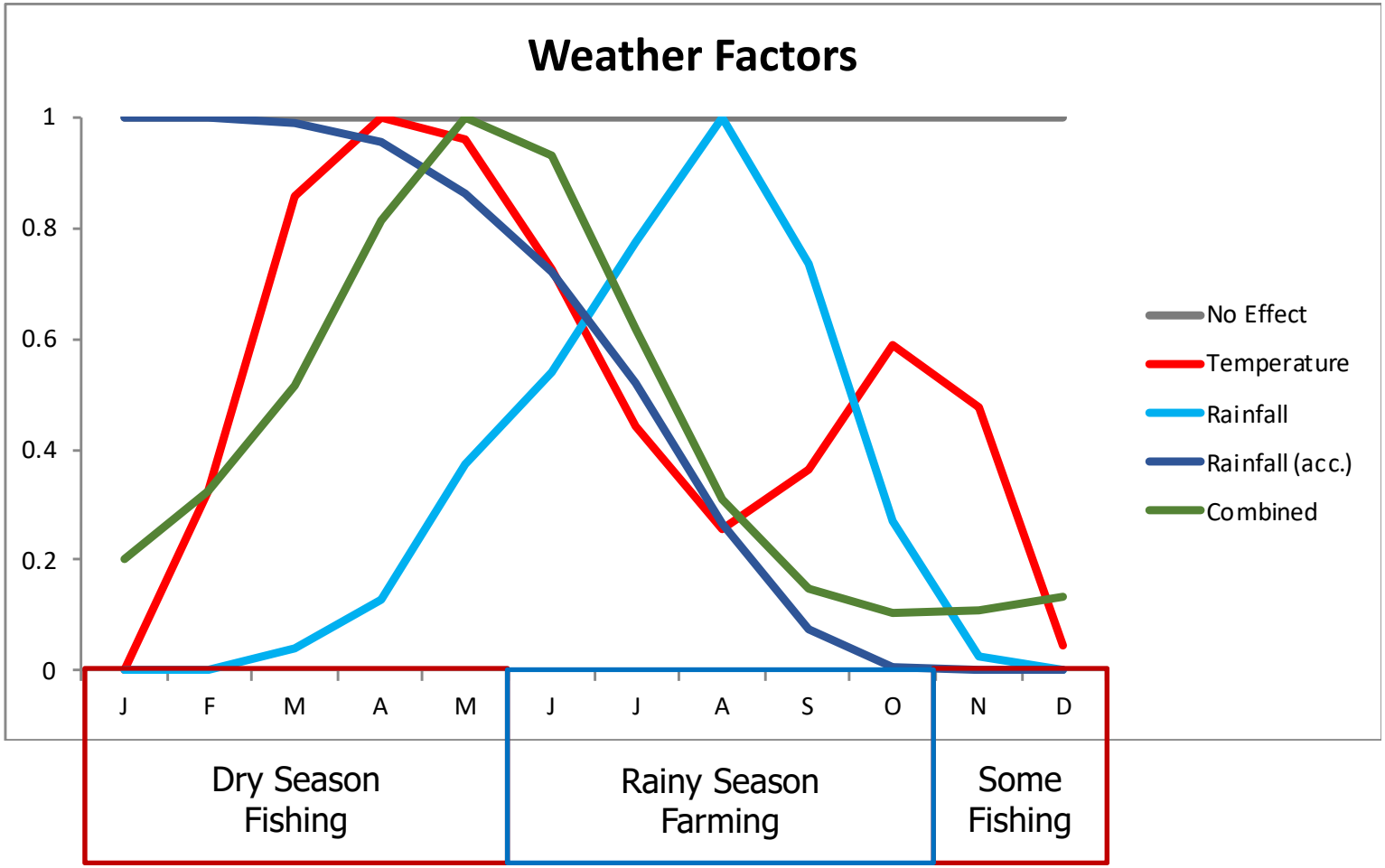
- Model "tracks" lifecycle of larvae and worms and infections of dogs in system
- Experiments explore different parameters and assumptions
  - Timing of high infectivity (e.g., June to Oct)
  - Length of L3 availability (e.g., through paratenic host)
  - Interventions (ABATE, tethering, other)
  - Hundreds to thousands of computational experiments (so far)
- Results are compared to Chad data (dogs) from 2014 to 2017
  - Weighted Mean Squared Error (WMSE) is an important quantification





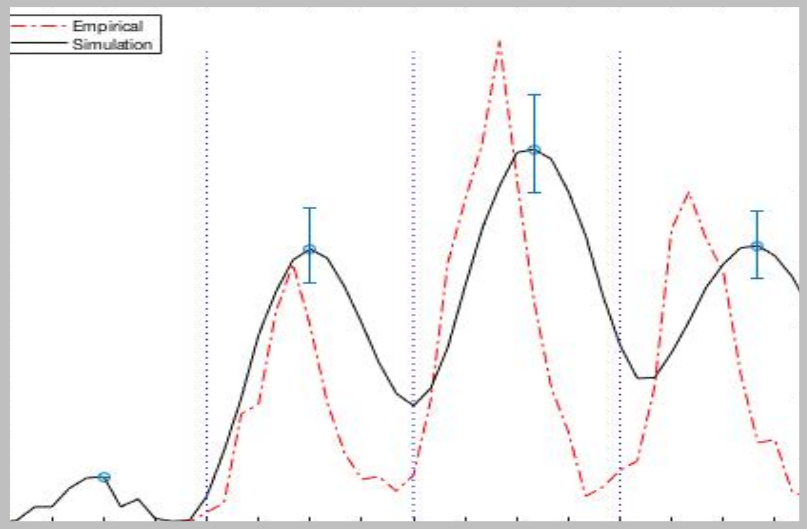
Seasonality & Environmental Factors

Hypothetical Environmental Factors affecting High Infectivity Periods

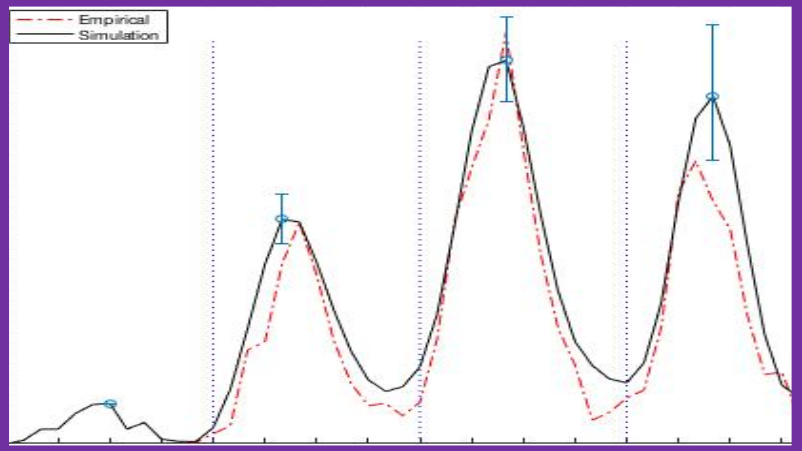


Model Fit (Examples)

No Seasonality (WMSE = 1069.88)

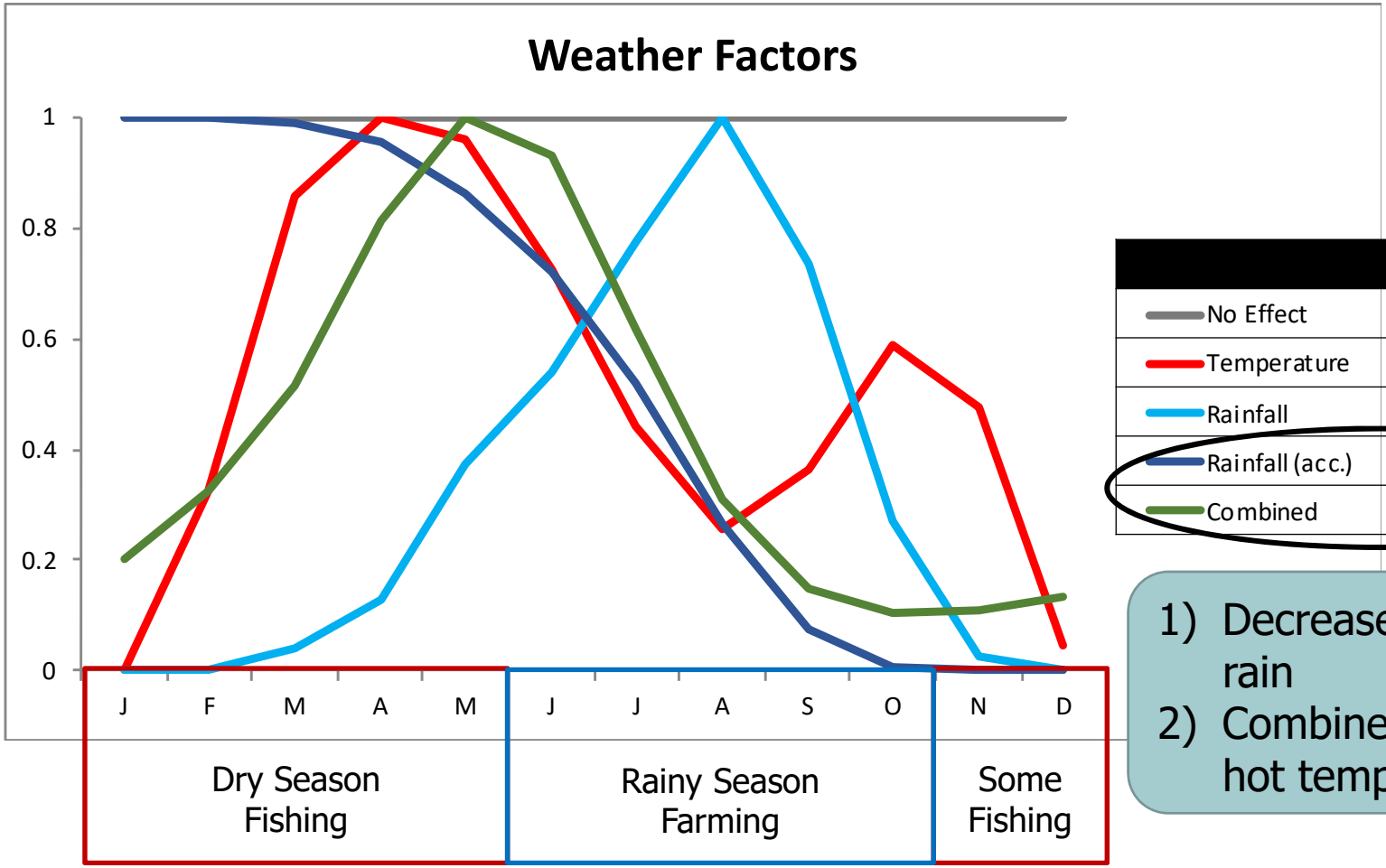


Combined (WMSE = 444.68)



Conclusion: Seasonality of infections is driven by more than just the life cycle. Infectivity is high (or low) in particular time periods.

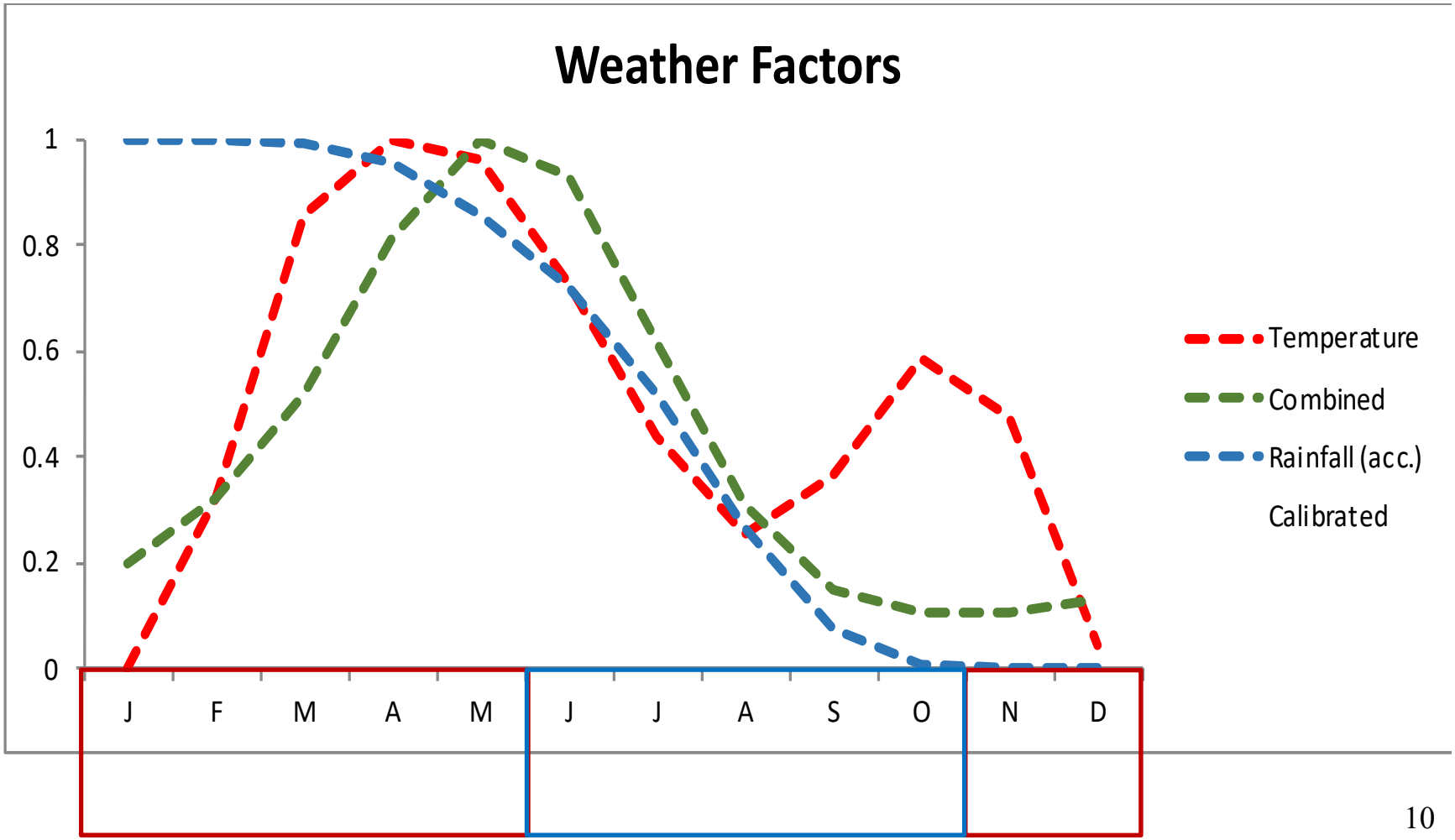
Hypothetical Environmental Factors affecting Seasonality of Infections



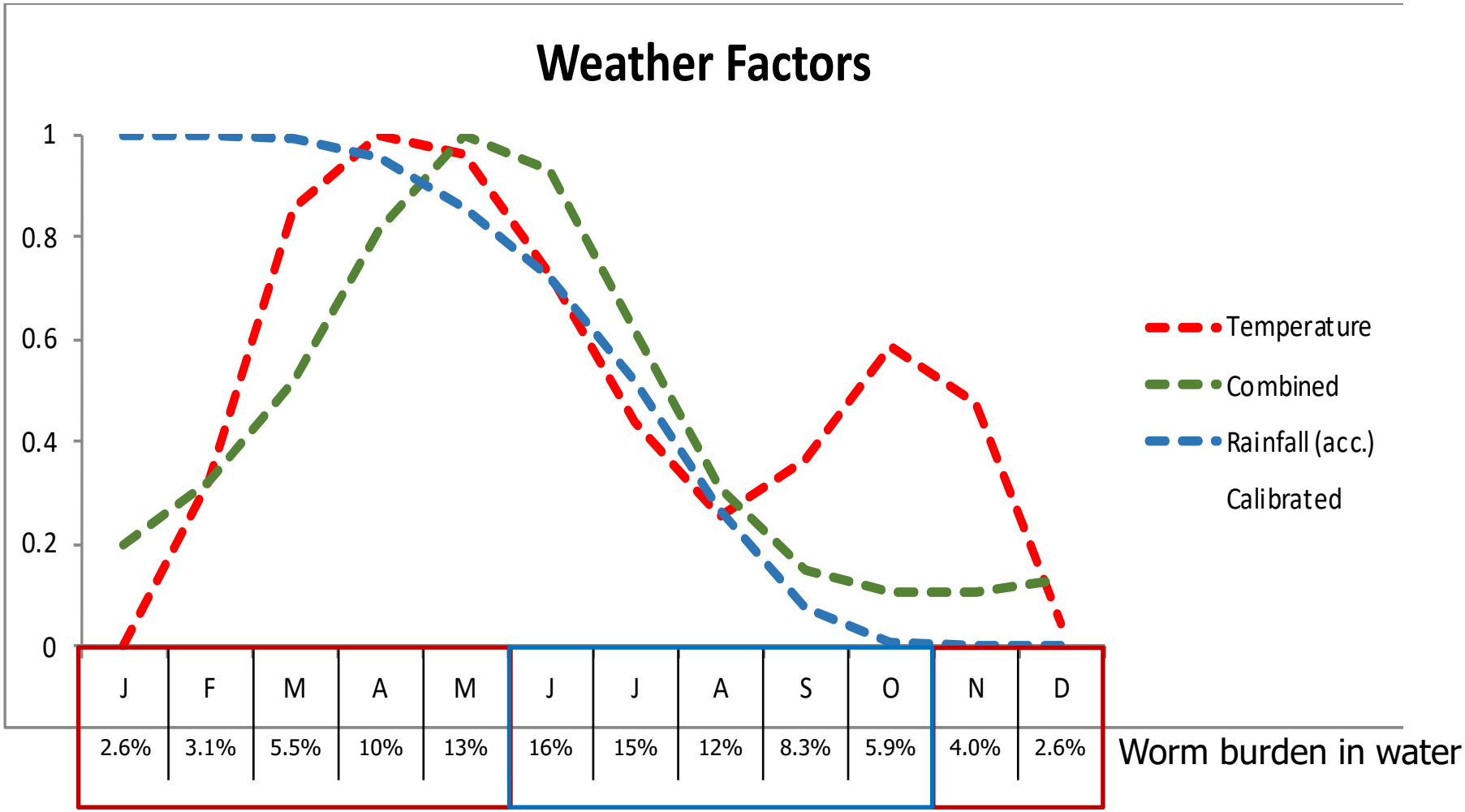
	Weighted MSE
No Effect	1069.88
Temperature	620.35
Rainfall	1259.65
Rainfall (acc.)	538.52
Combined	**444.68**

1) Decreases with more rain
2) Combined includes hot temperature

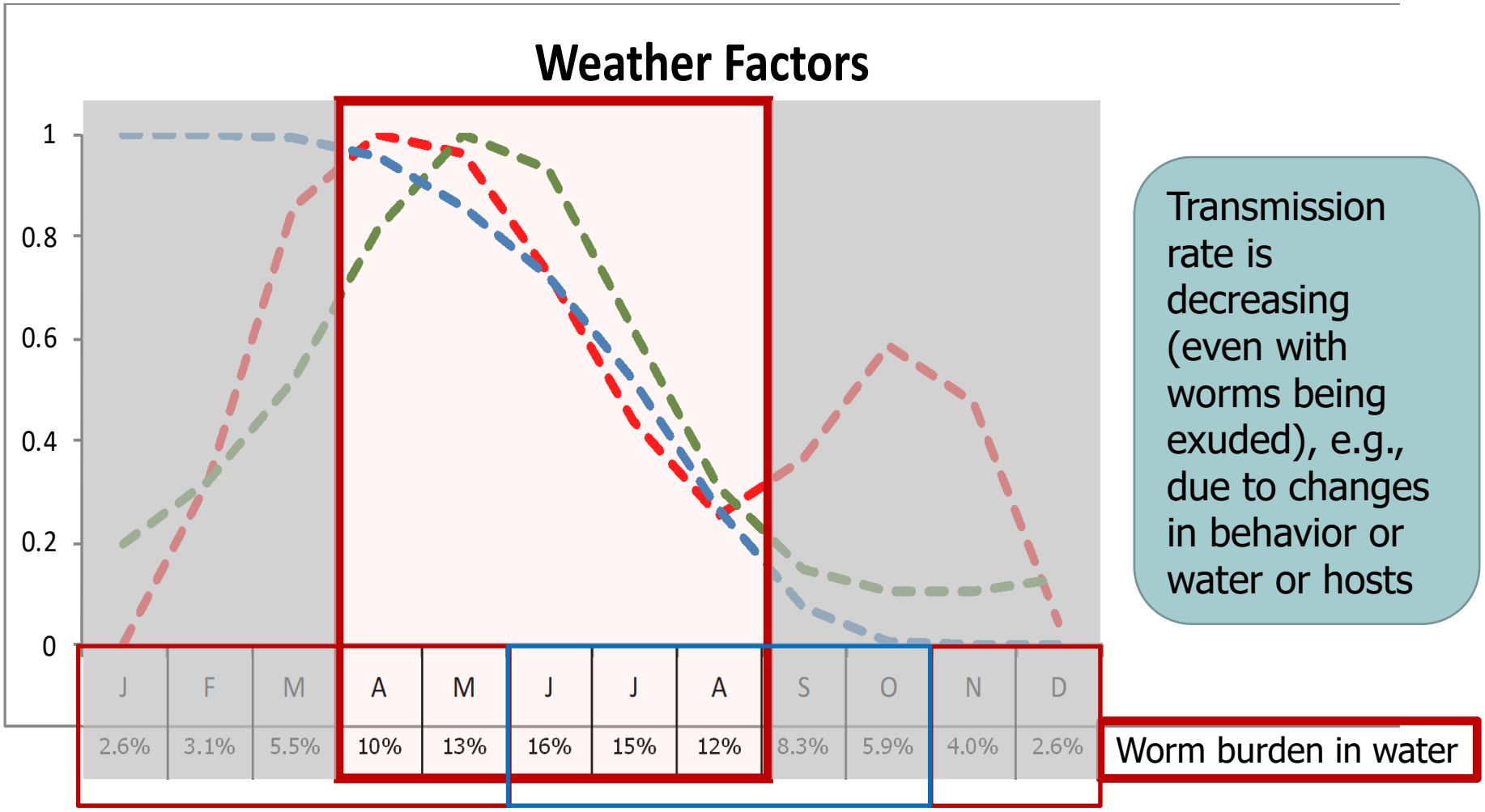
Calibrated Select Environmental Factors



Calibrated Environmental Factor



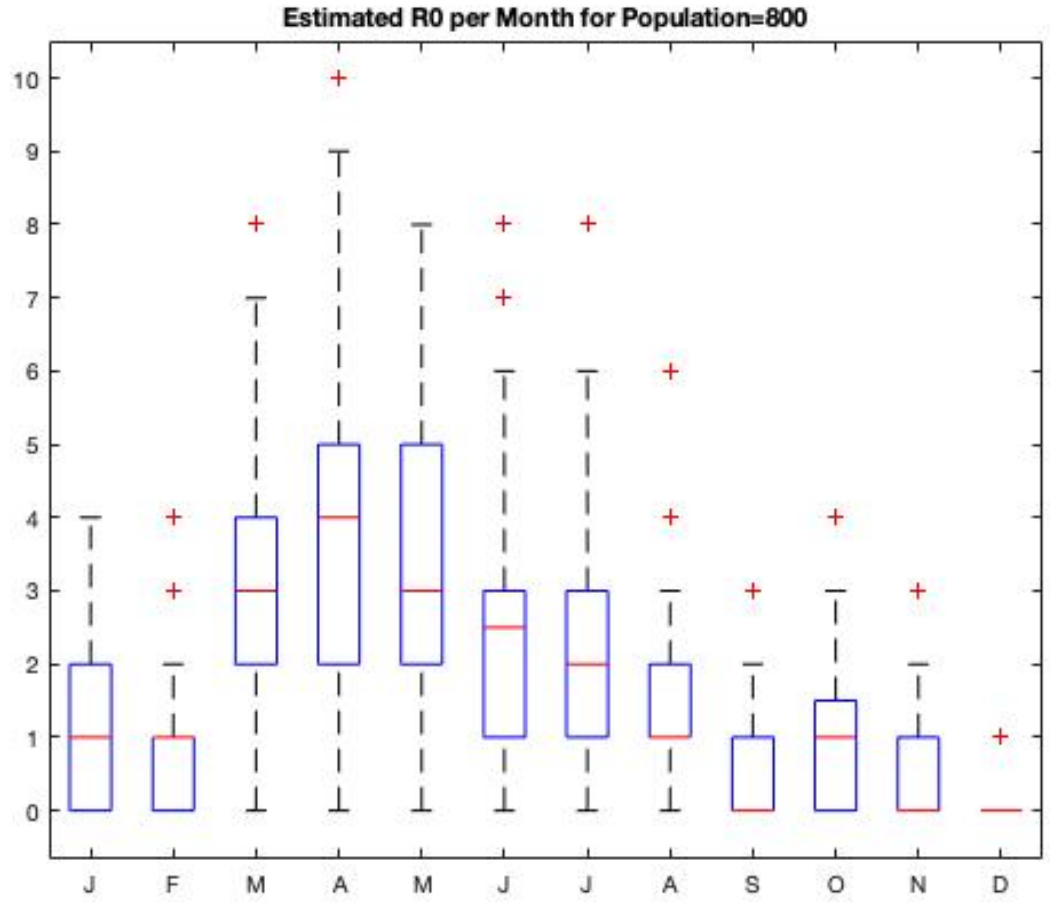
Calibrated Select Environmental Factors



Transmission rate is decreasing (even with worms being exuded), e.g., due to changes in behavior or water or hosts

68% of the worm burden between April-August. Also when the "good" environmental factors are most similar.

Estimates of reproductive rate vary with time

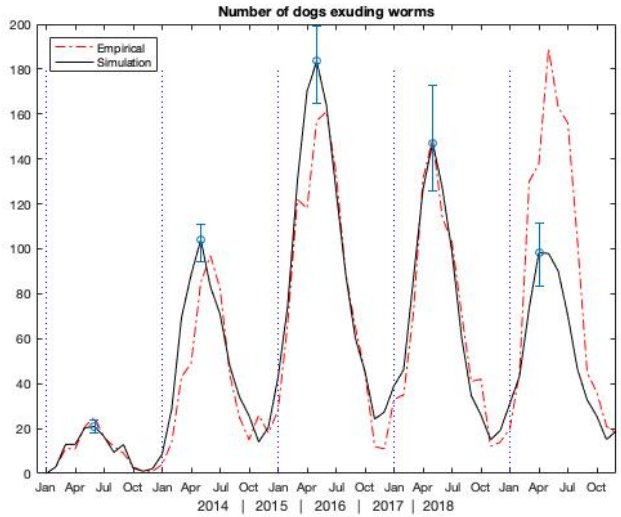


1 infected dog may result in 0 new infections or 4 to 10 new infections.

In the peak infectivity time periods or large villages, 1 infected dog is likely to infect more dogs.

Infections in 2018 (Increase)

- Greater surveillance in-country
- Gap between reported intervention and "effective" intervention
  - E.g., 40% less tethering or 30% less effective tethering and ABATE
- Impact from earlier peak in rainfall in 2017?



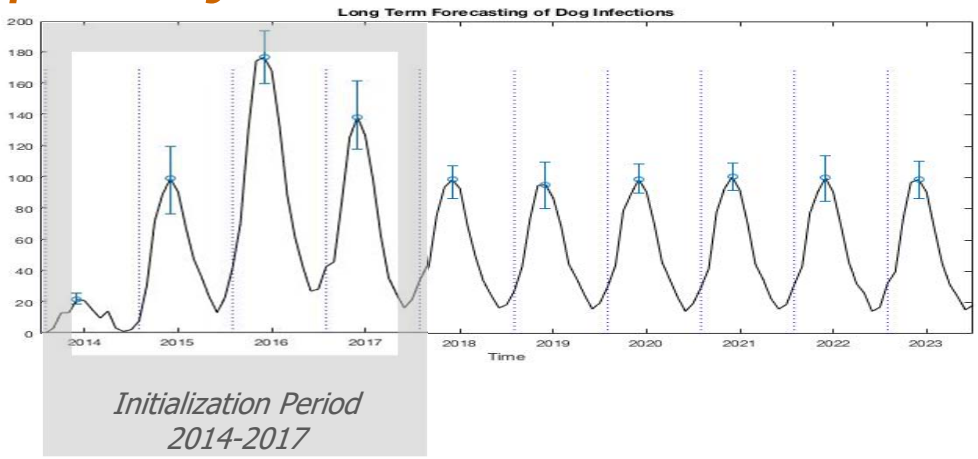
Predicting Future Years

"It's tough to make predictions, especially about the future". (Yogi Berra)

Intervention What-If Analysis

- BASELINE
  - Infections continue

ABATE	*Tether*	*Other*
40%	76%	17%

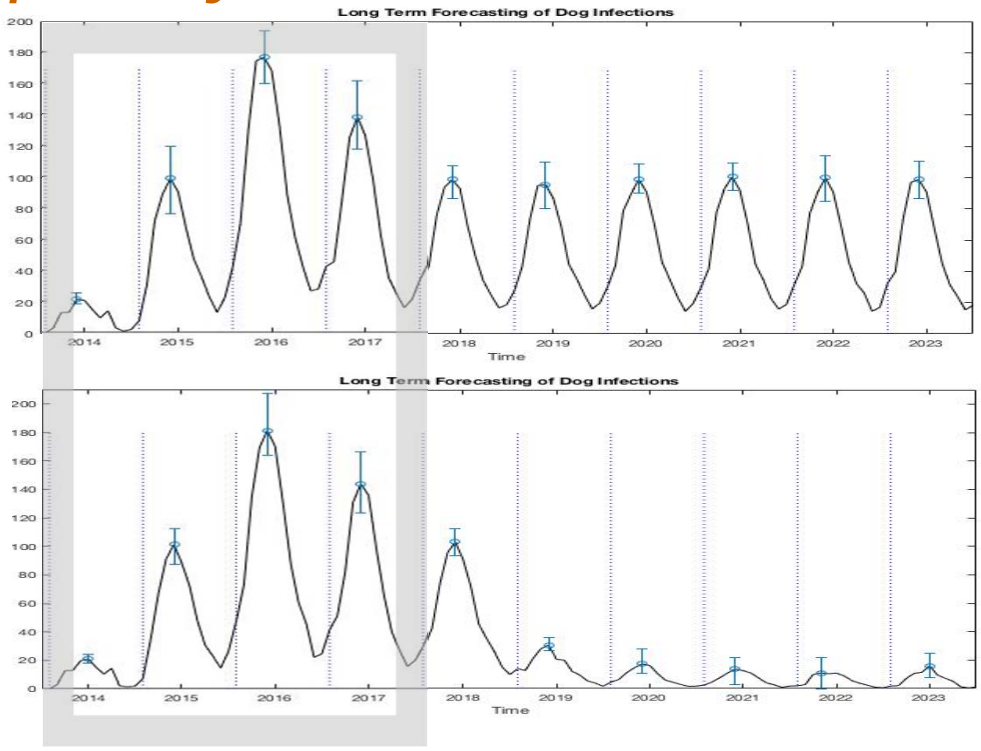


Initialization Period 2014-2017

Intervention What-If Analysis

- BASELINE
  - Infections continue
- INCREASE interventions significantly
  - Infections decrease

ABATE	*Tether*	*Other*
40%	76%	17%
70%	95%	17%

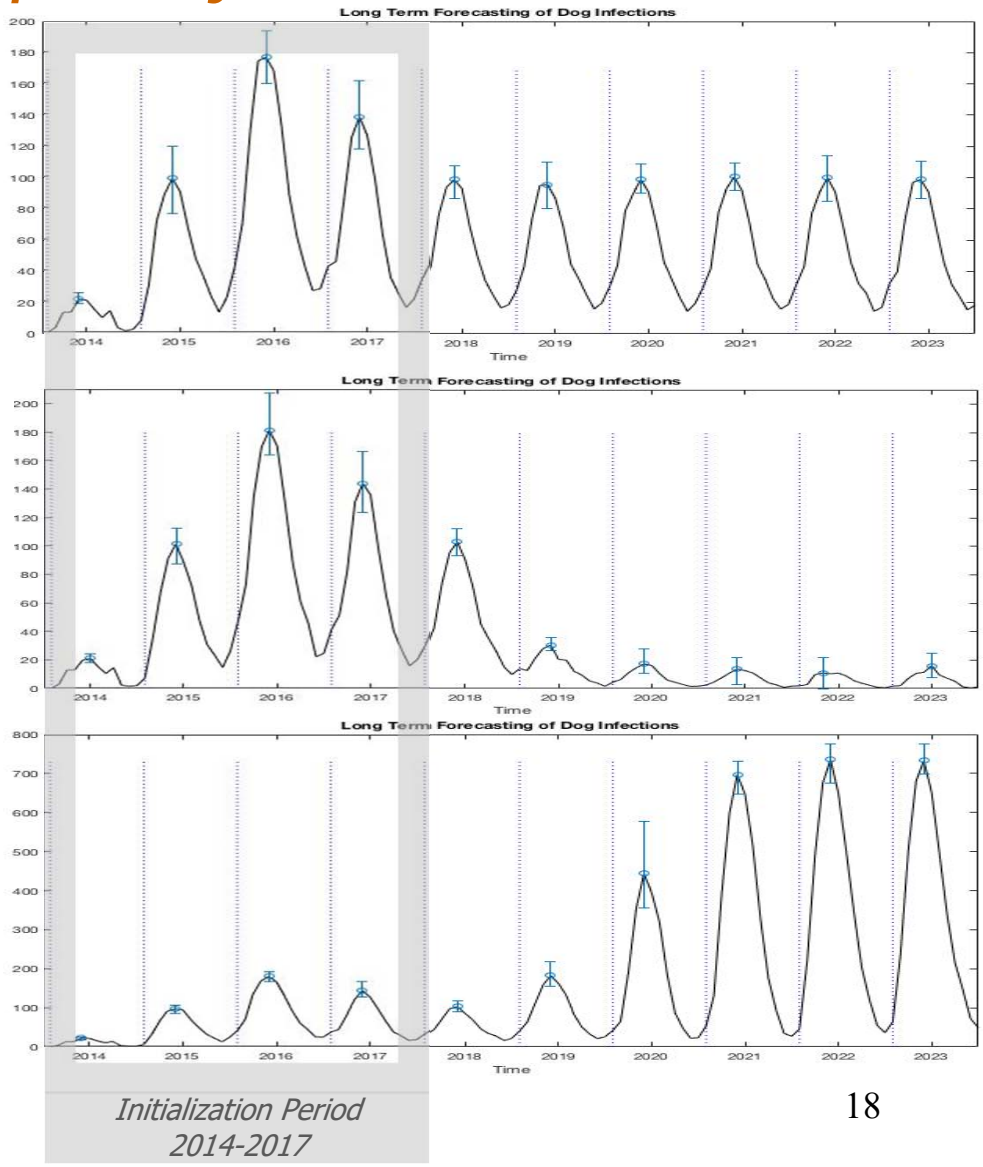


Initialization Period 2014-2017

Intervention What-If Analysis

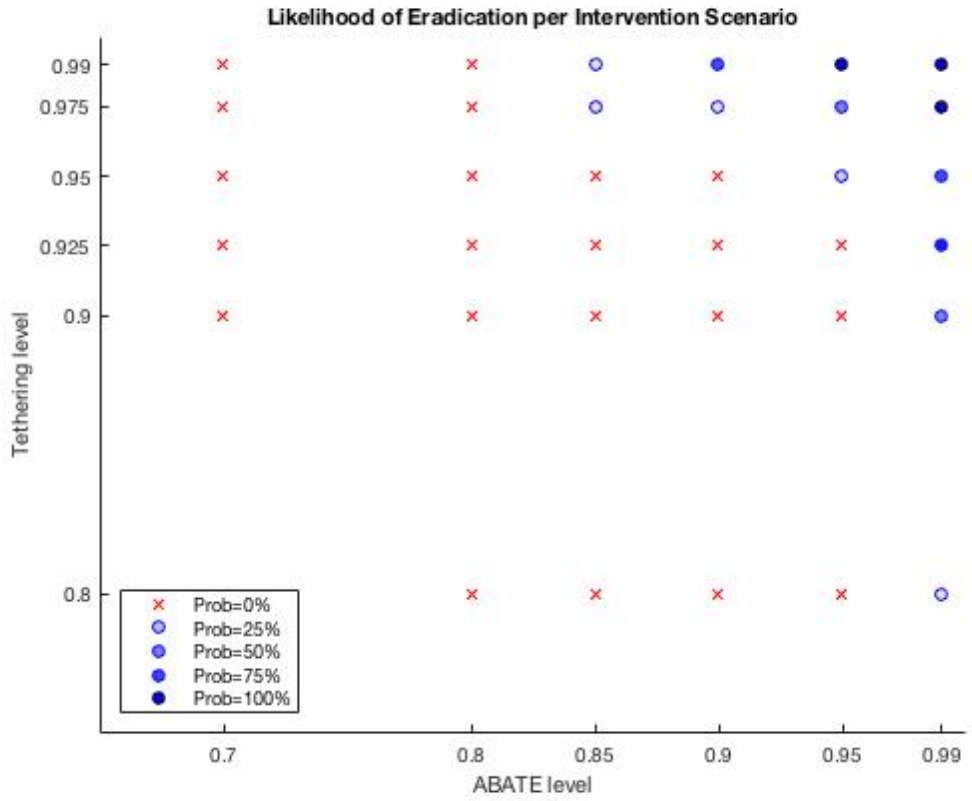
- BASELINE
  - Infections continue
- INCREASE interventions significantly
  - Infections decrease
- DECREASE interventions significantly
  - Infections explode

ABATE	*Tether*	*Other*
40%	76%	17%
70%	95%	17%
20%	50%	17%



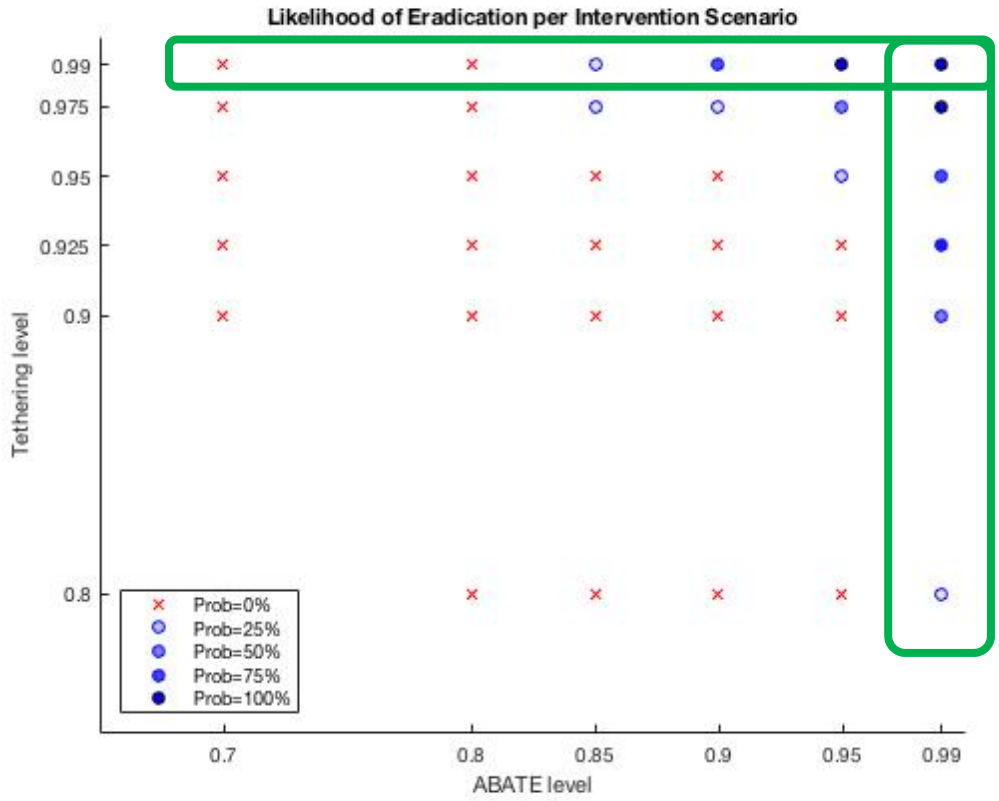
What might be needed for eradication within 10 years?

When comparing various levels of ABATE & Tethering coverage, we can identify the few combinations that are likely to eradicate within 10 years. 99% coverage is understandably impractical.



Likelihood of eradication within 10 years

When comparing various levels of ABATE & Tethering coverage, we can identify the few combinations that are likely to eradicate within 10 years. 99% coverage is understandably impractical.

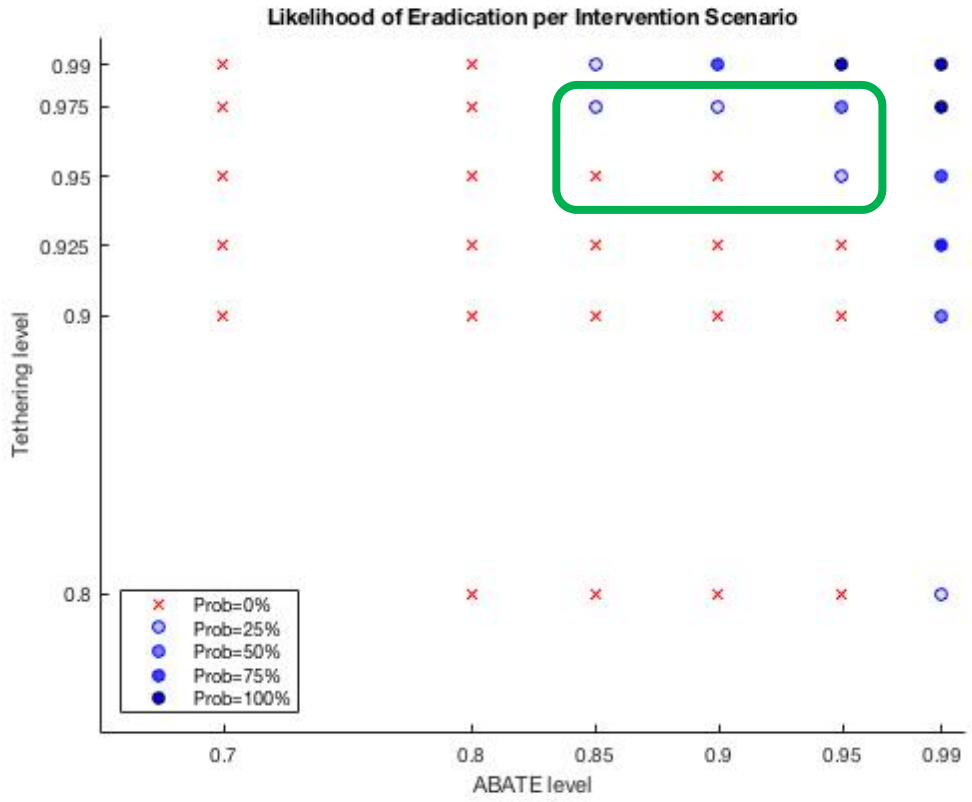


When ABATE is at its highest level, all 6 scenarios reach eradication.

When Tethering is at its highest level, only 4 out of 6 scenarios reach eradication.

Likelihood of eradication within 10 years

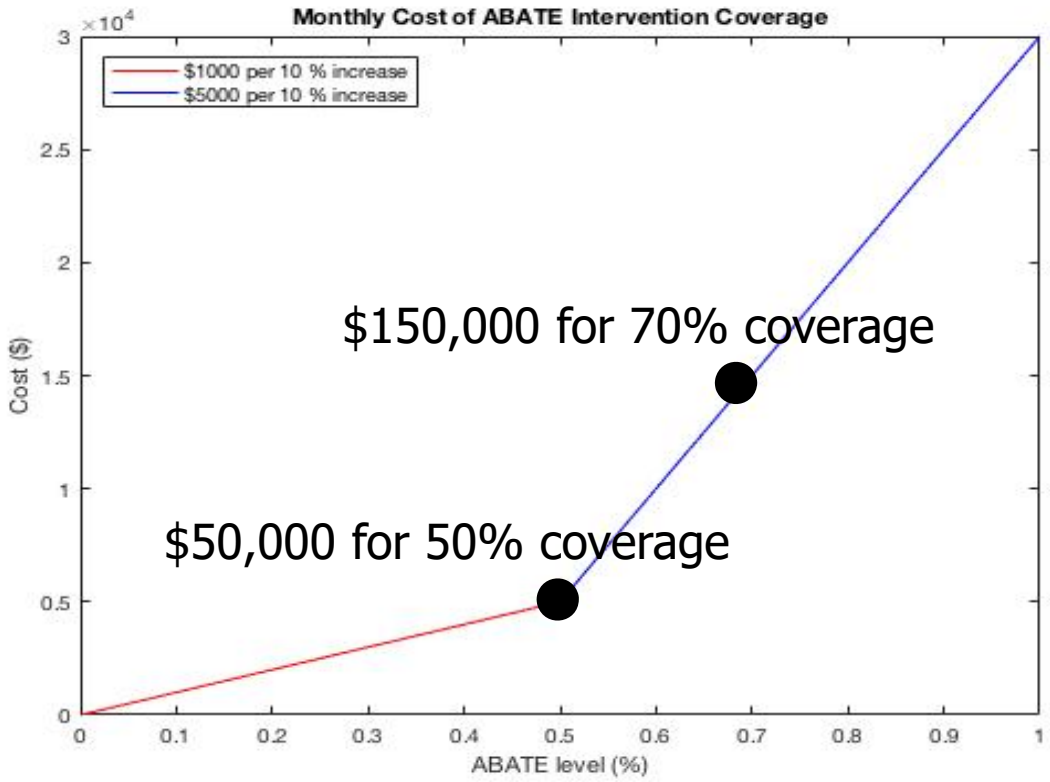
When comparing various levels of ABATE & Tethering coverage, we can identify the few combinations that are likely to eradicate within 10 years. 99% coverage is understandably impractical.



Few practical combinations where Tethering ≥ 95% And ABATE ≥ 85%

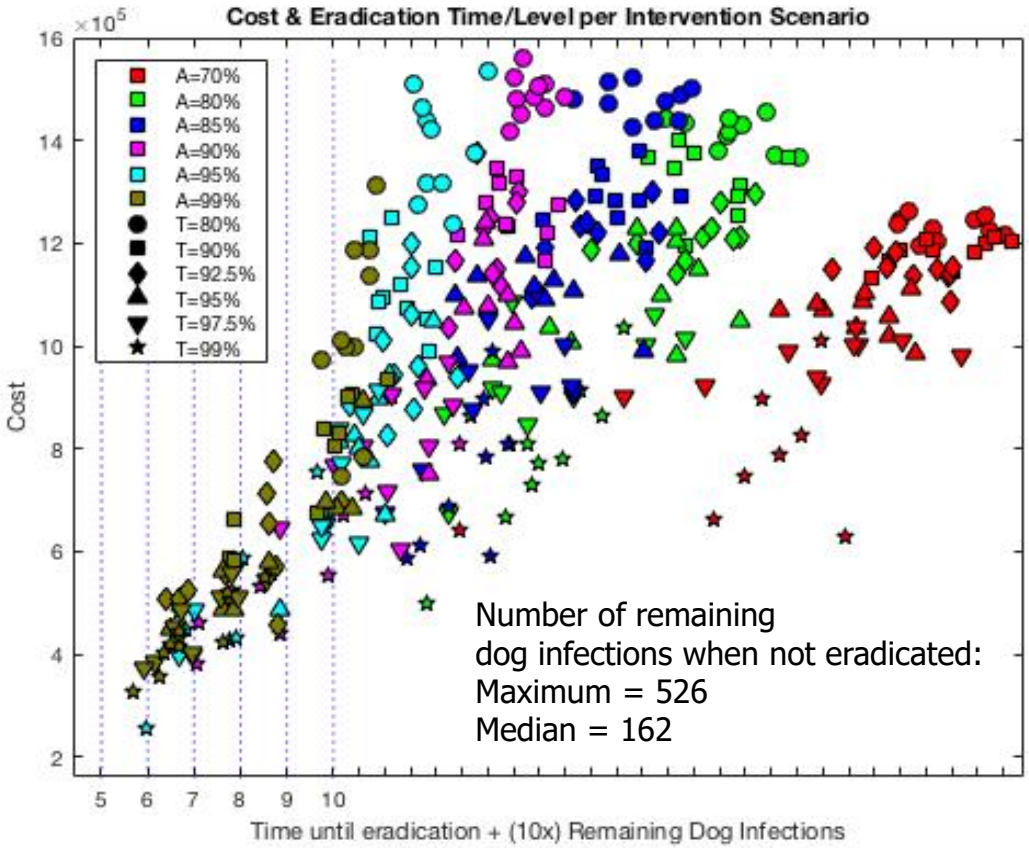
Cost-benefit analysis of interventions

By incorporating the costs of each intervention, we can do cost-benefit analysis. We have assumed tethering costs $100 per dog, and the cost of ABATE is piecewise linear along the following graph:



Cost-benefit analysis of interventions

When comparing the practical combinations, we can observe big picture patterns about the strengths of increasing ABATE vs. tethering coverage.



Cost-benefit analysis of interventions

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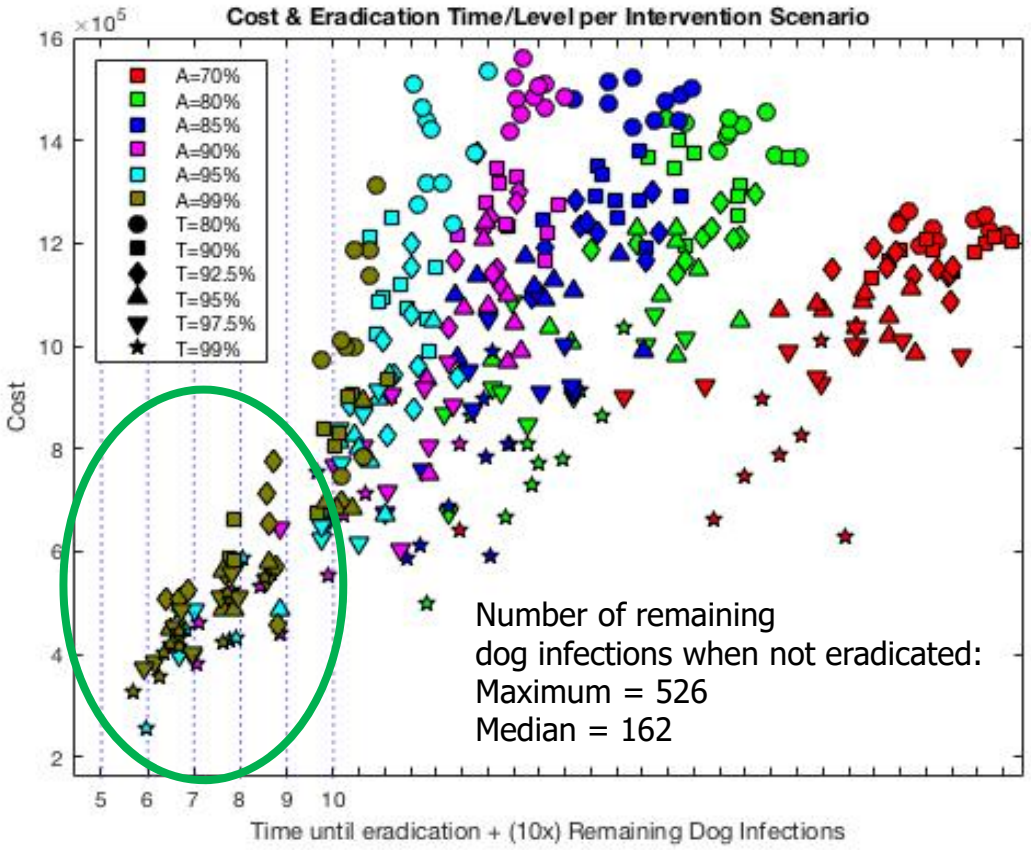
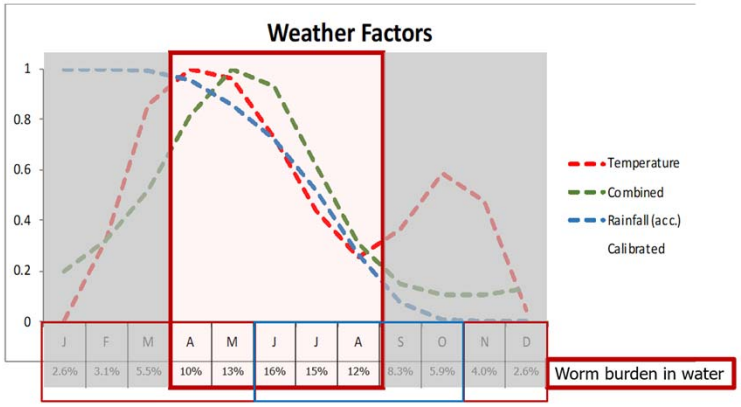


- Eradication will take time
- Least-costly solutions in the long-term are those that invest at highest levels immediately

Current Conclusions

- Timing of infectivity (and worm burden) is important to understanding causes and effective interventions
  - E.g., Shallow pools or tadpoles or fish entrails
  - E.g., Providing dogs water to drink, burying, tethering (possibly proactively)



- Eradication may take years
  - Early, full-level interventions are ultimately cheaper

- Continue current interventions while trying others
  - "Contain cases" and "Clean water"
  - Proactive tethering and providing dogs water to drink could also keep them away from shallow pools, especially during high infectivity periods

Contact Information

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