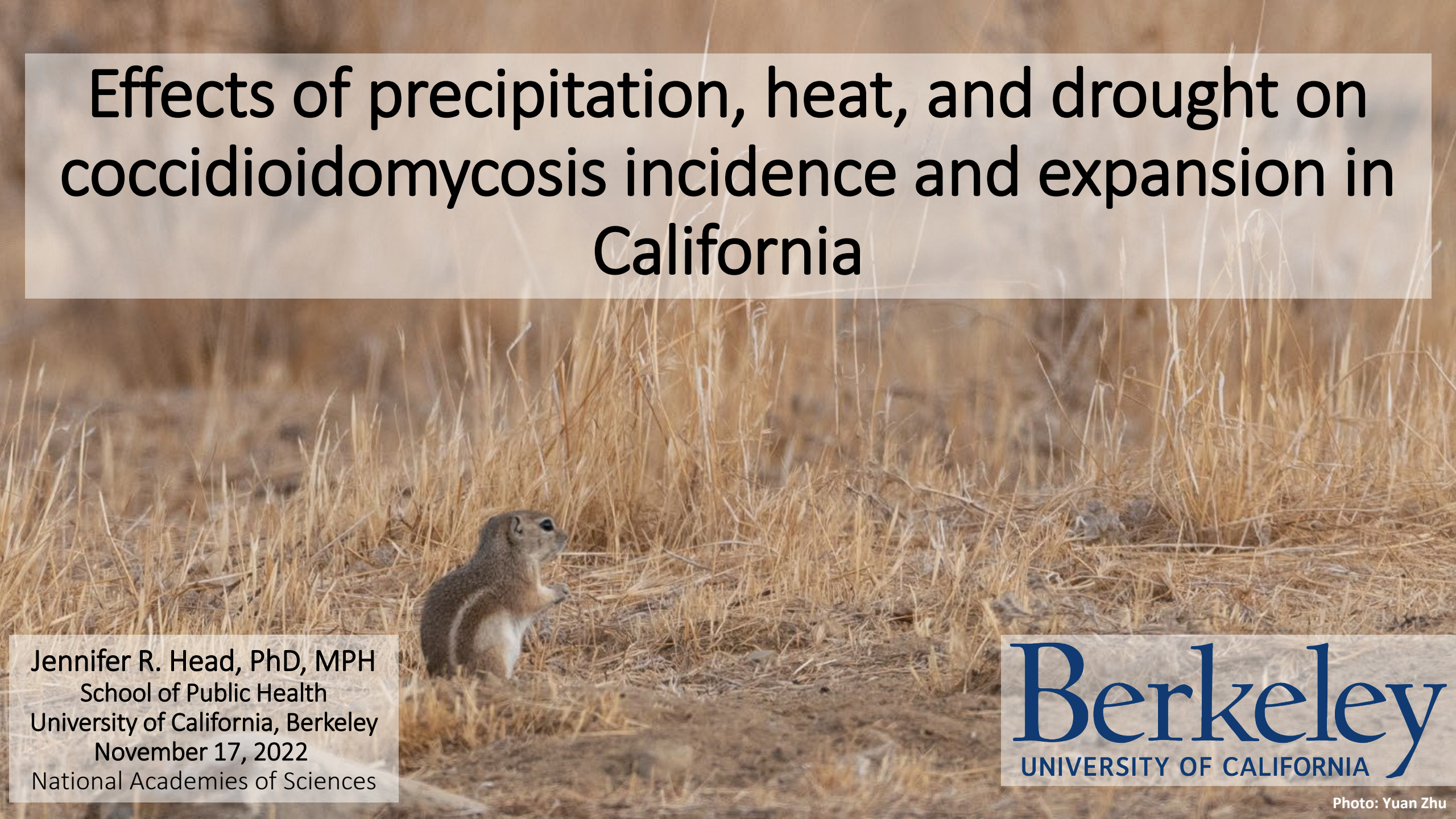
Effects of precipitation, heat, and drought on coccidioidomycosis incidence and expansion in California

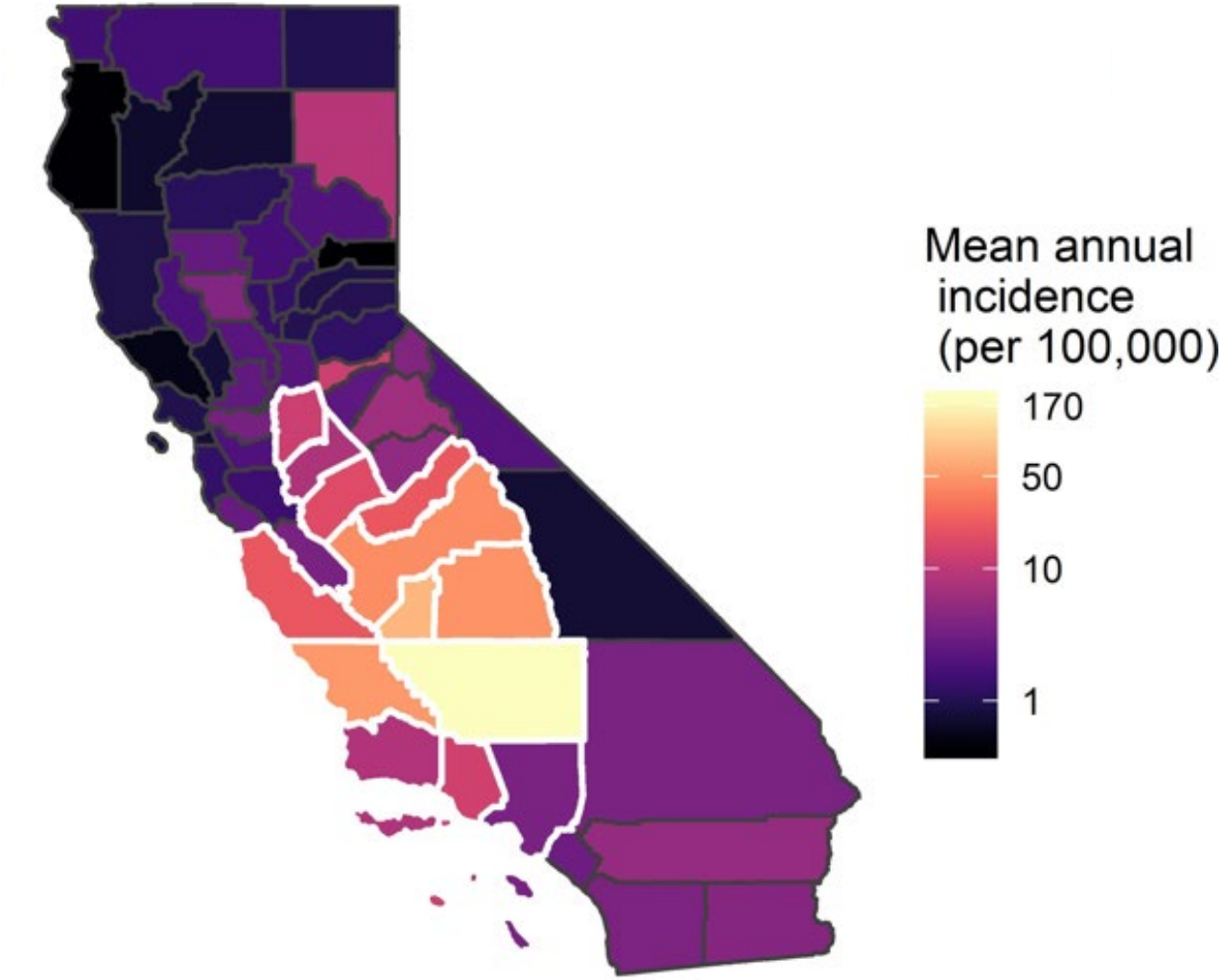


Jennifer R. Head, PhD, MPH
School of Public Health
University of California, Berkeley
November 17, 2022
National Academies of Sciences

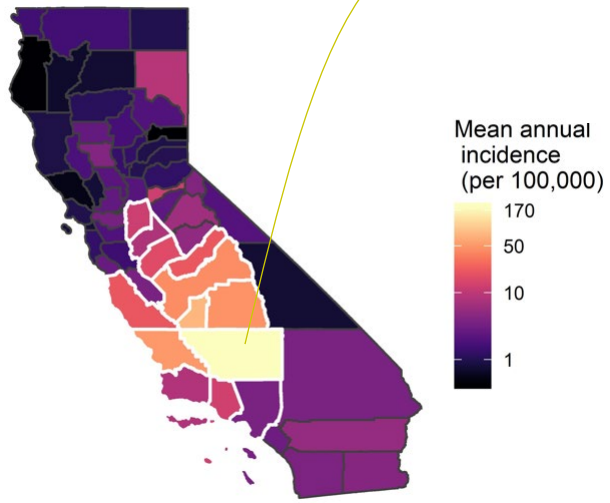
Berkeley
UNIVERSITY OF CALIFORNIA

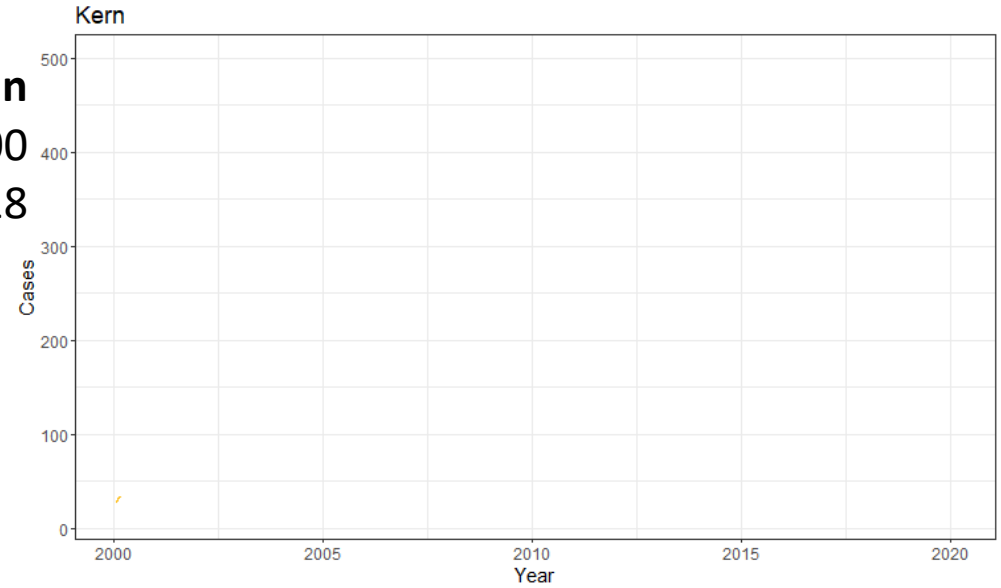
Photo: Yuan Zhu

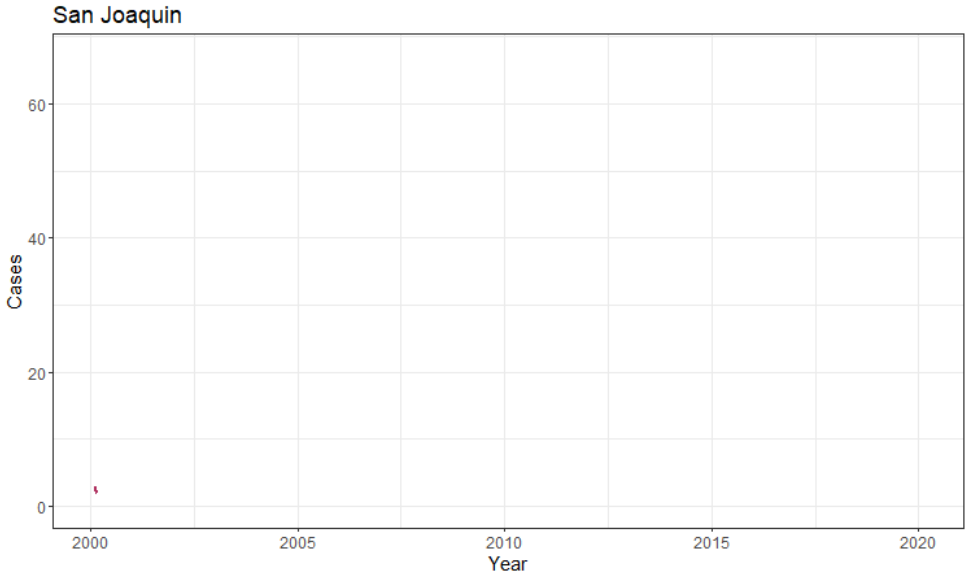
Incidence of infection with *C. immitis* is highest in the lower San Joaquin Valley, which is relatively dry and hot



Increases of **>8-fold in incidence** between 2000 and 2018

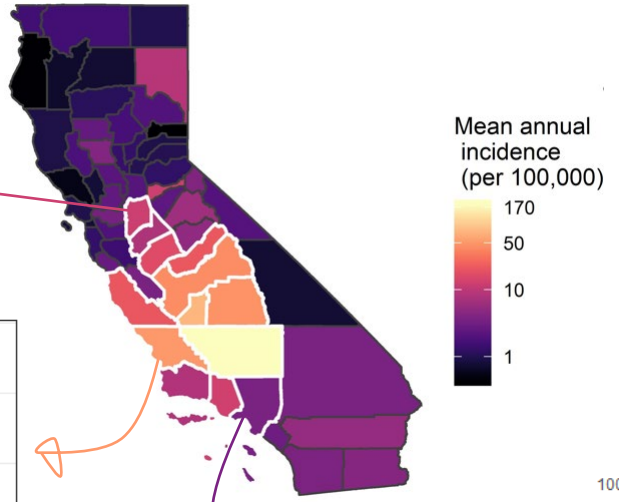


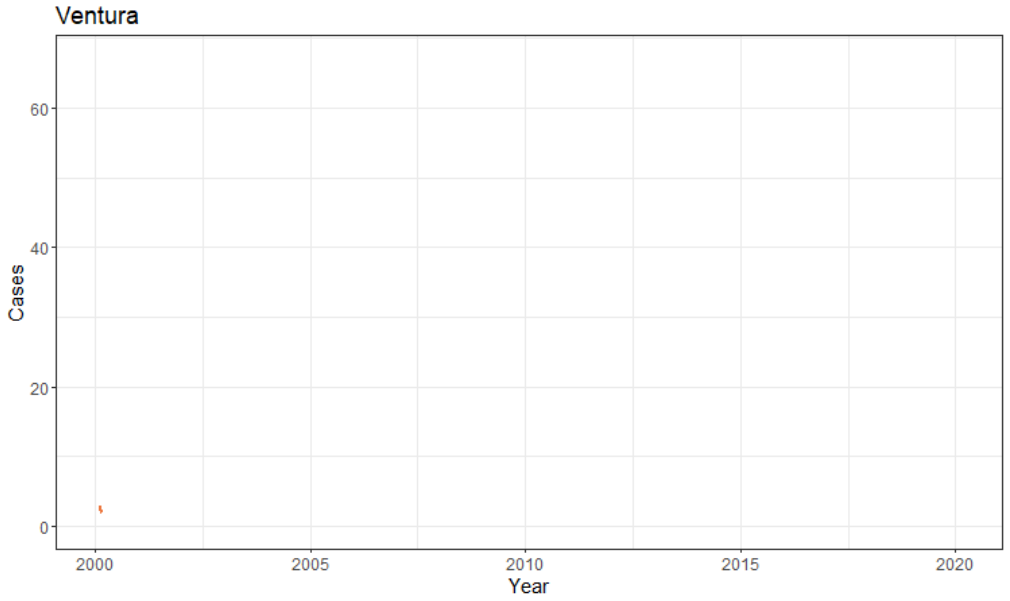


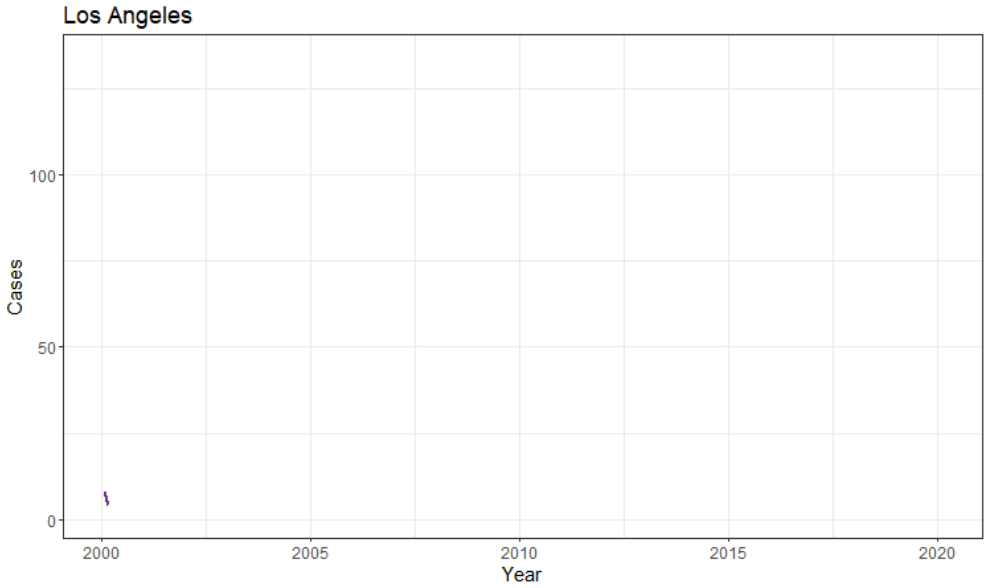


Incidence is increasing fastest in areas that are not uniformly hot and dry

Increases of **>15-fold in incidence** between 2000 and 2018







Increasing incidence comes amidst unprecedented megadrought

nature climate change

BRIEF COMMUNICATION

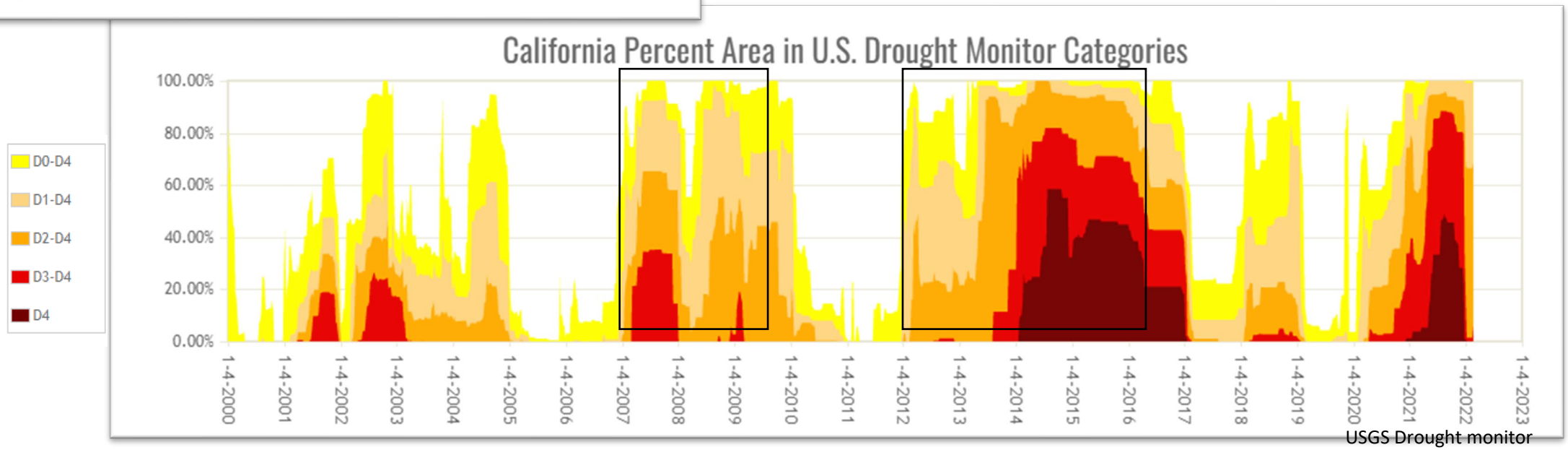
https://doi.org/10.1038/s41558-022-01290-z

Check for updates

Rapid intensification of the emerging southwestern North American megadrought in 2020–2021

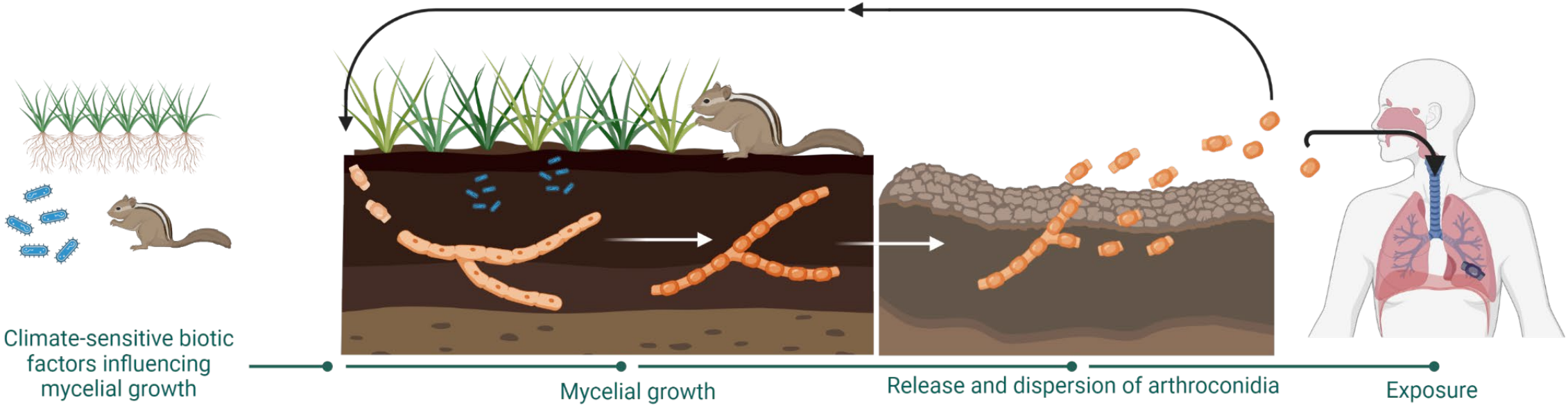
A. Park Williams[1,2] ✉, Benjamin I. Cook[2,3] and Jason E. Smerdon[2]

California is experiencing the driest 22-year period since 800 CE

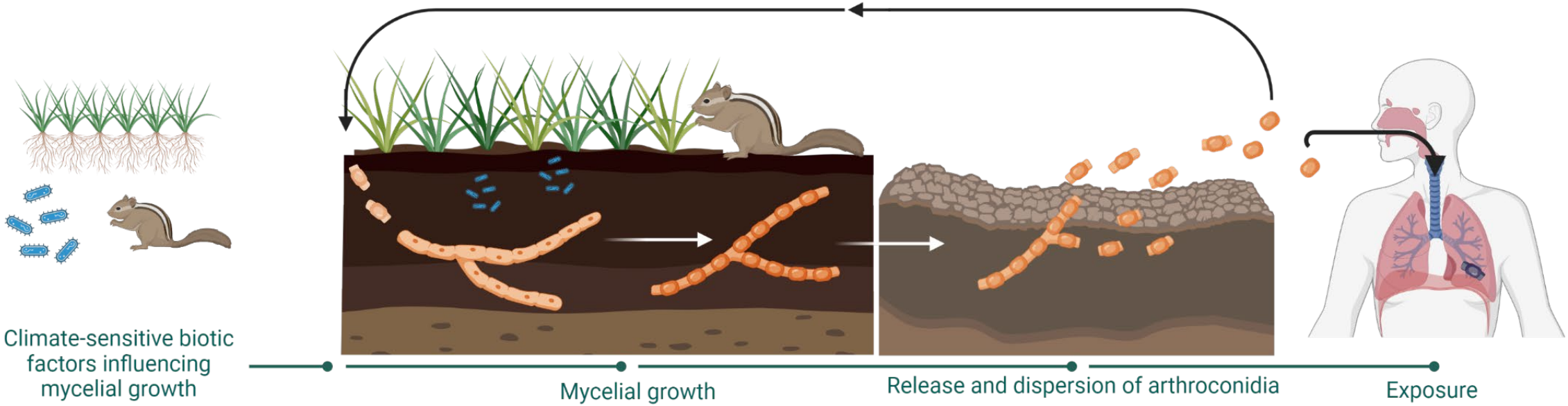


USGS Drought monitor

Climate affects *Coccidioides* growth and dispersion differently by time lags

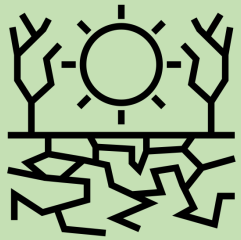


What is the effect of precipitation, temperature, and drought at each stage of the lifecycle?



Objectives:

1. Determine how prior sequences of **temperature** and **precipitation** affect incidence and compare effects across regions



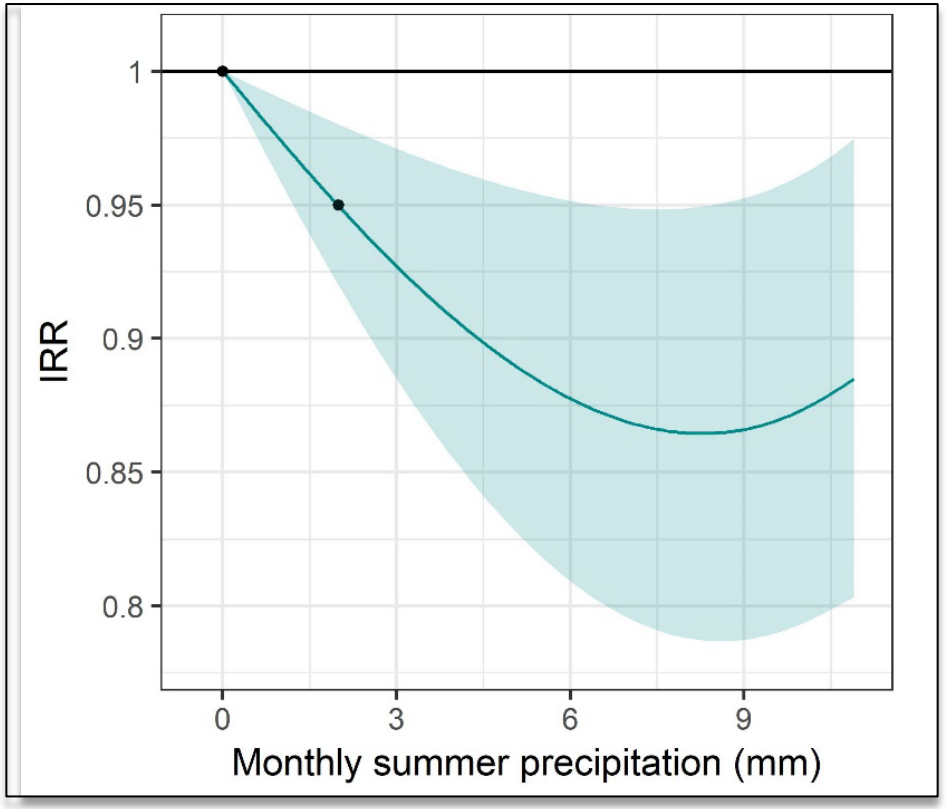
2. Determine **causal effect** of the **2007-2009** and **2012-2015 droughts** on incidence and compare effect across regions

1. Determine how prior sequences of **temperature** and **precipitation** affect incidence and compare effects across regions

Method: Meta-analysis of distributed-lag nonlinear models

Distributed lag nonlinear modeling approach

1) Linked census tract-level cases between Sept – Nov to environmental data lagged 1-36 mo
2) For each county, regressed cases against lagged temperature, precipitation, using splines to capture non-linear relationships

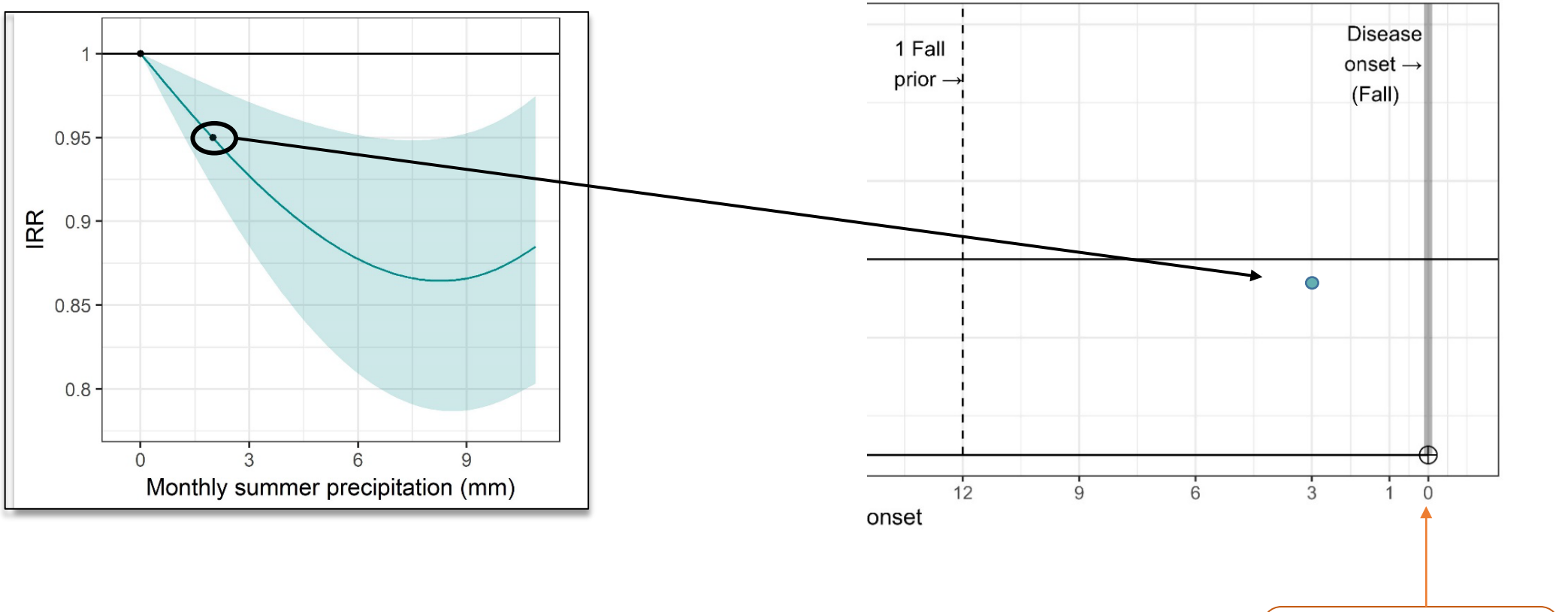


We obtained a non-linear exposure-response relationship for 36 lags

Head, et al., Lancet Planet Health, accepted, 2022

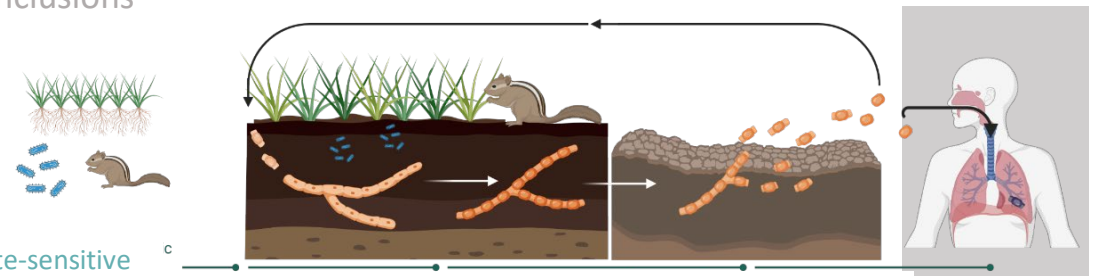
Distributed lag nonlinear modeling approach

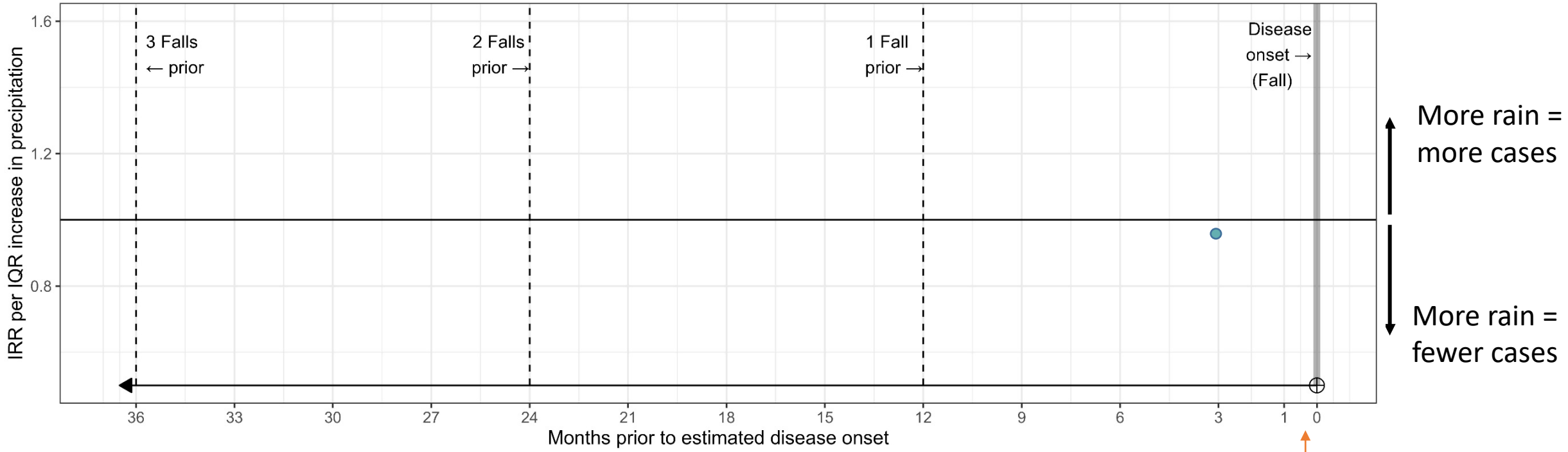
3) Computed the incidence rate ratio at the 75th percentile of lagged precipitation or temperature compared to the 25th percentile.



Head, et al., Lancet Planet Health, accepted, 2022

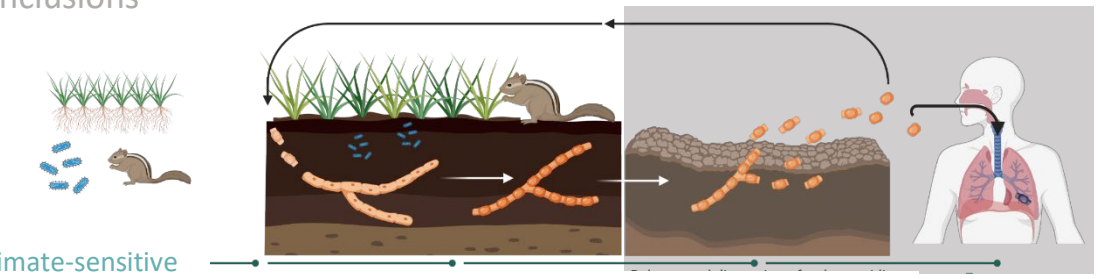
When is precipitation associated with incidence?

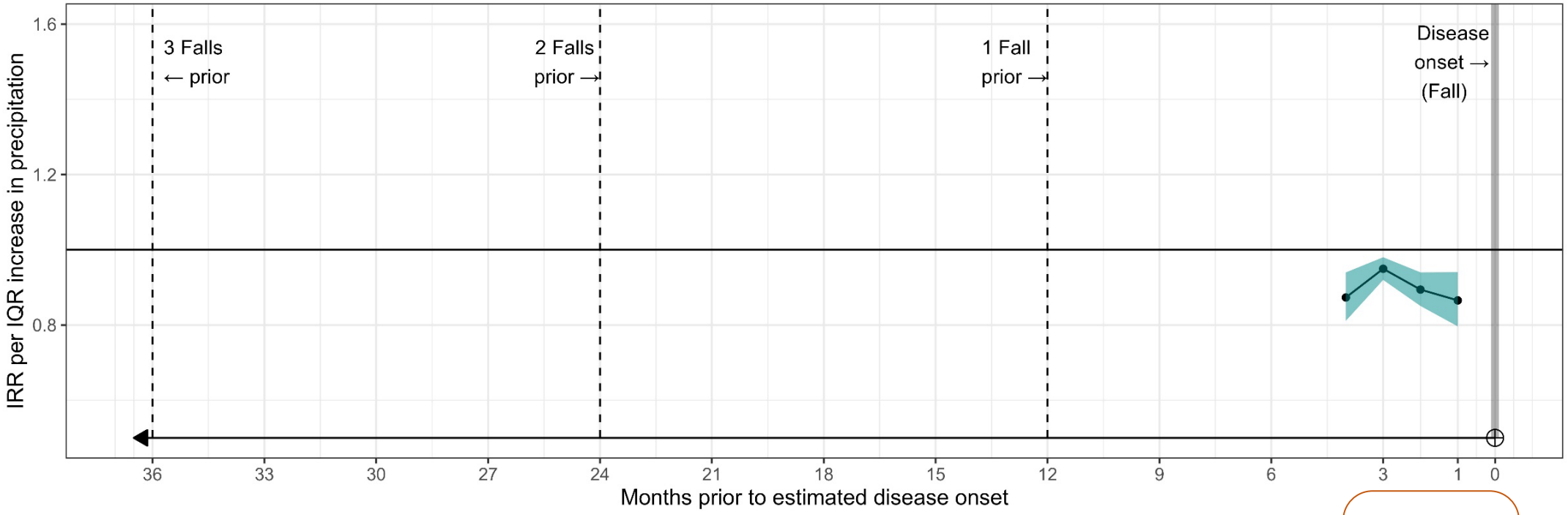




Head, et al., Lancet Planet Health, accepted, 2022

Recent rain →fewer cases





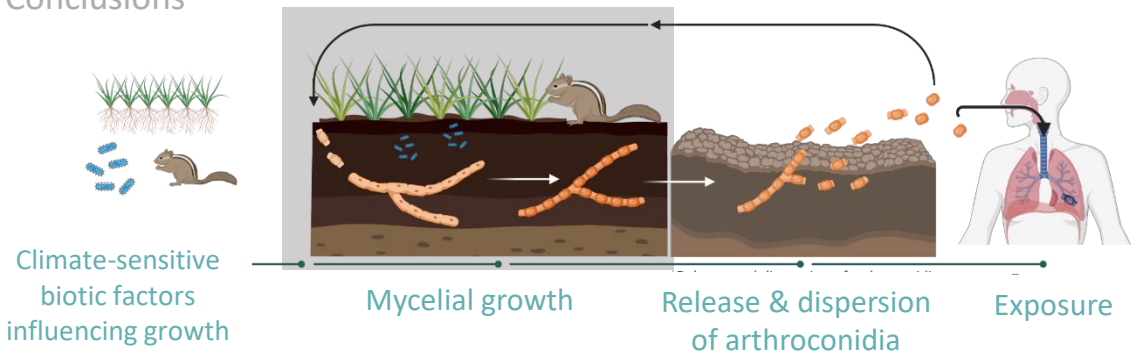
More rain = more cases

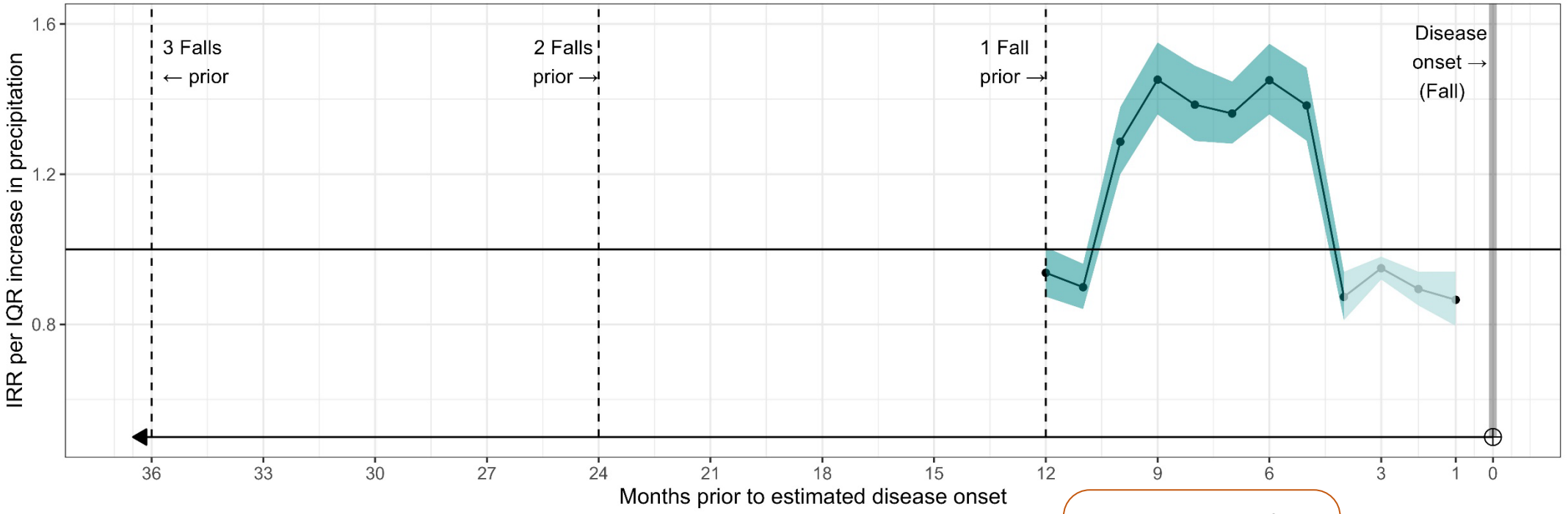
More rain = fewer cases

Summer and fall prior to onset

Head, et al., Lancet Planet Health, accepted, 2022

Rainfall lagged 5-10 months → more cases





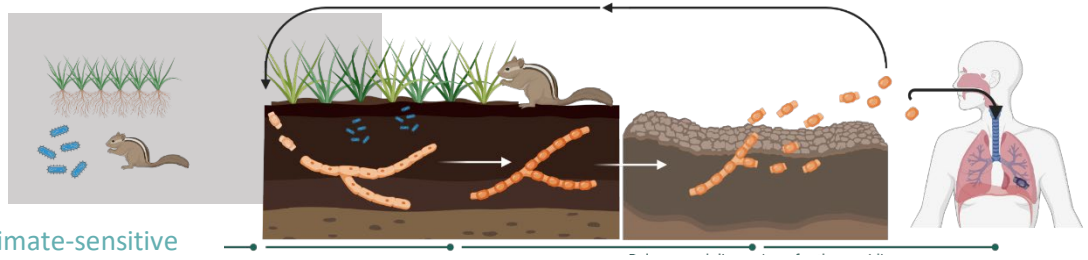
More rain = more cases

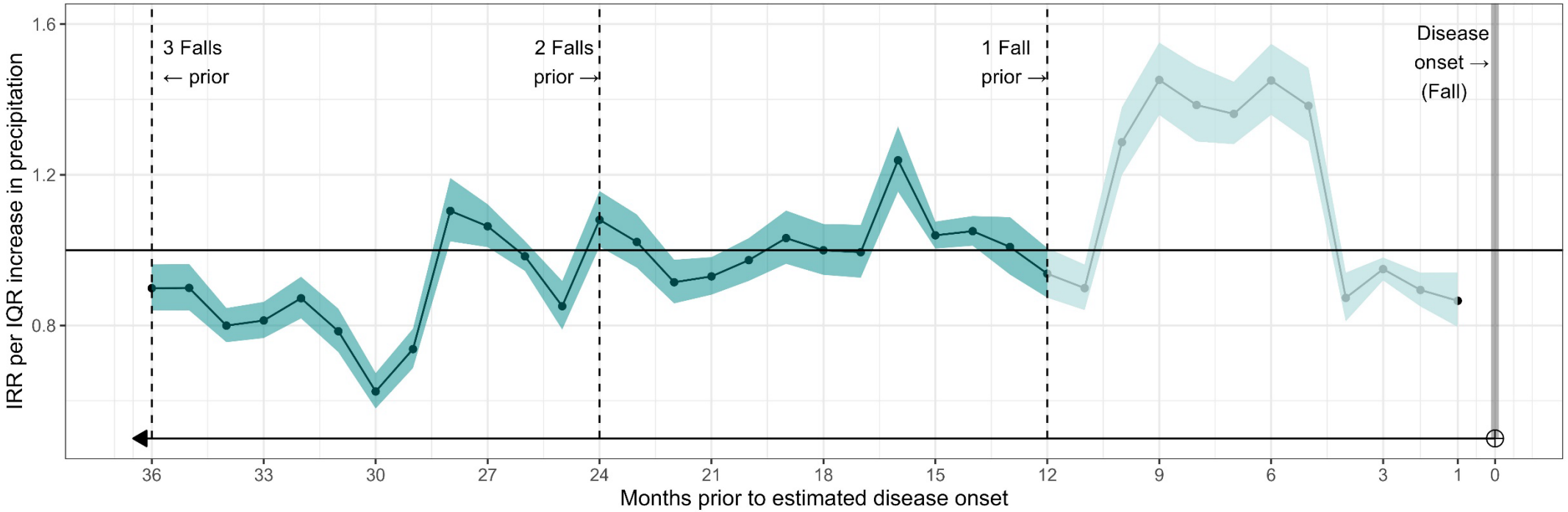
More rain = fewer cases

Spring and winter prior to onset

Head, et al., Lancet Planet Health, accepted, 2022

Antecedent rain → variable influence





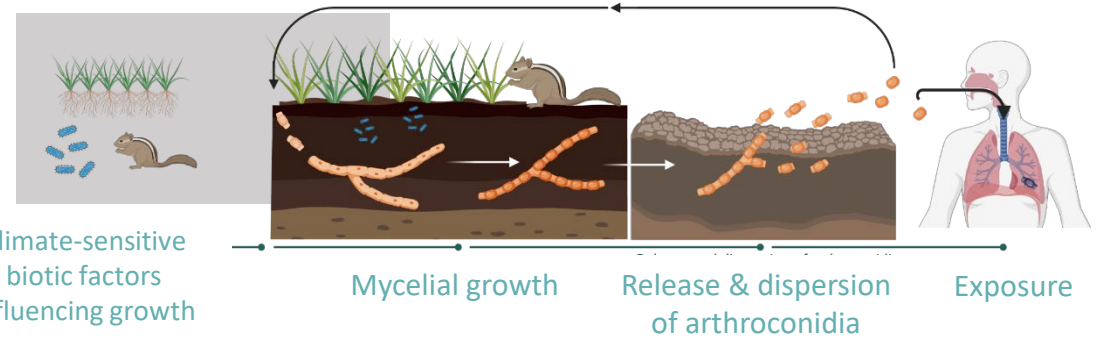
More rain = more cases

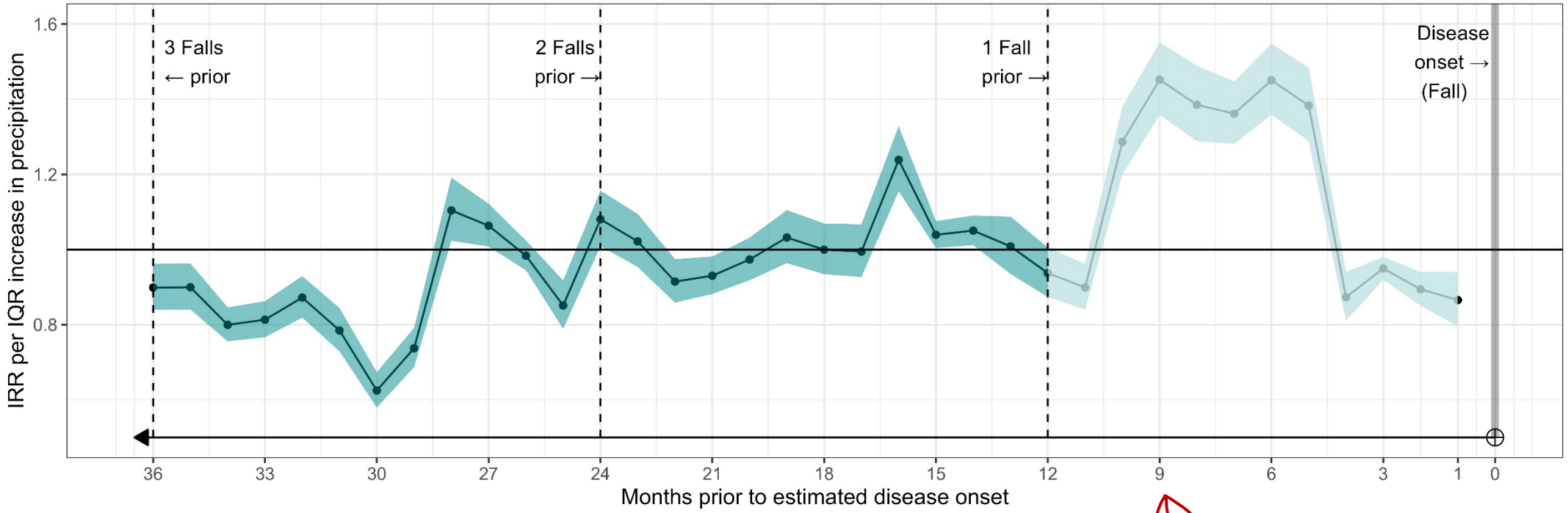
More rain = fewer cases

1-3 years prior to onset

Head, et al., Lancet Planet Health, accepted, 2022

Antecedent rain → variable influence





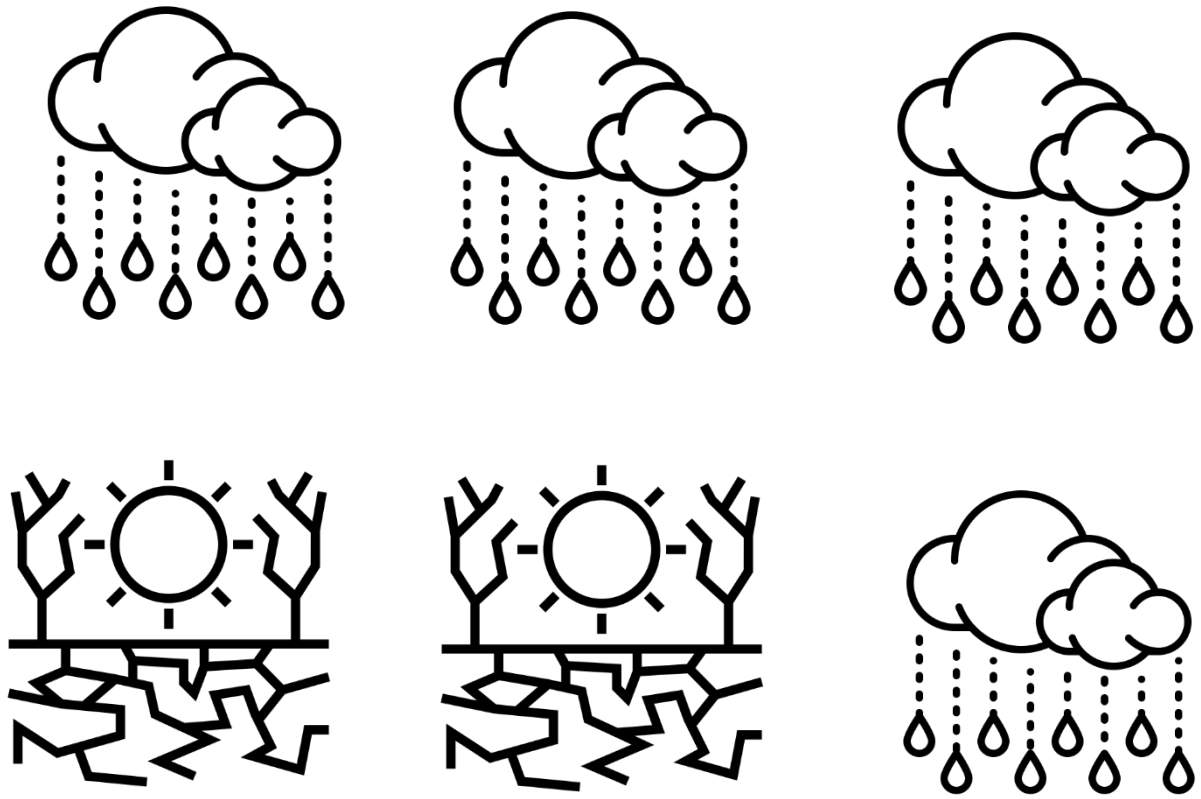
More rain = more cases

More rain = fewer cases

1-3 years prior to onset

Head, et al., Lancet Planet Health, accepted, 2022

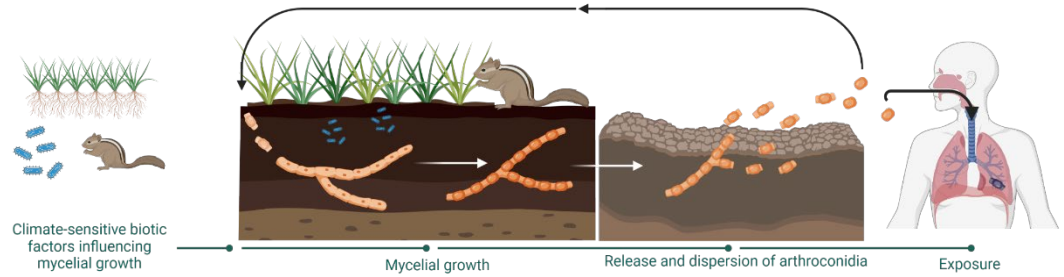
Positive effect of precipitation is *even more* enhanced when a wet winter follows *two* dry winters

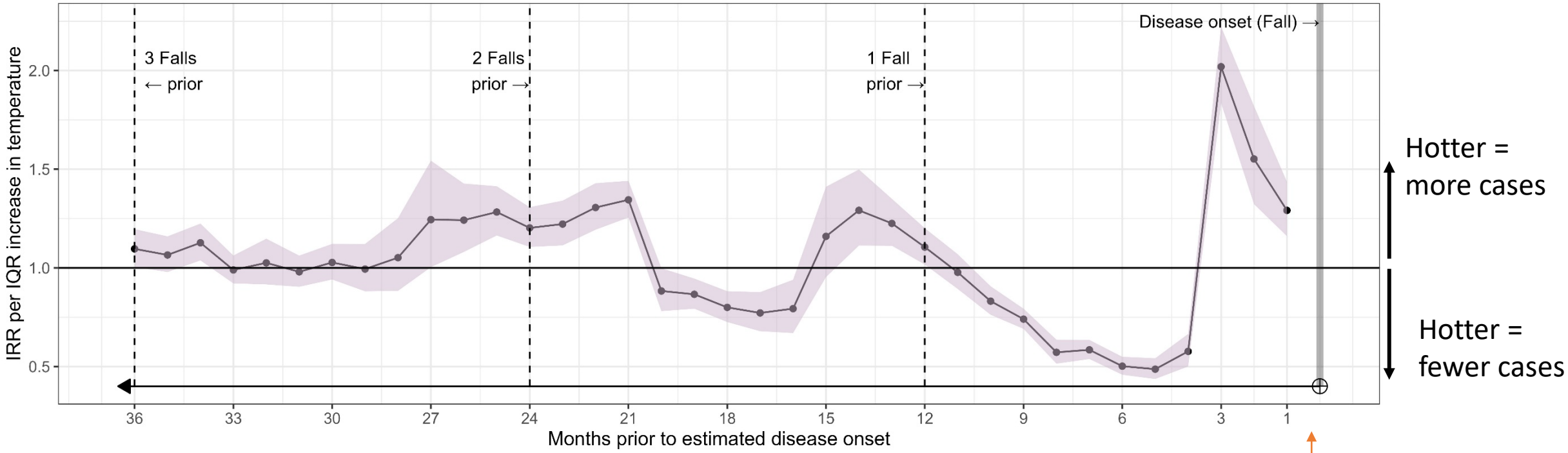


36% more cases associated with the wet period

Head, et al., Lancet Planet Health, accepted, 2022

When is temperature associated with incidence?





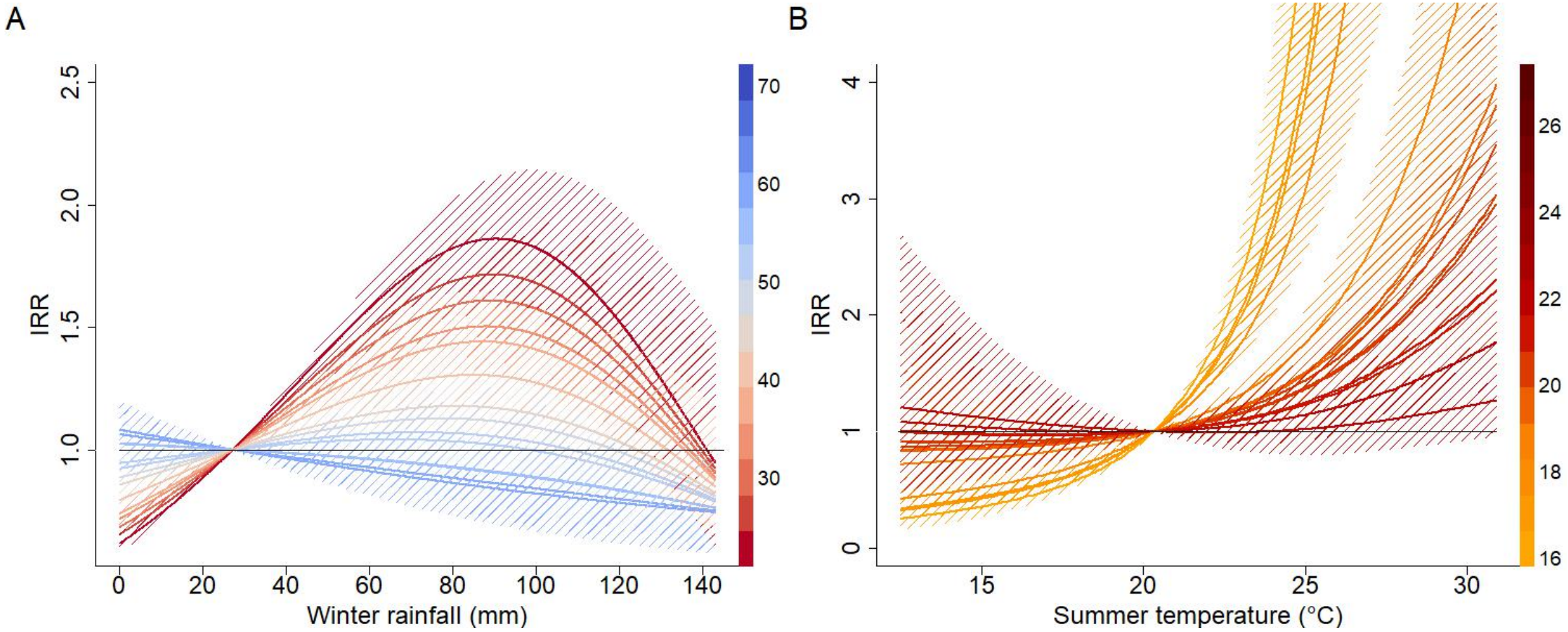
Hotter = more cases

Hotter = fewer cases

Disease onset = Fall

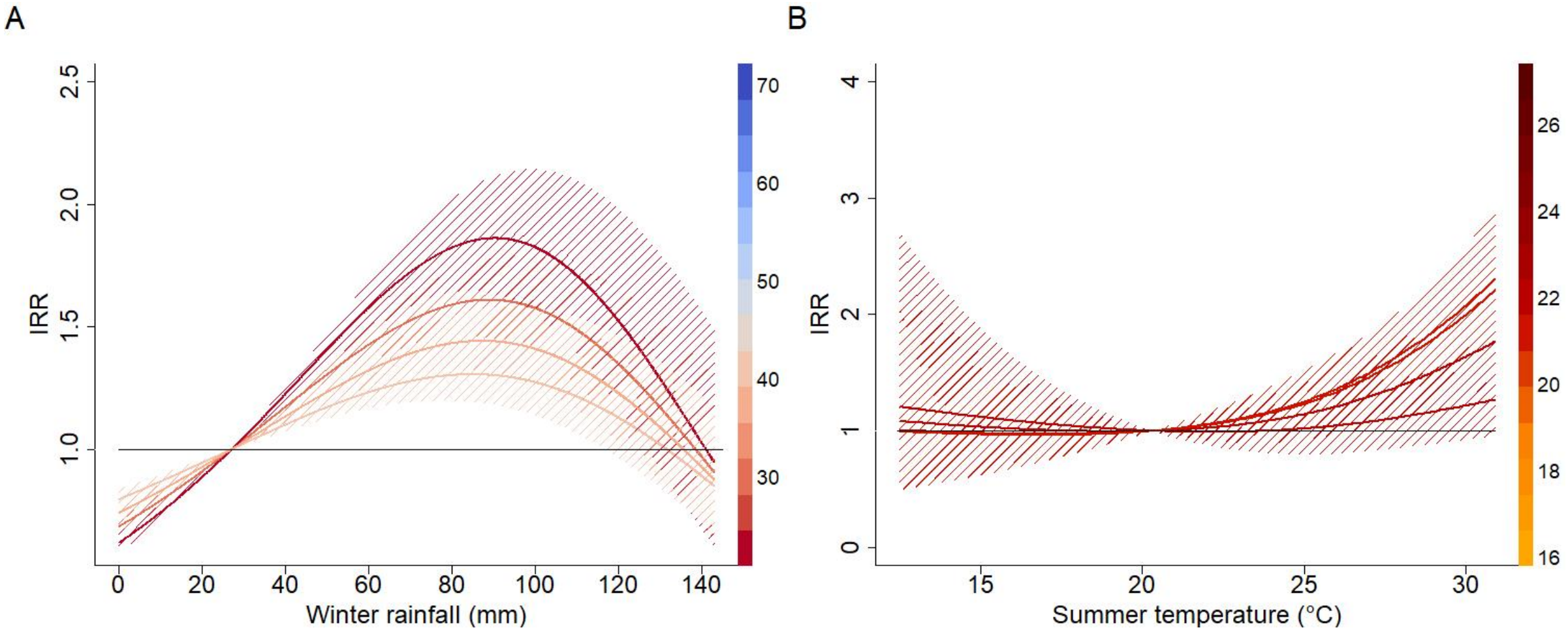
Head, et al., Lancet Planet Health, accepted, 2022

The strength of relationship varies by typical climate



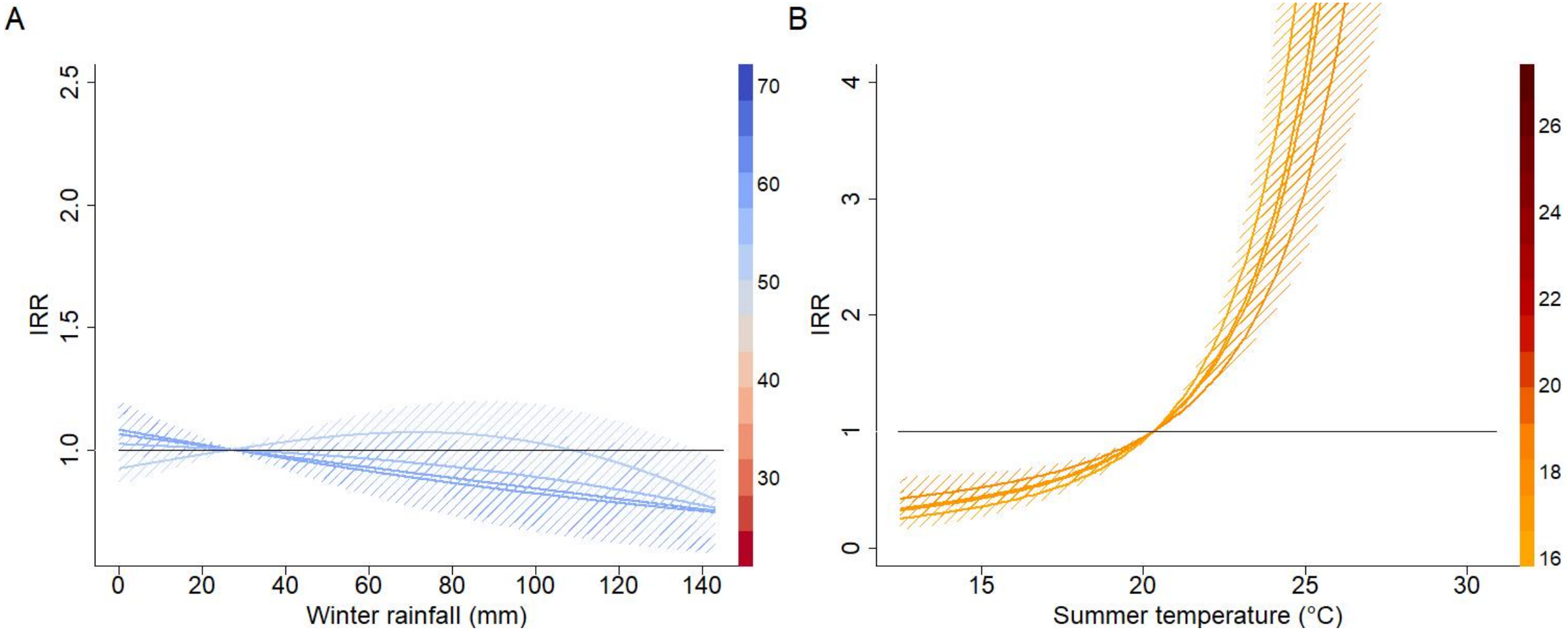
Head, et al., Lancet Planet Health, accepted, 2022

Hotter, drier counties strongly influenced by rainfall



Head, et al., Lancet Planet Health, accepted, 2022

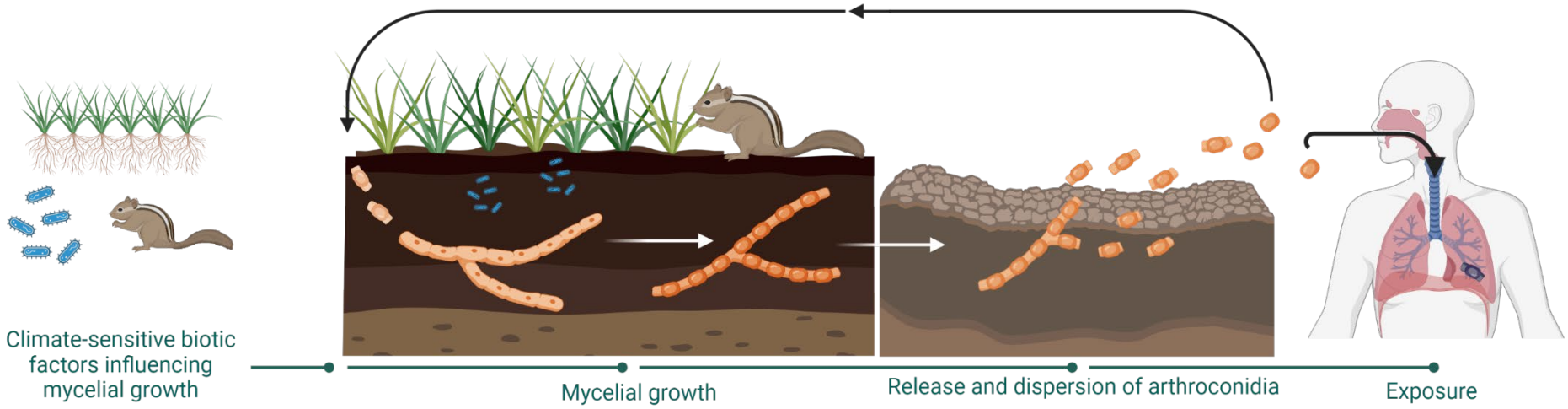
Cooler, wetter counties strongly influenced by **heat**



Head, et al., Lancet Planet Health, accepted, 2022

Summary of findings:

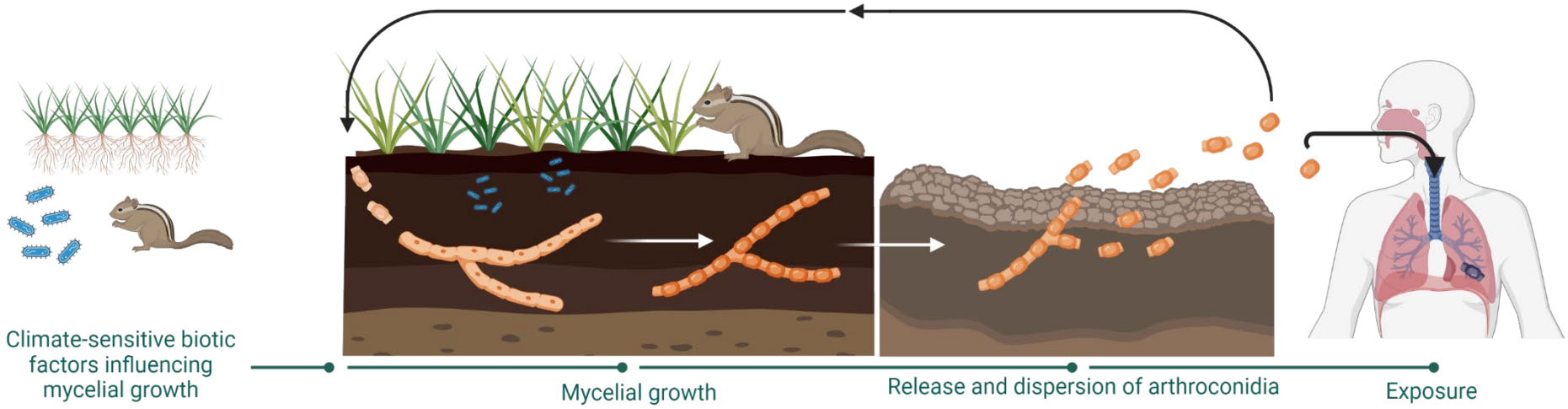
Climate affects *Coccidioides* growth and dispersion differently by time lags



Hot and dry conditions here promote incidence. **Cooler counties are especially sensitive** to heat

Summary of findings:

Climate affects *Coccidioides* growth and dispersion differently by time lags

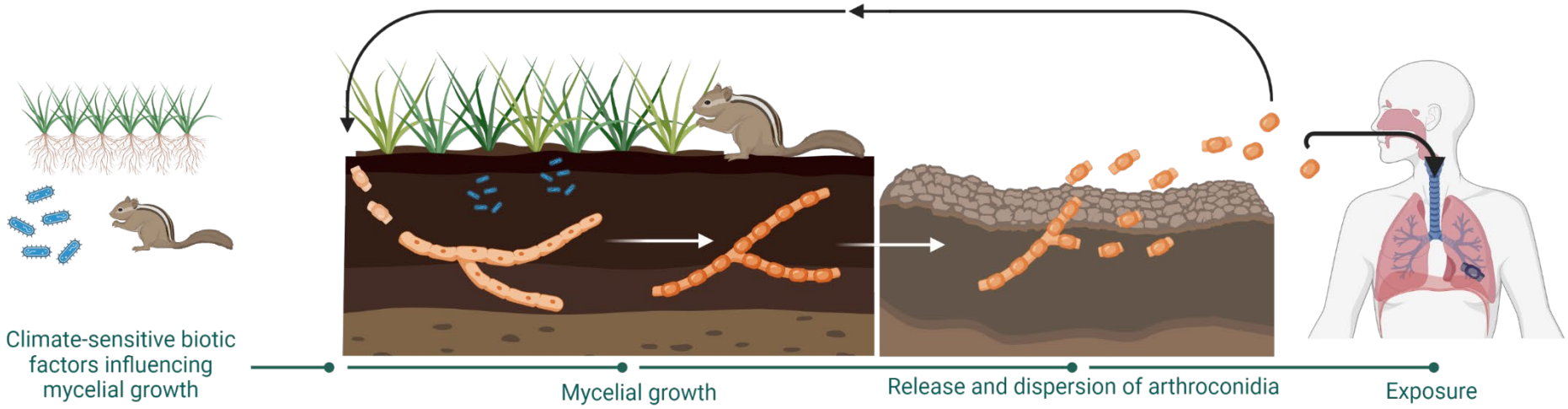


Wet conditions here promote incidence. **Drier counties are especially sensitive** to precipitation

Hot and dry conditions here promote incidence. Cooler counties are especially sensitive to heat

Summary of findings:

Climate affects *Coccidioides* growth and dispersion differently by time lags

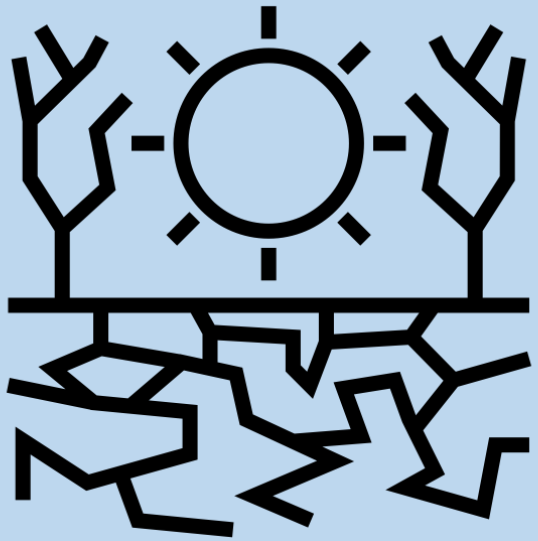


Consecutive dry years enhances the effect of a wet winter (drought?)

Wet conditions here promote incidence. Drier counties are especially sensitive to precipitation

Hot and dry conditions here promote incidence. Cooler counties are especially sensitive to heat

2. Determine causal effect of the 2007-2009 and 2012-2015 droughts on incidence and compare effect across regions



Method: Ensemble prediction models with G-computation

First, built ensemble prediction algorithm for each county in the study region

<u>Applied variety of candidate algorithms:</u>

Generalized linear models

Generalized additive models

Random forest models

$\hat{E}(Y_{i,t}|A_{i,t} = a_{i,t}, W_{i,t})$

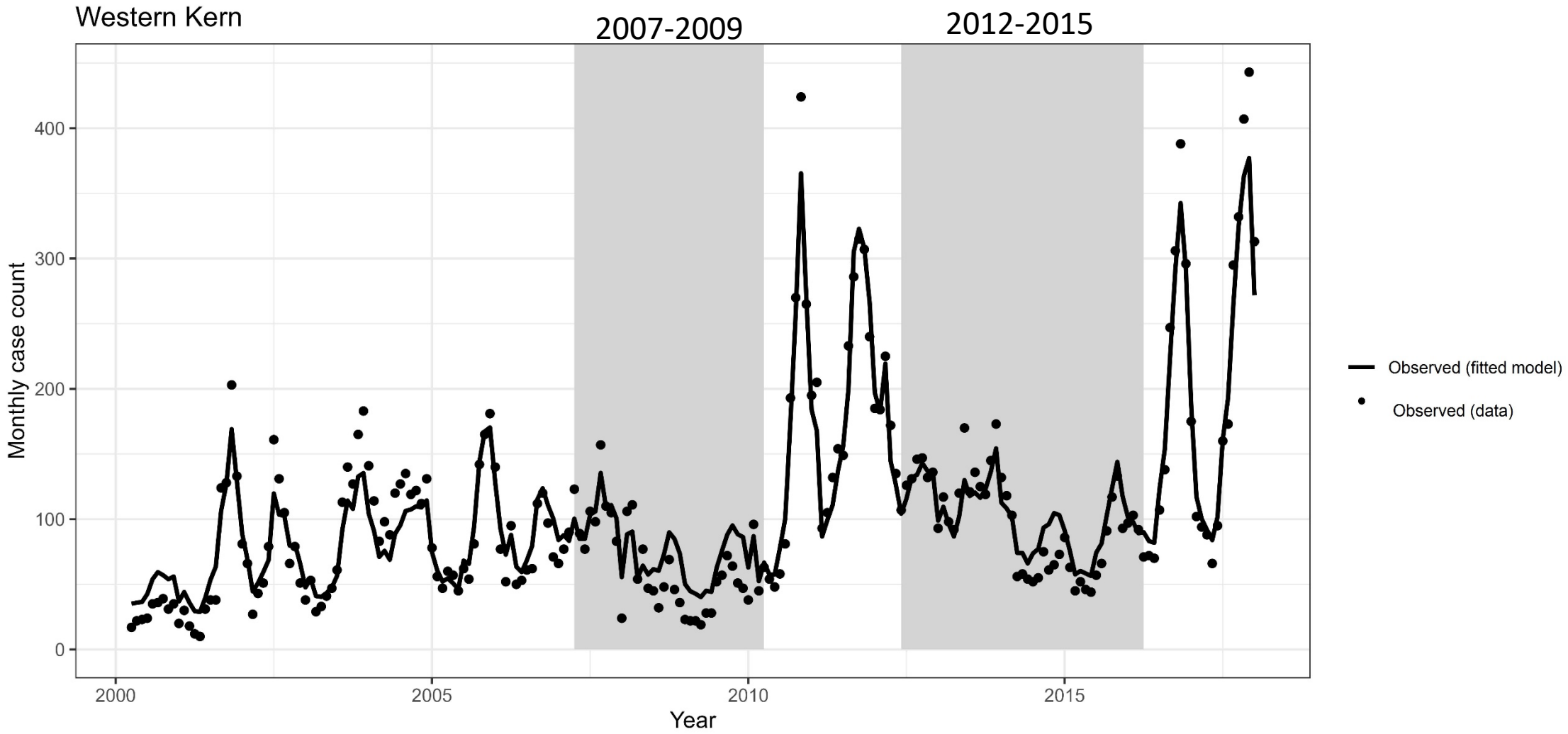
→

Used leave-out-one-year cross validation to determine out of sample prediction error

→

Computed weighted average of the models so as to minimize out of sample prediction error

First, built ensemble prediction algorithm for each county in the study region



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Using G-computation, estimated incidence under a counterfactual "no drought" scenario

$$\hat{E}(Y) = \sum_{t=t0}^{t=T} \sum_{i=1}^{N} \hat{E}(Y_{i,t} | A_{i,t} = a_{i,t}, W_{i,t})$$

$A_{i,t} \epsilon (Rainfall_{it}, Temperature_{it})$

$W_{i,t} \epsilon (Time, elevation, soil\ texture)$

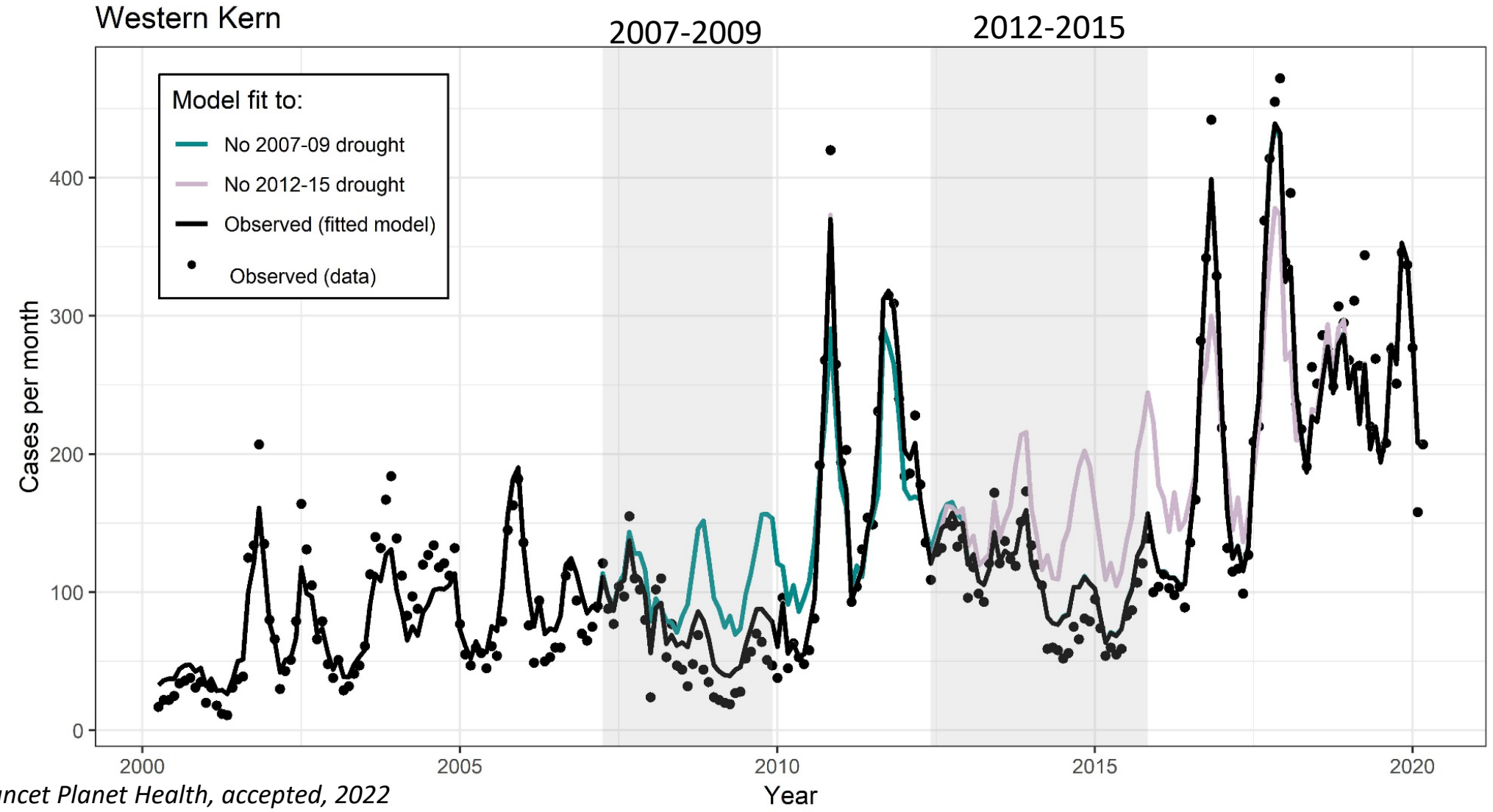
$\hat{E}(Y)$: expected number of cases under **observed** conditions for $A_{i,t} = a_{i,t}$

$\hat{E}(Y_0)$: expected number of cases under **counterfactual** conditions for $A_{i,t} = a_{i,t}$

- rainfall below average set to the average
- temperature above average set to the average

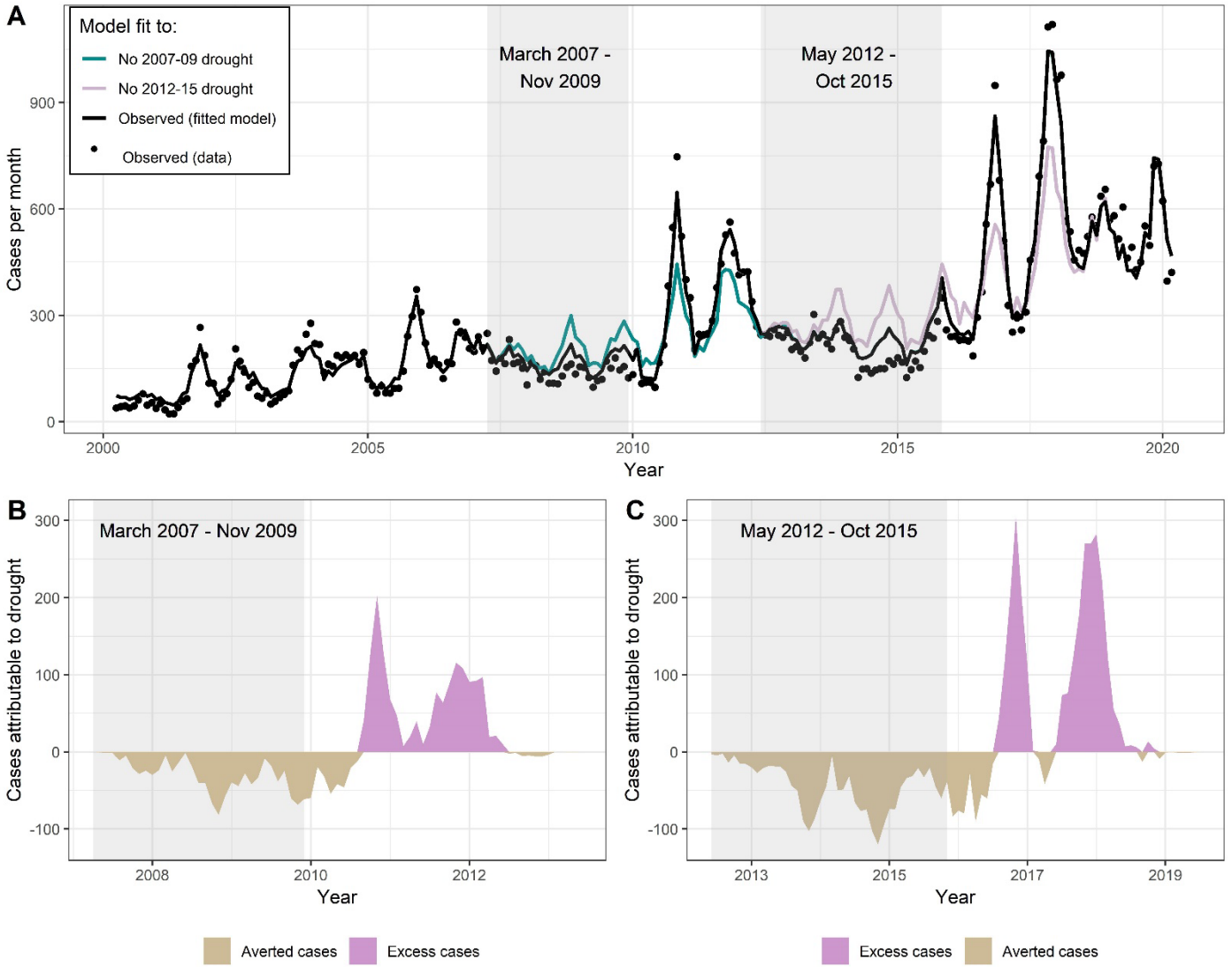
$$\hat{\psi} = \hat{E}(Y) - \hat{E}(Y_0)$$

Using G-computation, estimated incidence under a counterfactual "no drought" scenario

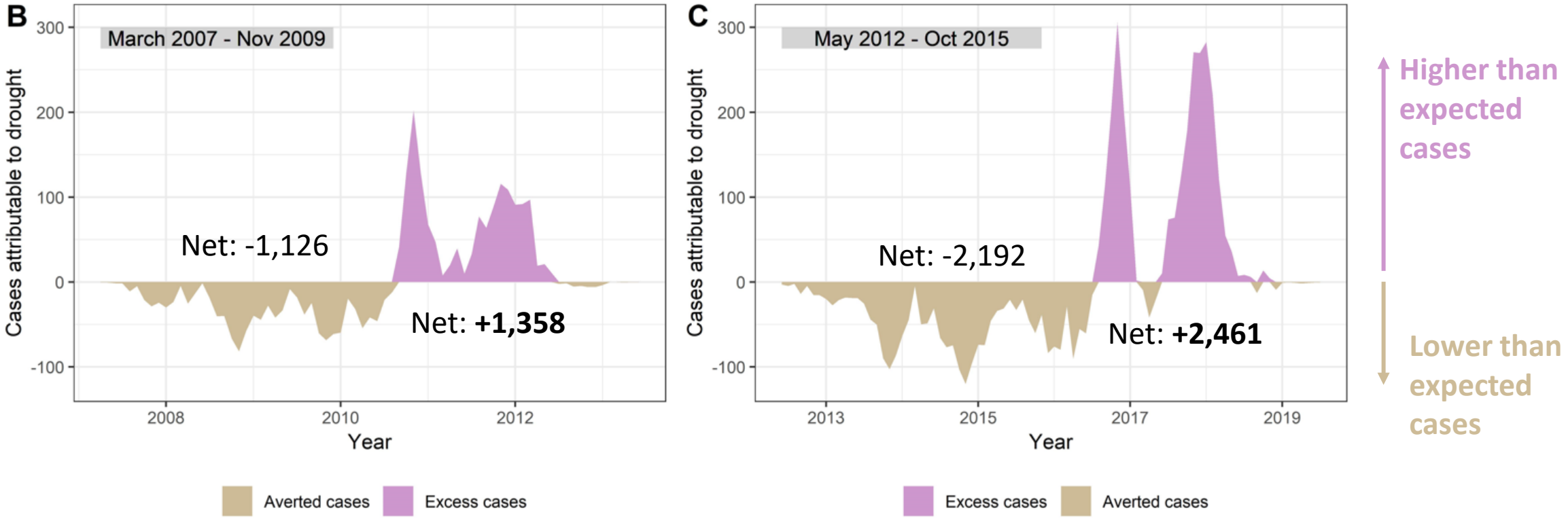


Head, et al., Lancet Planet Health, accepted, 2022

Compared differences across counties and the full study region

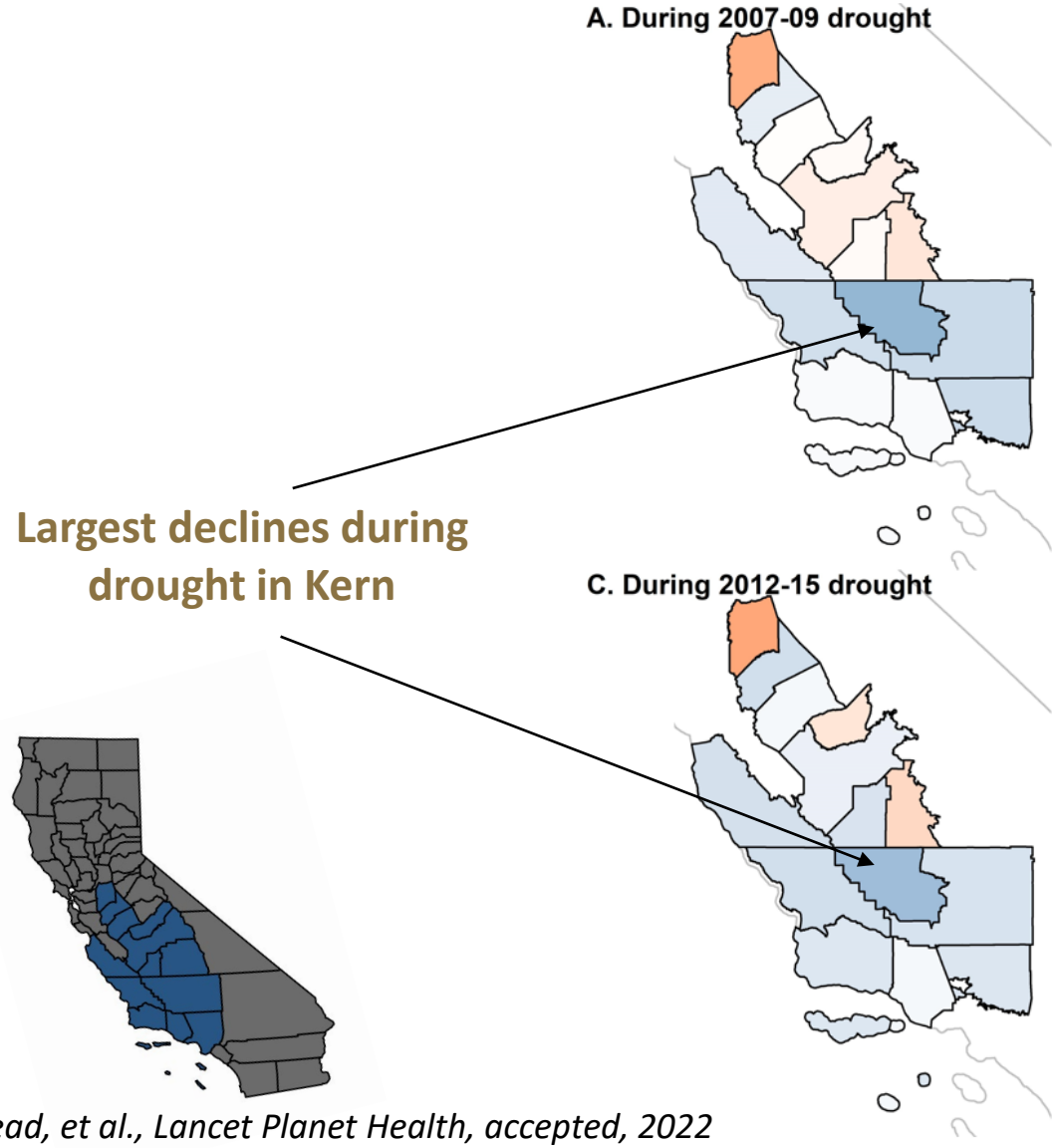


For both droughts, the decline in cases during drought was more than offset by the increase following

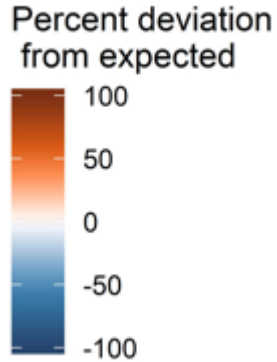


Head, et al., Lancet Planet Health, accepted, 2022

Kern County experienced the largest relative declines during droughts

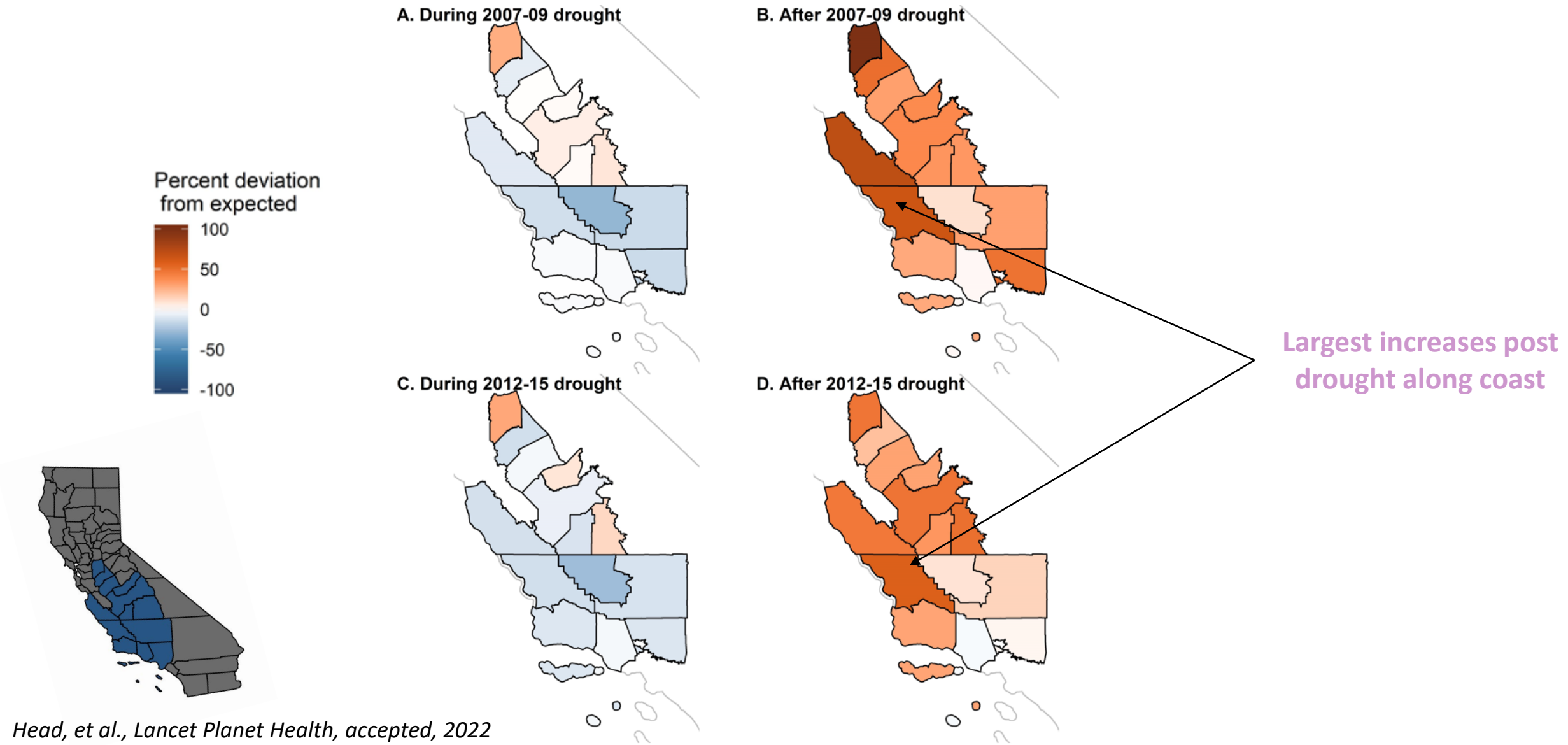


Largest declines during drought in Kern



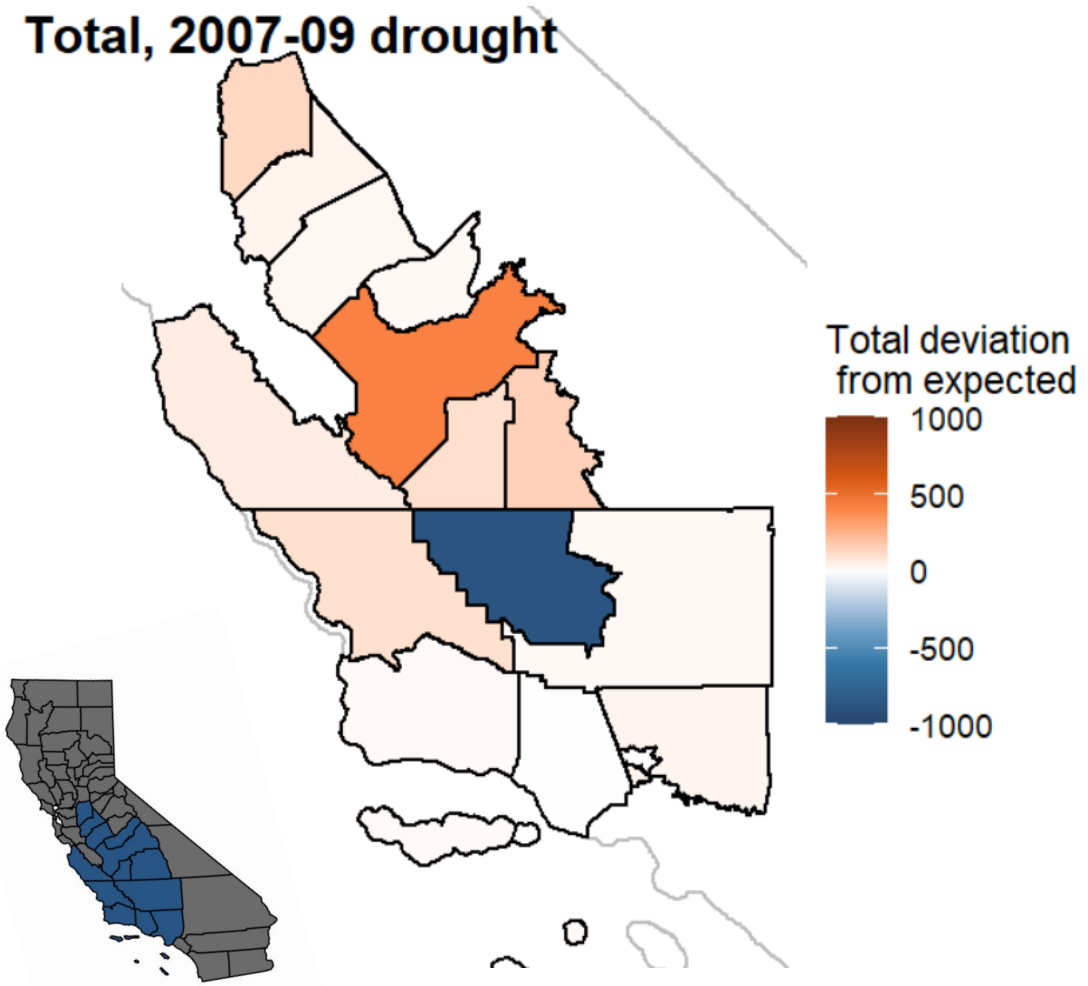
Head, et al., Lancet Planet Health, accepted, 2022

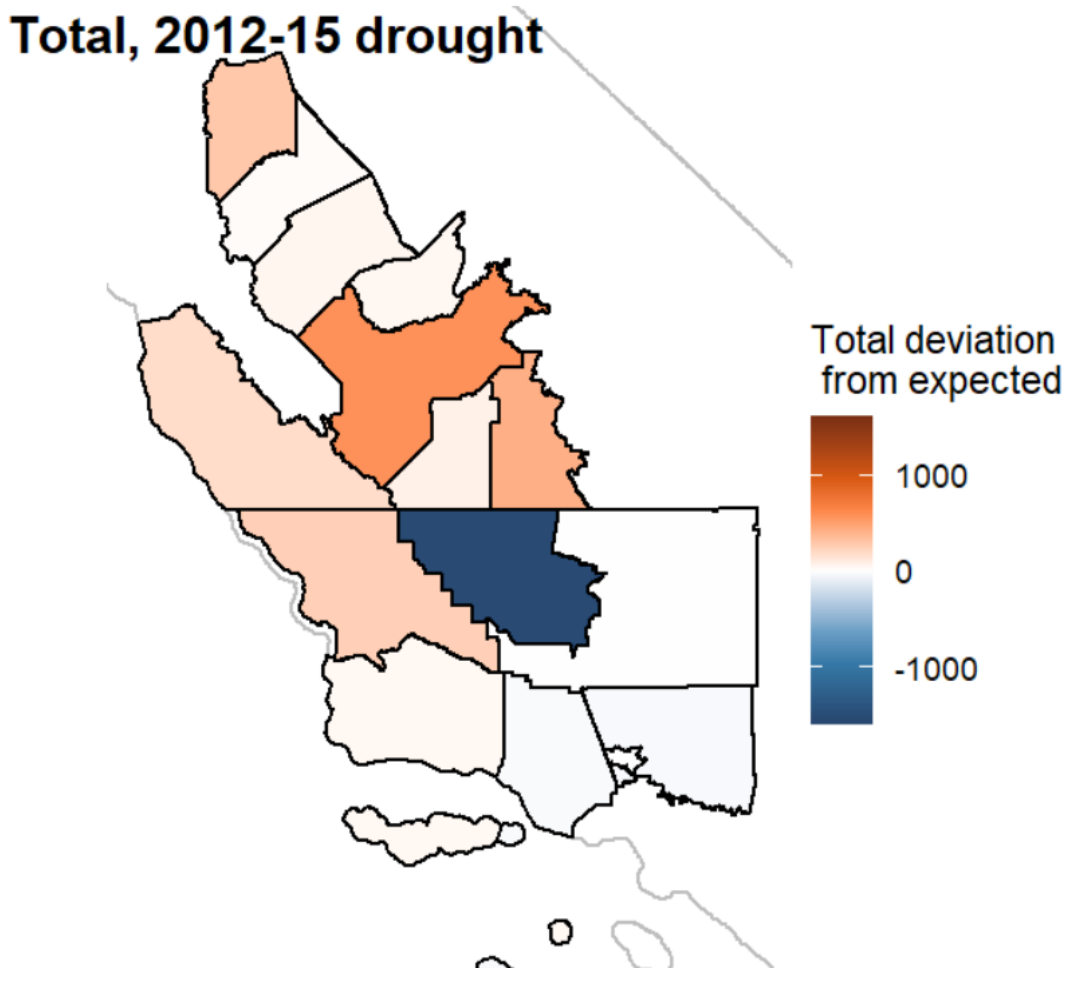
Coastal and northern valley counties experienced largest relative increases post-drought



Head, et al., Lancet Planet Health, accepted, 2022

Drought increases were most notable along the coast and northern valley; only western Kern had cases averted by drought





Head, et al., Lancet Planet Health, accepted, 2022

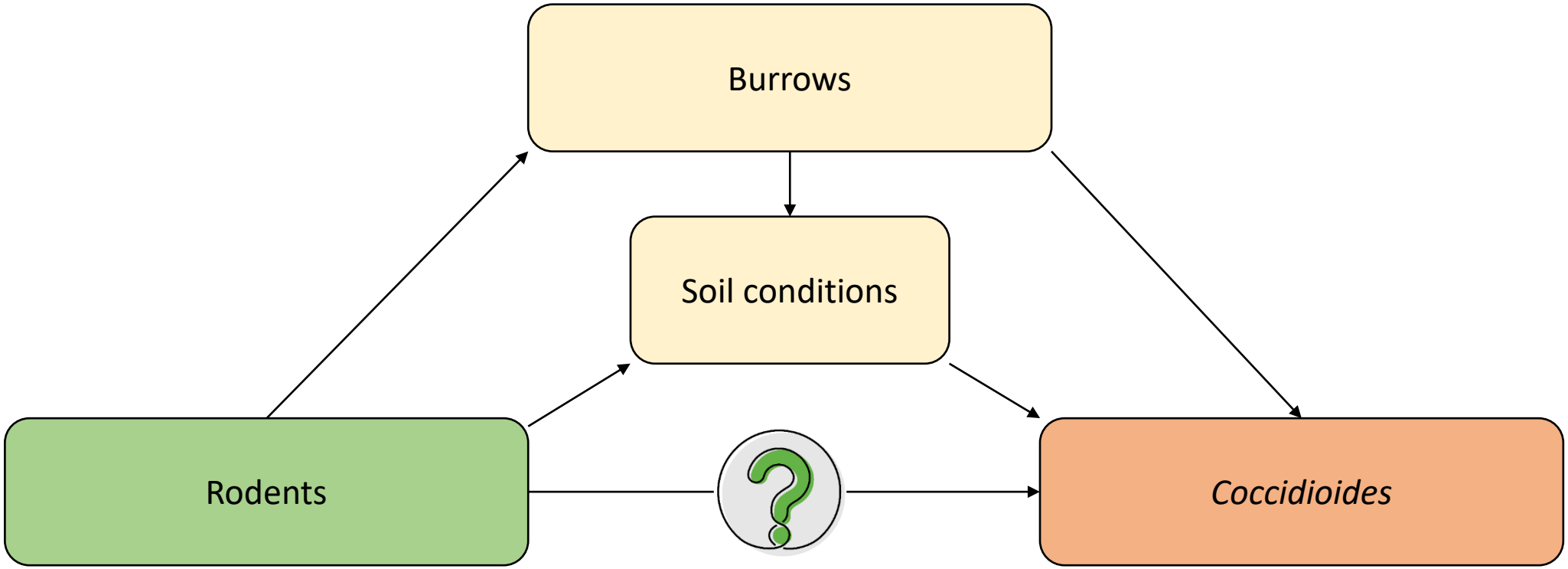
How do our findings relate to the small mammal endozoan hypothesis?

Coccidioidomycosis incidence rebounds sharply after drought

Rodent populations (generally) rebound sharply after drought

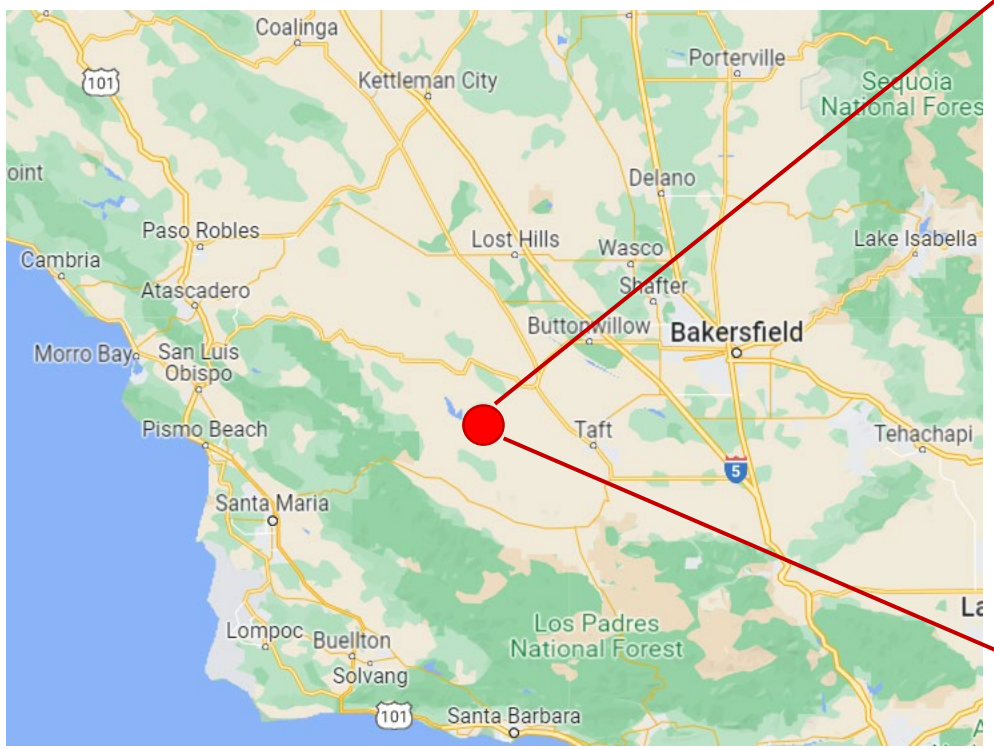
Photo: Yuan Zhu

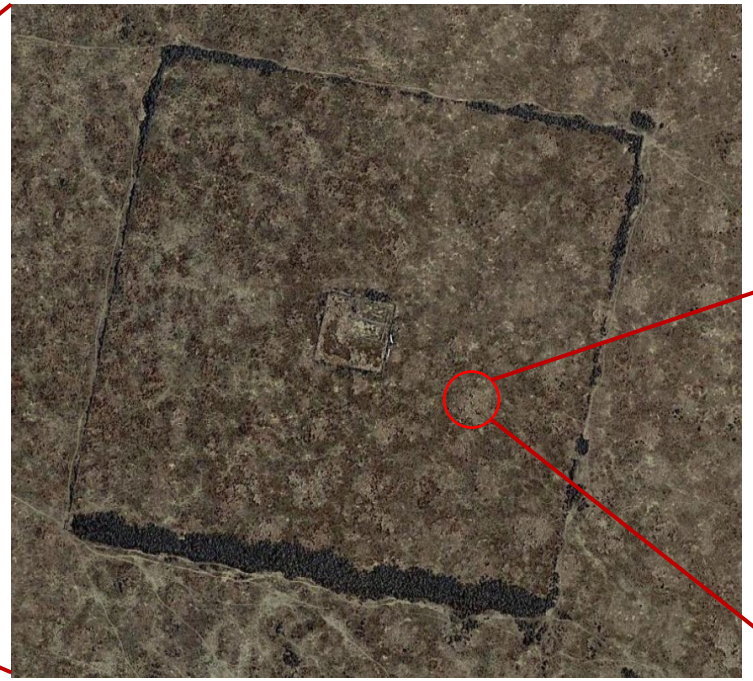
Disentangling the rodent from the burrow has been a challenge



Carrizo Plain Ecology Project

Establishment of rodent exclosures in 2007 permits disentanglement of rodents and burrows



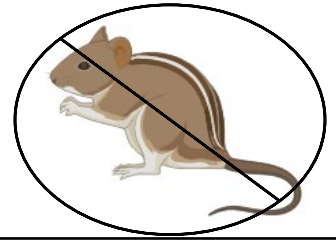
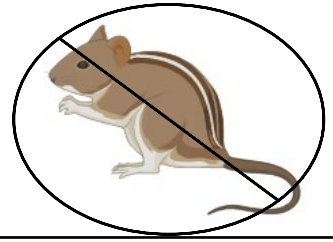
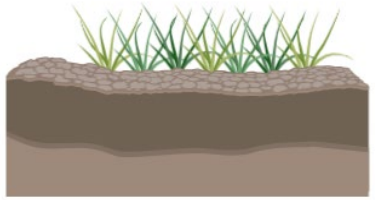
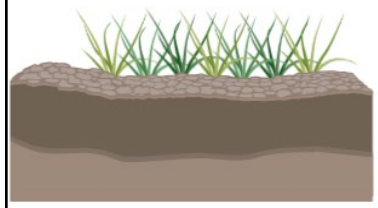


Experimental plot

Rodent precinct

Head, et al., in prep

Sample seasonally across a factorial design

Burrows x Exclosures				
				
				

Clusters per plot	2	1	1	1
Samples per plot	10	5	5	5
Samples per season	200	100	100	100

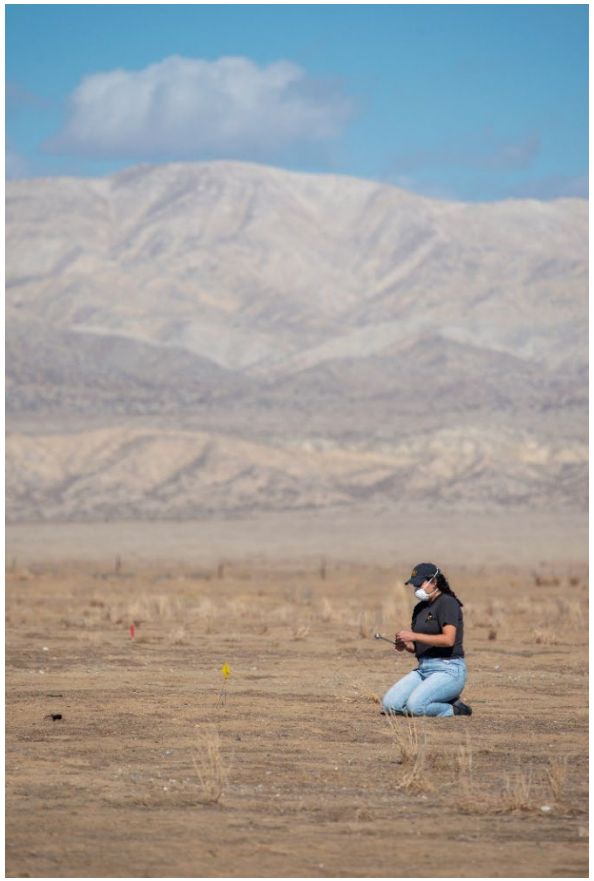
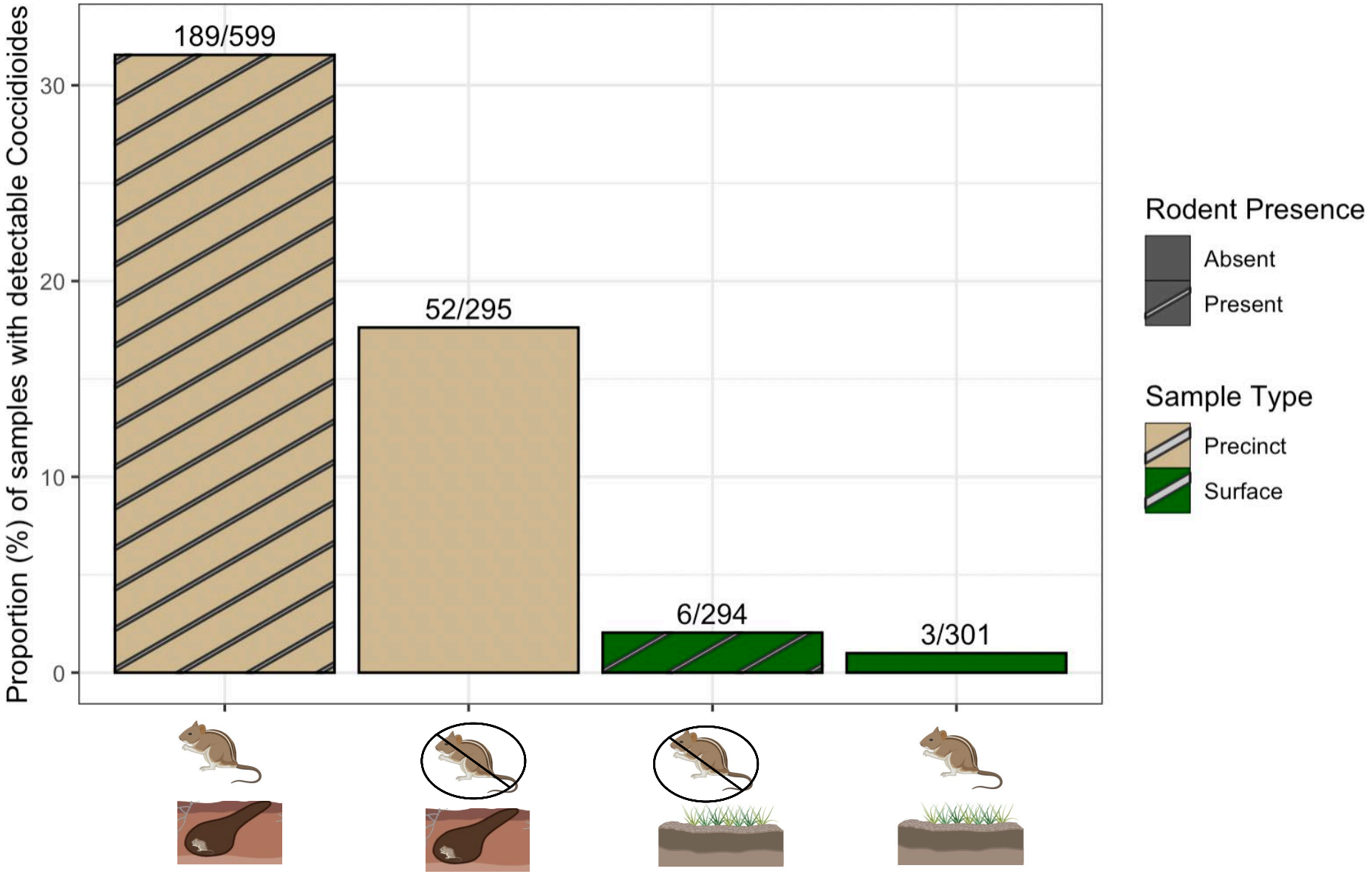


Photo: Yuan Zhu

Coccidioides was detected in 250/1,489 (16.8%) of samples



Head, et al., in prep

Updating of our understanding of the role of climate in coccidioidomycosis epidemiology

- Drought displaces and then amplifies incidence
- Incidence is increasing most rapidly in the wetter and cooler counties. We show evidence that incidence in these counties is very sensitive to temperature variation, and have seen the largest increases following drought.
- Frequency and severity of drought is expected to increase. Increasing aridity and greater swings in climate extremes may lead to expansion in wetter, cooler areas. Increasing aridity may lead to declines among already very dry counties.
- The role of climate and rodent populations on *Coccidioides* may be complex and interrelated

Photo: Yuan Zhu

Strengths and limitations of these analyses

+ Applies causal inference techniques to the question of drought and incidence
+ Links incidence to environmental exposures at the census tract level
+ Use flexible model structures to capture interactions and non-linear relationships

– Cases are assigned to the month of estimated date of disease onset
– Cases are assigned to the census tract of residence
– Drought can be defined in multiple manners

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Thank you!

Head et al., Effects of precipitation, heat and drought on incidence and expansion of coccidioidomycosis in western USA: a longitudinal surveillance study, *Lancet Planetary Health*, accepted, 2022.

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NIH National Institutes of Health

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