Model Description

# Continuous time model

This model describes changes in the biomass of annuals (), first-year perennials (), and adult perennials () over the growing season. Biomass is affected by disease and competition. We assume all biomass belonging to one plant group (e.g., stems, leaves, etc.) experiences the same growth rate, competitive effects, and disease transmission. The biomass of plant group , where , can either be susceptible () or infected (). The total biomass of a plant group is and inoculum in the litter produced by annuals is . Inoculum is lost from the litter over the growing season as rate .

Total biomass grows at a rate , which is slowed due to competition ( values). Infection ( values) moves biomass from the susceptible to infected category. Transmission is asymptotic (Antonovics et al. 1995, McCallum et al. 2001) to represent saturating contact rates with increasing density. Both susceptible and infected biomass contribute to competition because susceptible biomass contributes to photosynthesis and resource uptake and both types of biomass contribute to shading. Infected biomass does not grow, but is converted from susceptible biomass. Infected biomass is lost at a rate due to processes such as shedding or cell death.

We simulate the continuous time model for the number of days in a growing season (). The initial states of the variables are derived from the discrete time model and described below.

# Discrete time model

This model describes annual changes in the population densities of annual plant seeds (), perennial plant seeds (), and perennial adult plants ().

Because we found that infected annual seeds have reduced germination, we separately track susceptible and infected annual seeds. Susceptible annual seeds either stay dormant in the seed bank or germinate () while infected seeds can only germinate at a reduced fraction () and do not survive for another year in the seed bank. If seeds germinate, they establish and grow regardless of whether they are infected. The seeds that germinate and establish are used to initiate the continuous time model () with initial biomass . The final biomass of annual plants in the continuous time model () is used to estimate seed production with a conversion constant . We assume a fraction of the seeds produced are infected, based on the empirical relationship between leaf severity (Estimated with ) and seed infection. Each gram of annual litter () reduces the establishment of annuals () by .

The processes the determine perennial plant seeds are similar to those for annual plant seeds except that perennial seeds can be produced either by first year plants or by adults.

Perennial adult plants are either adults that survived through the year or seeds that germinated, established, and survived through the non-growing season (e.g., winter).

The litter is composed of litter remaining from the previous year and new litter produced by annuals. Infected annual biomass from the previous year becomes the inoculum source at the beginning of the growing season.

# Parameters

Parameter

Description

Estimate

Lower

Upper

Units

Source

alpha\_AA

annual-annual competition

0.013

0.005

0.022

g-1

experiment

alpha\_AF

annual-first-year perennial competition

0.000

NA

NA

g-1

experiment

alpha\_AP

annual-adult perennial competition

0.118

0.034

0.200

g-1

experiment

alpha\_FA

first-year perennial-annual competition

0.011

0.003

0.020

g-1

experiment

alpha\_FF

first-year perennial-first-year perennial competition

0.000

NA

NA

g-1

experiment

alpha\_FP

first-year perennial-adult perennial competition

0.099

0.007

0.184

g-1

experiment

alpha\_PA

adult perennial-annual competition

0.000

NA

NA

g-1

experiment

alpha\_PF

adult perennial-first-year perennial competition

0.000

NA

NA

g-1

experiment

alpha\_PP

adult perennial-adult perennial competition

0.164

0.020

0.298

g-1

experiment

r\_A

annual growth rate

0.017

0.014

0.020

day-1

experiment

r\_F

perennial first-year growth rate

0.003

0.000

0.006

day-1

experiment

r\_P

perennial adult growth rate

0.011

0.007

0.015

day-1

experiment

beta\_AA

annual-annual transmission

0.038

0.012

0.067

day-1 g-1

experiment

beta\_AF

annual-first-year perennial transmission

0.000

NA

NA

day-1 g-1

experiment

beta\_AP

annual-adult perennial transmission

0.000

NA

NA

day-1 g-1

experiment

beta\_FA

first-year perennial-annual transmission

0.068

0.000

0.135

day-1 g-1

experiment

beta\_FF

first-year perennial-first-year perennial transmission

0.000

NA

NA

day-1 g-1

experiment

beta\_FP

first-year perennial-adult perennial transmission

0.034

0.005

0.063

day-1 g-1

experiment

beta\_PA

adult perennial-annual transmission

0.071

0.034

0.108

day-1 g-1

experiment

beta\_PF

adult perennial-first-year perennial transmission

0.000

NA

NA

day-1 g-1

experiment

beta\_PP

adult perennial-adult perennial transmission

0.000

NA

NA

day-1 g-1

experiment

p0

seed infection parameter

-2.914

-3.199

-2.647

NA

experiment

p1

seed infection parameter

2.524

1.184

3.863

NA

experiment

g\_I

infected annual germination fraction

0.316

0.182

0.458

NA

experiment

g\_S

susceptible annual germination fraction

0.767

0.733

0.800

NA

experiment

g\_P

perennial germination fraction

0.240

0.035

0.440

NA

experiment

c\_A

annual seed conversion

76.912

69.191

84.425

seeds g-1

experiment

c\_F

first-year perennial seed conversion

8.476

6.997

10.000

seeds g-1

experiment

c\_P

adult perennial seed conversion

19.084

16.209

21.981

seeds g-1

experiment

e\_A

annual establishment fraction

0.949

0.914

0.981

NA

experiment

e\_P

perennial establishment fraction

0.553

0.407

0.696

NA

experiment

l\_P

adult perennial survival fraction

0.876

0.620

0.983

NA

experiment

w\_F

first-year perennial non-growing season survival fraction

0.902

0.832

0.963

NA

experiment

b\_A

annual initial biomass

0.031

NA

NA

g

experiment

b\_F

first-year perennial initial biomass

0.004

NA

NA

g

experiment

b\_P

adult perennial initial biomass

0.031

NA

NA

g

experiment

beta\_Al

litter transmission to annuals

0.010

NA

NA

day-1 g-1

NA

beta\_Fl

litter transmission to first-year perennials

0.010

NA

NA

day-1 g-1

NA

beta\_Pl

litter transmission to adult perennials

0.010

NA

NA

day-1 g-1

NA

k\_A

transmission saturation constant for annuals

10.000

NA

NA

g

NA

k\_F

transmission saturation constant for first-year perennials

10.000

NA

NA

g

NA

k\_P

transmission saturation constant for adult perennials

10.000

NA

NA

g

NA

v\_A

annual infected tissue loss

0.000

NA

NA

day-1

NA

v\_F

perennial first-year infected tissue loss

0.000

NA

NA

day-1

NA

v\_P

perennial adult infected tissue loss

0.000

NA

NA

day-1

NA

h

inoculum loss from litter

0.100

NA

NA

day-1

NA

s\_A

annual surviving seed fraction

0.150

NA

NA

NA

Redwood et al. 2018

s\_P

perennial surviving seed fraction

0.050

NA

NA

NA

Garrison and Stier 2010

gamma\_A

litter suppression of annuals

0.000

NA

NA

g-1

NA

gamma\_P

litter suppression of perennial first-years

0.000

NA

NA

g-1

NA

d

annual litter decomposition fraction

0.590

NA

NA

NA

DeMeester and Richter 2010