parameter_sweeps

January 15, 2020

1 Notebook 1: Parameter sweeps

This is a jupyter notebook to give additional information about exploring some of the parameters of our agent-based model for the manuscript: "An agent-based model of the Foraging Ascomycete Hypothesis." The model is coded in python3, using the Mesa package.

contents

Section **??**

1.0.1 Non-viaphyte fungi

Section **??**

Section **??**

Section **??**

Section **??**

1.1 Viaphyte fungi

Section **??**

Section **??**

1.2 Non-viaphyte vs. Viaphyte fungi

Section **??**

Section **??**

1.3 Deforestation

Section **??**

Section 2

* Section 2 * Section **??** * Section **??**

Setup and model defaults

```
In [35]: import pickle
         import os
         import pandas as pd
         import numpy as np
         import matplotlib.pyplot as plt
```

```
from FAmodel import Forest
from FAmodel import sumendos
from FAmodel import sumdecomps
from FAagents import Tree, Wood, Fungus
import thomasprocess as tp
import  plotparsers as pr

%matplotlib inline
```

1.4 Setup and model defaults

Many of these are set using our notebooks for calibrating dispersal and placement of agents, notebook 2 and notebook 3.

Note: in the original scripts of the model, we labeled viaphytic fungi as "endophyte competent" or "EC+", and non-viaphytic fungal agents as "endophyte competent" or "EC-", so this language is used at various points throughout this documentation.

The parameters not used for calibration to our study site are here explored using parameter sweeps. The various simulations to follow vary one or a few of these at a time:

parameter	level	explanation
endophytism	True	allow endophyte life style in model run
ws	30	initial total energy of wood agents on the landscape
endodisp	2.0	dispersal of endos
decompdisp	10.0	dispersal of decomps
leafdisp	4.0	how well do leaves disperse
leaffall	1	how frequently do leaves disperse
numdecomp	1	initial number of decomposers
numendo	1	initial number of endos
endoloss	0.05	rate of loss of endophyte infect per step
newwood	15	total energy added in new logs each step
woodfreq	1	how often to put new logs onto the landscape
width	100	grid dimensions only one (squares only)
kappa	0.03	average rate of parent tree clusters per unit distance
sigma	3.0	variance of child tree clusters +/- spread of child clusters
mu	2.2	average rate of child tree clusters per unit distance
nuke	False	make landscape but no agents

Section **??**

1.5 Survival of the...only?

For our first parameter sweep, let's see what it takes to get established as a decomposer fungus new to an area that has recently been subject to nasty storm, with lots of wind-throw. This could represent a little bit of an ecological disturbance, blowing in fungal spores from far-away and a lot of fresh wood, with reduced loads of decomposer fungi on them.

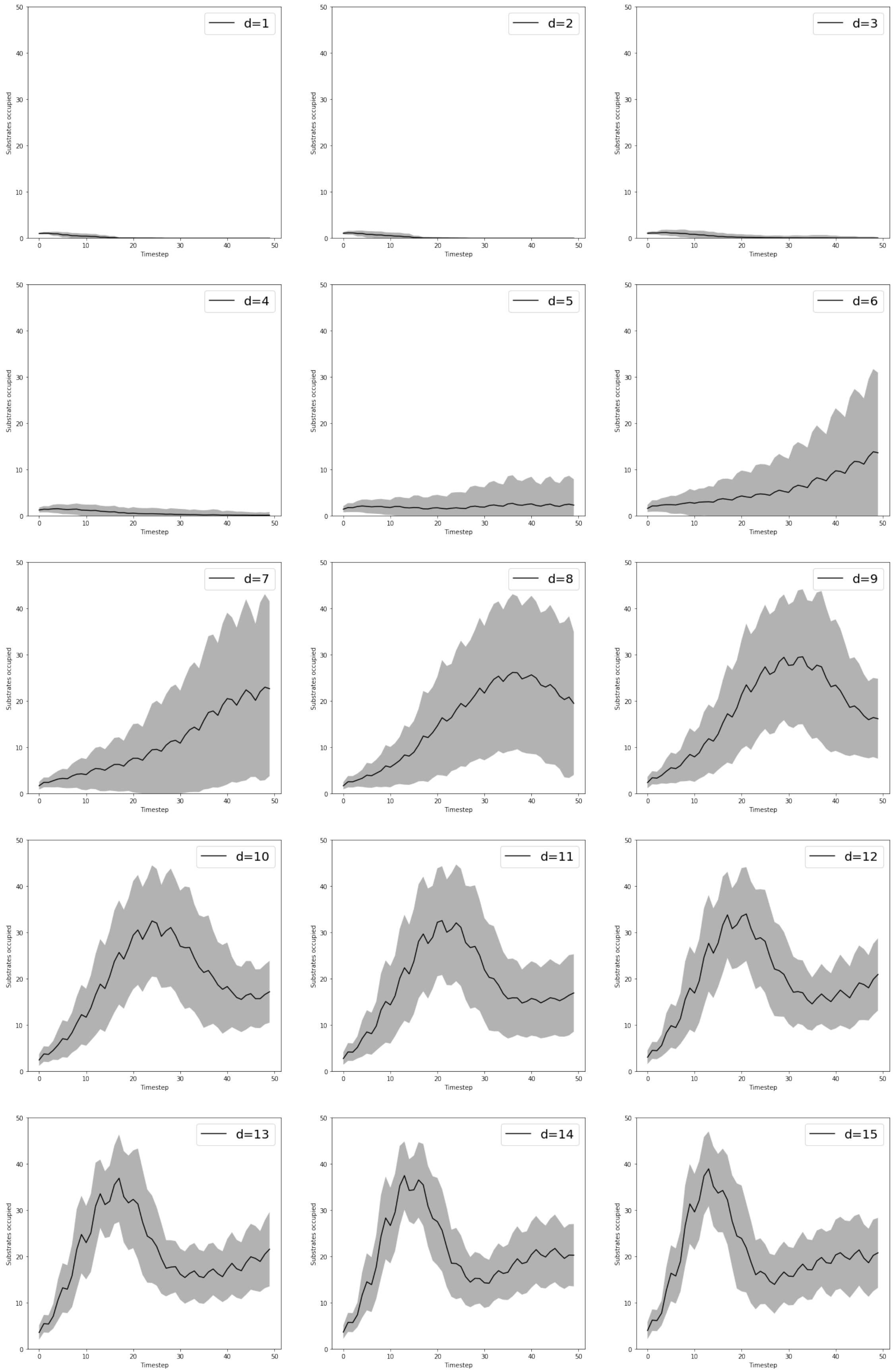
To model this, we keep the Section **??** of a fair amount of initial wood present on the landscape (ws = 30), and then a steady, lower rate of wood deposition from this point on. Our single species of fungus is not viaphytic. We'll sweep the coefficient of dispersal for this fungus, from 1 to 15. Our aciss scripts look like this, with the decompdist incremented up to 15:

```
In [ ]: mpiexec -n 10 python3 runFA.py -sims 10 -decompdisp 1   -numendo 0 -fileout sweeps/resu
```

```
In [21]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/onefungusdisp/one
```

```
In [22]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i)
```

```
In [24]: x = list(range(50))
         fig, axes = plt.subplots(5,3, figsize=(25, 40)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             z.set_ylim(0,50) ## yaxis
             ## plot fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='black',
                     label=('d=%s' %lvls[i]),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='black',
                             alpha = 0.3,
                             )
             handles, labels = z.get_legend_handles_labels()
             z.legend(handles, labels, prop={'size':20})
             z.set_ylabel("Substrates occupied")
             z.set_xlabel("Timestep")
```


d=1
d=2
d=3
d=4
d=5
d=6
d=7
d=8
d=9
d=10
d=11
d=12
d=13
d=14
d=15
Substrates occupied
Timestep

Looks like it take at least a dispersal coefficient of d=8 to survive reliably on the default landscape conditions of the model, so we'll use this as an example of a "typical decomposer" for the purposes of our manuscript. But at d=8, it looks like much initial wood remains, so d=8 probably isn't an incredibly competitive dispersal coefficient. At d=10, the initial wood is consumed, and an equilibrium around the rate of wood deposit is achieved. There is little risk during the "lift-off" phase at d=10, in that even in the early steps of model runs there is little risk of extinction. So let's set this dispersal, d=10 as an example of an "aggressive decomposer" as used in our manuscripts. Interesting that at greater levels of dispersal it seems like there is an overshoot, where populations dip before recovering to a steady state.

Section **??**

1.6 Changing initial abundances of wood

We can hold the default non-viaphyic dispersal coefficient constant at d=8 and vary the initial abundance/energy of wood agents and wood-deposition rates. So first, what will it look like if we vary initial abundances of wood?

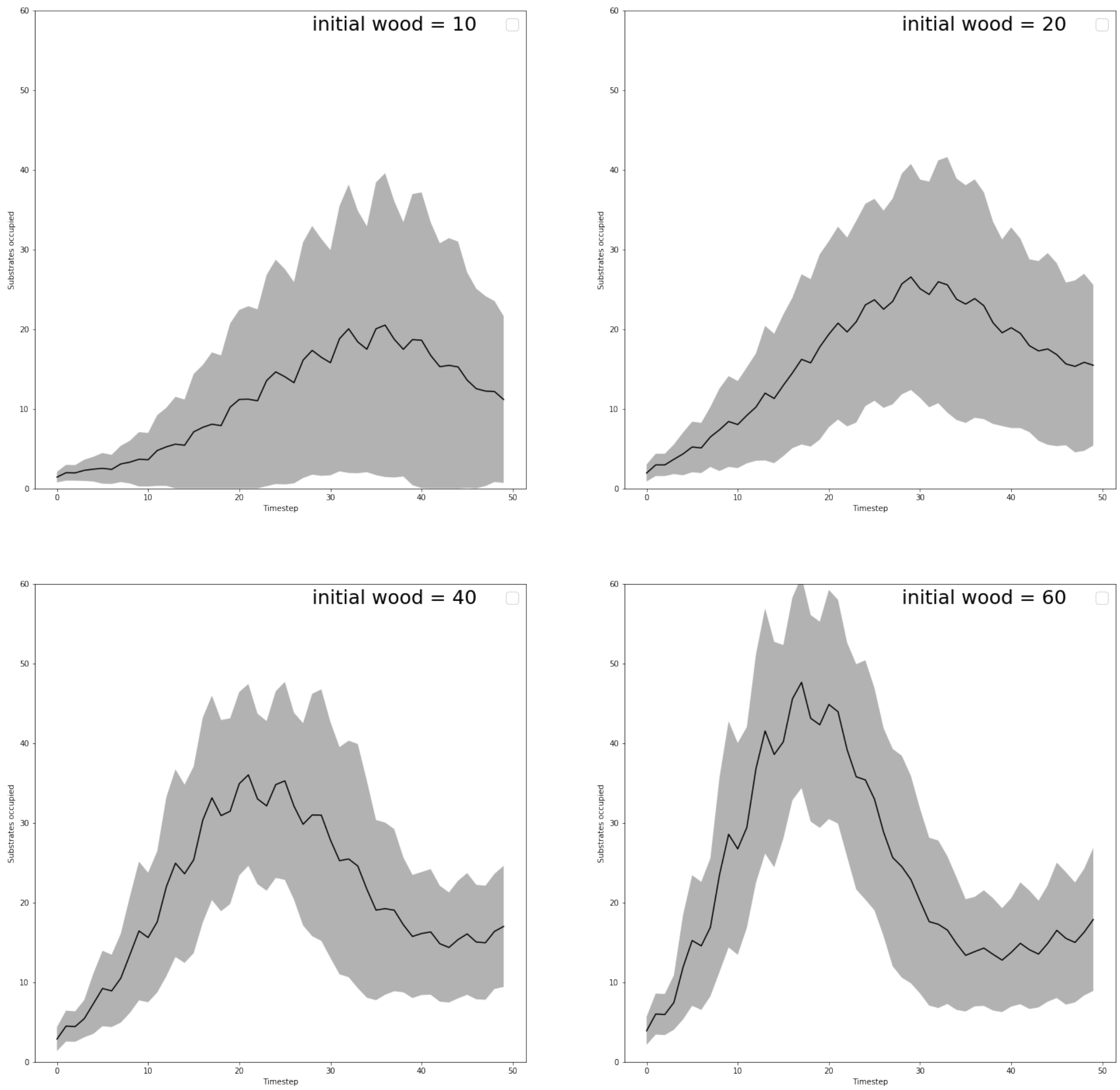
```
In [2]: ## aciss:
        mpiexec -n 10 python3 runFA.py -sims 10 -ws 10 -numendo 0 -fileout /home6/dthomas/FAsi
```

```
In [27]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/initwood/initwood
```

```
In [28]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i)
```

```
In [43]: x = list(range(50))
         fig, axes = plt.subplots(2,2, figsize=(25, 25)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             z.set_ylim(0,60) ## yaxis
             ## plot fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='black',
                     #label=('initial=%s' %lvls[i]),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='black',
                             alpha = 0.3,
                             )
             z.text(0.90, 0.95, 'initial wood = %s' %lvls[i] +"0",
                     verticalalignment='bottom', horizontalalignment='right',
                     transform=z.transAxes,
```

```
                color='black', fontsize=25)

        handles, labels = z.get_legend_handles_labels()
        z.legend(handles, labels, prop={'size':20})
        z.set_ylabel("Substrates occupied")
        z.set_xlabel("Timestep")
```



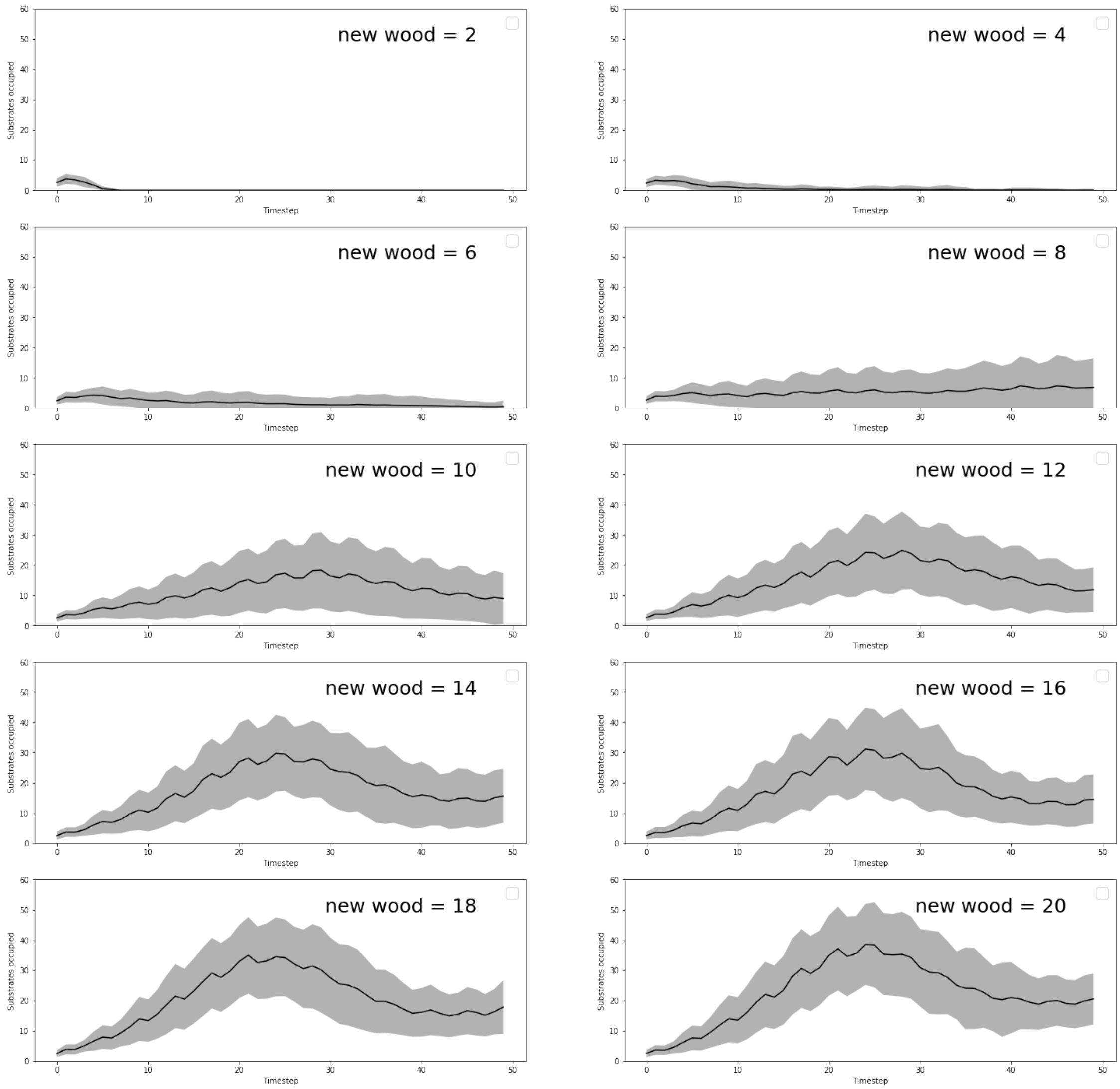
In general, if there is wood out there, a well-dispersed fungus will get it, then equilibriate to the steady state of wood as it falls.

Section **??**

Effect of wood deposition rates

Here we assume an initial amount of 30 energy in wood agents on the site, a medium-strong dispersing fungus (not endophyte-competent), and sweep over the rate of new wood deposition on the landscape. Note we aren't varying the frequency here of new wood agent deposition, this is kept the current model default of new wood every step (there is a parameter for this, can be changed, see Section **??**). Also note that the amount of energy in wood agents that being dropped over the landscape is being varied. Our model doesn't directly control the number of wood agents on the landscape - it allows user control of total energy stored in wood-agents to be modified. The number of new wood agents that act as containers of this energy every time step varies randomly (see ODD protocol description), but on average wood agent abundance is correlated closely with amount of energy.

```
In [ ]: ## aciss
       mpiexec -n 10 python3 runFA.py -sims 10 -newwood 2  -numendo 0 -fileout /home6/dthomas/

In [44]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/newwood/newwood.p

In [45]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i)

In [52]: x = list(range(50))
         fig, axes = plt.subplots(5,2, figsize=(25, 25)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             z.set_ylim(0,60) ## yaxis
             ## plot fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='black',
                     #label=('initial=%s' %lvls[i]),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='black',
                             alpha = 0.3,
                             )
             z.text(0.90, 0.80, 'new wood = %s' %lvls[i],
                     verticalalignment='bottom', horizontalalignment='right',
                     transform=z.transAxes,
                     color='black', fontsize=25)

             handles, labels = z.get_legend_handles_labels()
             z.legend(handles, labels, prop={'size':20})
             z.set_ylabel("Substrates occupied")
             z.set_xlabel("Timestep")
```



It looks like with the forest and fungi we've built, a non-viaphytic fungus needs a regular supply of at least 12 or 14 in wood energy deposited each step to survive. With less than than this, we have some level of starvation. Also interesting to note that there is an abundance of wood on these landscapes from initialization of the model, but that more even more wood is required to enable fungal populations to rise sharply to and consume these resources. This is presumably due to the need for new wood to bridge gaps to areas of plentiful uncolonized substrate.

Section **??**

Basic competition experiments

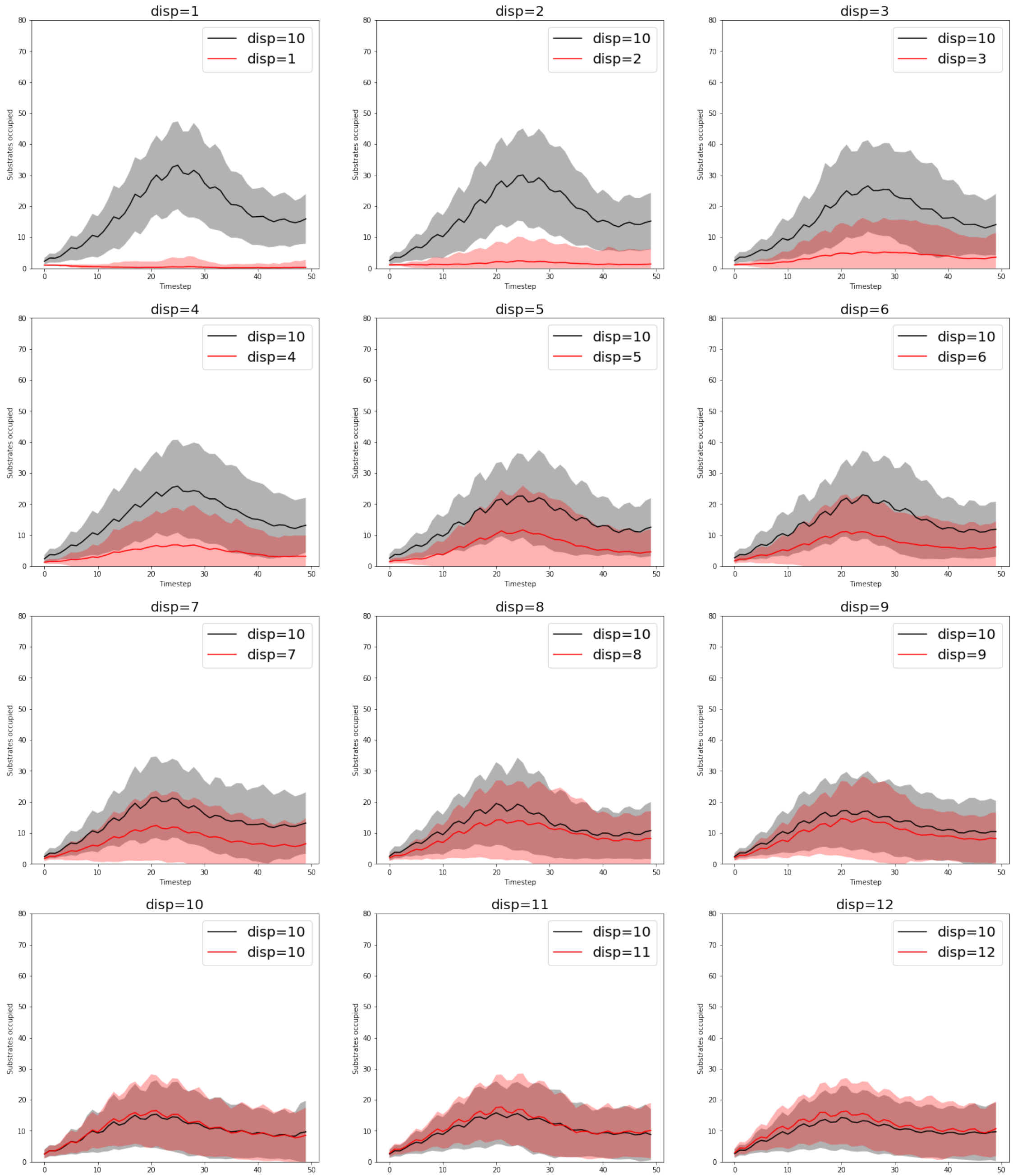
Let's examine what happens when we compete two non-viaphytic fungi. We'll hold one species' dispersal ability constant at d=10, and vary the other's from 1 to 14.

```
In [ ]: ## aciss
        mpiexec -n 11 python3 runFA.py -no-endophytism -sims 10 -endodisp 1  -fileout /home6/d
```

```
In [27]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/EC-EC-comp/DDdisp
```

```
In [28]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i)
```

```
In [29]: x = list(range(50))
         fig, axes = plt.subplots(4,3, figsize=(25, 30)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ## c
             z.set_ylim(0,80) ## yaxis

             ## plot unchanging, default fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='black',
                     label=('disp=10'),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='black',
                             alpha = 0.3,
                             )

                 ## plot fungus with changing disp:
             z.plot(x, runplotdata[lvls[i]]['endo_means'],
                     '-',
                    c='red',
                     label=('disp=%s' %lvls[i]),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                             runplotdata[lvls[i]]['endo_downdev'],
                             linewidth=0,
                             facecolor='red',
                             alpha = 0.3,
                             )

             handles, labels = z.get_legend_handles_labels()
             z.legend(handles, labels, prop={'size':20})
             z.set_ylabel("Substrates occupied")
             z.set_xlabel("Timestep")
             z.set_title('disp=%s' %lvls[i], {'fontsize':20})
```



Any fungal agent population with a dispersal coefficient d less that 8 just can't keep up. Conversely, when we ratchet our newcomer to d=11 or 12, both populations seem to suffer - both have a chance of going to zero. So there is a dispersal arms race here. For a competitor to persist on a landscape that contains aggressive fungal agents, the competitor must have dispersal abilities very close to their high rates and distance of spore dispersal. Or they must seek another strategy for dispersal...

Section **??**

Viaphyte survival

Let's see how viaphytes survive on the landscape, if we give leaves from trees a dispersal coefficient of 4 (see notes on this. As above we start with the model defaults. From here on, the sweeps are too expensive to be run serially, use mpi on aciss to handle them, even patches.

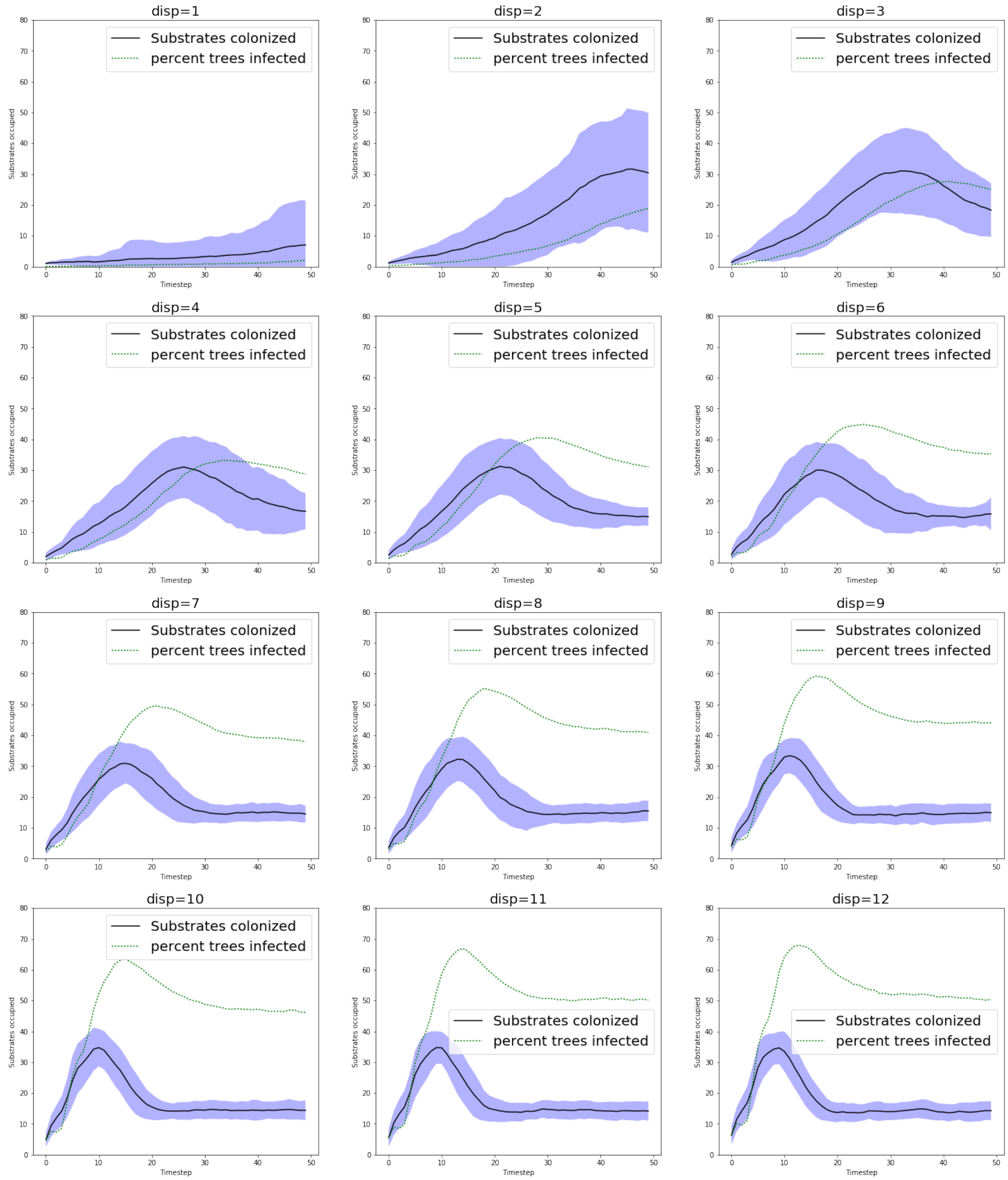
So let's run a sweep of viaphytes dispersal coefficients, from 1 to 12.

```
In [ ]: mpiexec -n 11 python3 runFA.py -sims 10 -endodisp 1 -endophytism True -fileout '/home6/
```

```
In [53]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/endo_disp/endodisp
```

```
In [54]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i)
```

```
In [83]: x = list(range(50))
         fig, axes = plt.subplots(4,3, figsize=(25, 30)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ## c
             z.set_ylim(0,80) ## yaxis
             ## plot fungus:
             z.plot(x, runplotdata[lvls[i]]['endo_means'],
                     '-',
                    c='black',
                     label=('Substrates colonized'),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                           runplotdata[lvls[i]]['endo_downdev'],
                           linewidth=0,
                           facecolor='blue',
                           alpha = 0.3,
                           )
             ## trees infected:
             z.plot(x, treepercent,
                     ':',
                     label=('percent trees infected'),
                     c='green',
                   )

             handles, labels = z.get_legend_handles_labels()
             z.legend(handles, labels, prop={'size':20})
             z.set_ylabel("Substrates occupied")
             z.set_xlabel("Timestep")
             z.set_title('disp=%s' %lvls[i], {'fontsize':20})
```



Even with a pretty low rate of endophyte loss (5% per step), the endophytes in the trees are affected by the amount of litter on the forest floor.

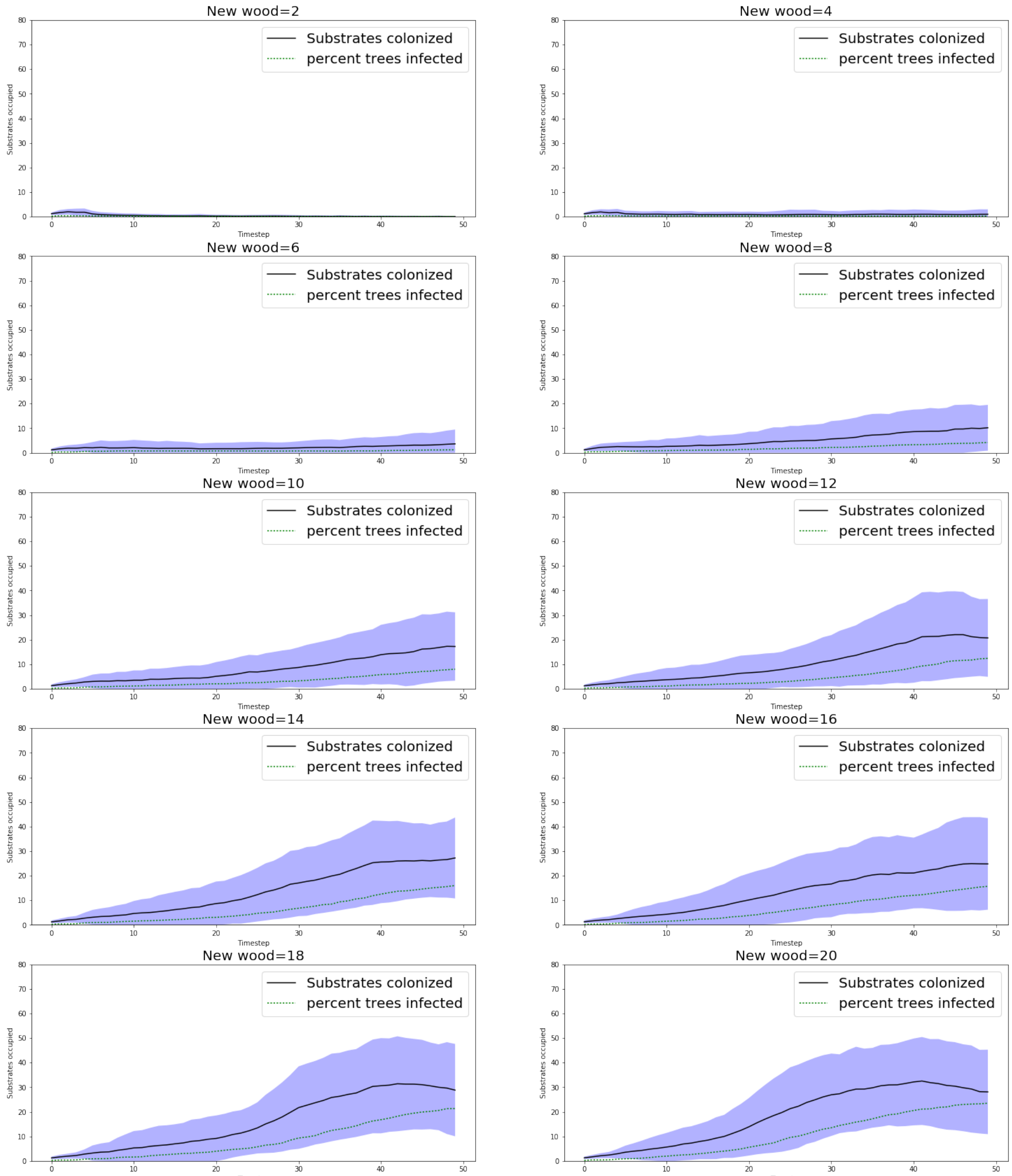
Interesting. Under these, being an endophyte is useful quickly. Even fungus that can only disperse it's spores at disp=1 to persist on the landscape much of the time, in the dense forest scenario we are using. Notice also that even with the low default rate of endophyte loss (5% per step), the abundance of endophyte-stage fungi is sensitive to the patterns of woody debris on the forest floor.

Section **??**

1.7 Effect of wood deposition on viaphytes

Does having an endophytice phase in your lifestyle change your relationship to wood? Sweeping the rate of deposition of new wood on the landscape, with only viaphytic fungal agents present.

```
In [ ]: mpiexec -n 11 python3 runFA.py -numdecomp 0 newwood 2 -sims 10 -fileout /home6/dthomas/

In [106]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/endo_newwood/endo

In [107]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
          runplotdata = {}
          for i in lvls:
              runplotdata[i] = pr.pldata(runs, i)

In [110]: x = list(range(50))
          fig, axes = plt.subplots(5,2, figsize=(25, 30)) ## set figure, nrows and ncols, size
          for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
              treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ##
              z.set_ylim(0,80) ## yaxis
              ## plot fungus:
              z.plot(x, runplotdata[lvls[i]]['endo_means'],
                      '-',
                     c='black',
                      label=('Substrates colonized'),
                      )
              ## error fill
              z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                              runplotdata[lvls[i]]['endo_downdev'],
                              linewidth=0,
                              facecolor='blue',
                              alpha = 0.3,
                              )
              ## trees infected:
              z.plot(x, treepercent,
                      ':',
                      label=('percent trees infected'),
                      c='green',
                     )

              handles, labels = z.get_legend_handles_labels()
              z.legend(handles, labels, prop={'size':20})
              z.set_ylabel("Substrates occupied")
              z.set_xlabel("Timestep")
              z.set_title('New wood=%s' %lvls[i], {'fontsize':20})
```



Section **??**

1.8 Endophyte competition experiments

Now let's see if viaphytic fungi can compete against more aggressive, non-viaphytic fungi. In this sweep, we hold a non f-viaphytic fungal agent constant at the default d=10, and increment our viaphytic fungal agent from d=1 to d=12. The instructions to aciss for the first level (viaphyte d=1, non-viaphyte d=10) look like this:

```
In [ ]: mpiexec -n 10 python3 runFA.py -endodisp 1 -sims 10  -fileout ##...

In [117]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/endodecomp_comp/e

In [118]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
          runplotdata = {}
          for i in lvls:
              runplotdata[i] = pr.pldata(runs, i)

In [120]: x = list(range(50))
          fig, axes = plt.subplots(4,3, figsize=(25, 30)) ## set figure, nrows and ncols, size
          for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with the
              treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ##
              z.set_ylim(0,80) ## yaxis

              ## plot red fungus:
              z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                      '-',
                     c='red',
                      label=('Strong decomposer'),
                      )
              ## error fill
              z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                                runplotdata[lvls[i]]['decomp_downdev'],
                                linewidth=0,
                                facecolor='red',
                                alpha = 0.3,
                                )

                  ## plot blue fungus:
              z.plot(x, runplotdata[lvls[i]]['endo_means'],
                      '-',
                     c='blue',
                      label=('disp=%s' %lvls[i]),
                      )
              ## error fill
              z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                                runplotdata[lvls[i]]['endo_downdev'],
                                linewidth=0,
                                facecolor='blue',
                                alpha = 0.3,
                                )

              ## trees infected:
              z.plot(x, treepercent,
                      ':',
                      linewidth=1,
                      label=('percent trees infected'),
```

```
        c='green',
      )

handles, labels = z.get_legend_handles_labels()
z.legend(handles, labels, prop={'size':20})
z.set_ylabel("Substrates occupied")
z.set_xlabel("Timestep")
z.set_title('disp=%s' %lvls[i], {'fontsize':20})
```

Under default settings, the endophytic lifestyle seems to be pretty beneficial. Even at viaphytic d=2 vs. non-viaphytic d=10, we have endophytes persisting on the landscape in some runs. At 3/8, viaphytism becomes a clear advantage, and beyond this the viaphyte species totally outcompetes the non-viaphyte.

Section **??**

Effect of endophyte loss

The residence time of endophytes in host trees isn't really understood and probably varies wildly with species of host and microbe. The defaults are set at endoloss=0.05, so that every infected tree has a 5% chance of losing it's infection. Our model defaults give viaphytes fungi a strong advantage at d=2, over default non-viaphytic fungi (d=10). But loss of endophyte infection by trees if fairly low in defaults, and we don't know how sensitive endophyte competitiveness is to the rate of endophyte loss. We'll increment the rate of endophyte loss from 0 to 90%.

```
In [ ]: #aciss
        mpiexec -n 11 python3 runFA.py -sims 10 -endodisp 3 -endoloss 0   -endophytism True  -
```

```
In [124]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/endoloss/endolos
```

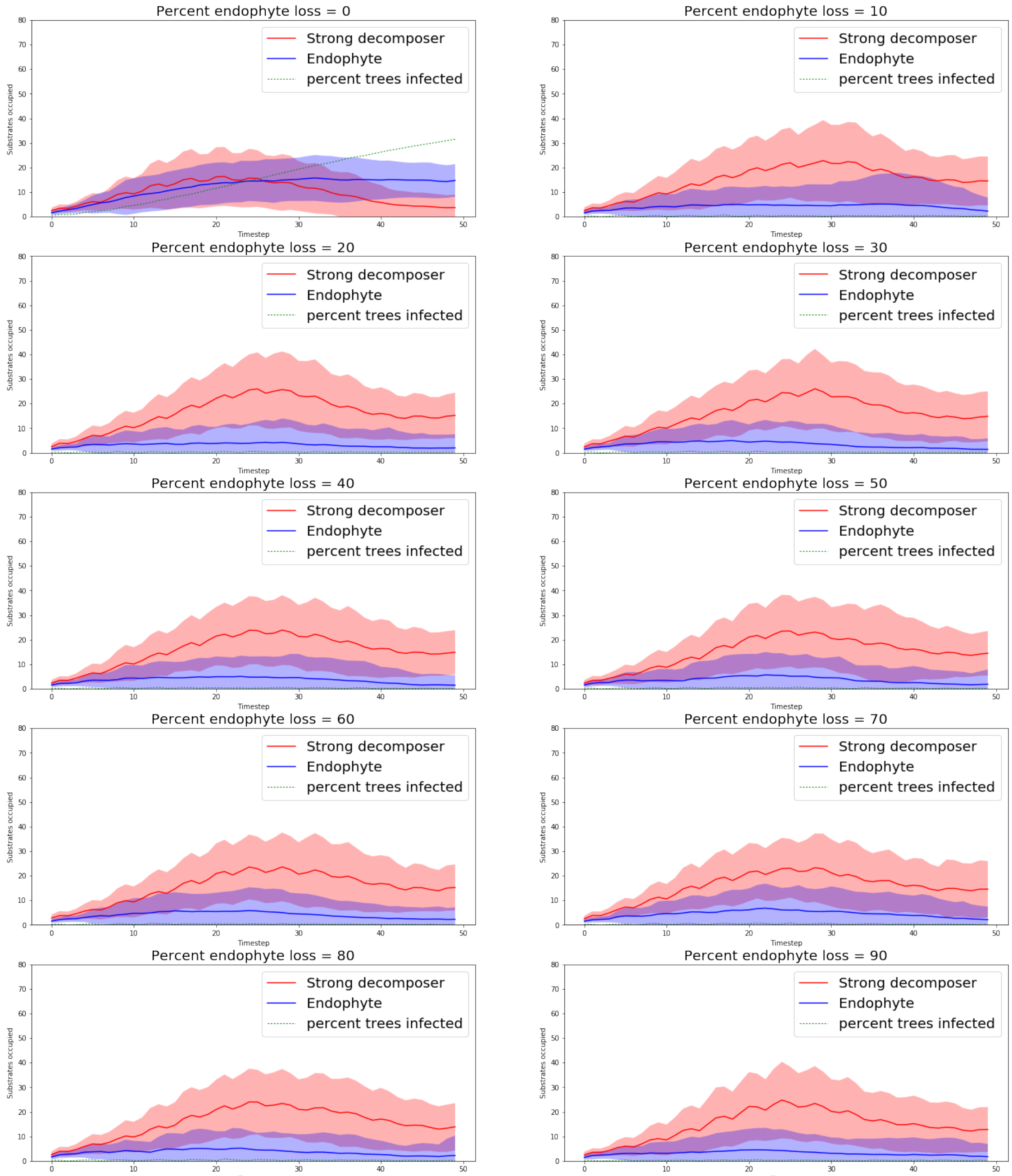
```
In [125]: lvls = sorted(list(runs.keys())) ## lvls of the run, from large to small
          runplotdata = {}
          for i in lvls:
              runplotdata[i] = pr.pldata(runs, i)
```

```
In [126]: lvls
```

```
Out[126]: [0, 10, 20, 30, 40, 50, 60, 70, 80, 90]
```

```
In [127]: x = list(range(50))
          fig, axes = plt.subplots(5,2, figsize=(25, 30)) ## set figure, nrows and ncols, size
          for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with the
              treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ##
              z.set_ylim(0,80) ## yaxis

              ## plot red fungus:
              z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                      '-',
                     c='red',
                      label=('Strong decomposer'),
                      )
              ## error fill
              z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                              runplotdata[lvls[i]]['decomp_downdev'],
                              linewidth=0,
                              facecolor='red',
                              alpha = 0.3,
                              )

                  ## plot blue fungus:
              z.plot(x, runplotdata[lvls[i]]['endo_means'],
```

```
         '-',
        c='blue',
         label=('Endophyte'),
         )
## error fill
z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                runplotdata[lvls[i]]['endo_downdev'],
                linewidth=0,
                facecolor='blue',
                alpha = 0.3,
                )

## trees infected:
z.plot(x, treepercent,
         ':',
         linewidth=1,
         label=('percent trees infected'),
         c='green',
       )

handles, labels = z.get_legend_handles_labels()
z.legend(handles, labels, prop={'size':20})
z.set_ylabel("Substrates occupied")
z.set_xlabel("Timestep")
z.set_title('Percent endophyte loss = %s' %lvls[i], {'fontsize':20})
```



Okay, looks like this system is extremely sensitive to endophyte loss by trees. If endophytes are lost at ~10% or higher per step, it looks like the decomposer stage of the viaphyte fungal agent serves as the main propopagator, and endophytism is a little bit of a dead end. Less that, under otherwise default conditions, endophytism as a dispersal strategy rewards the fungus.

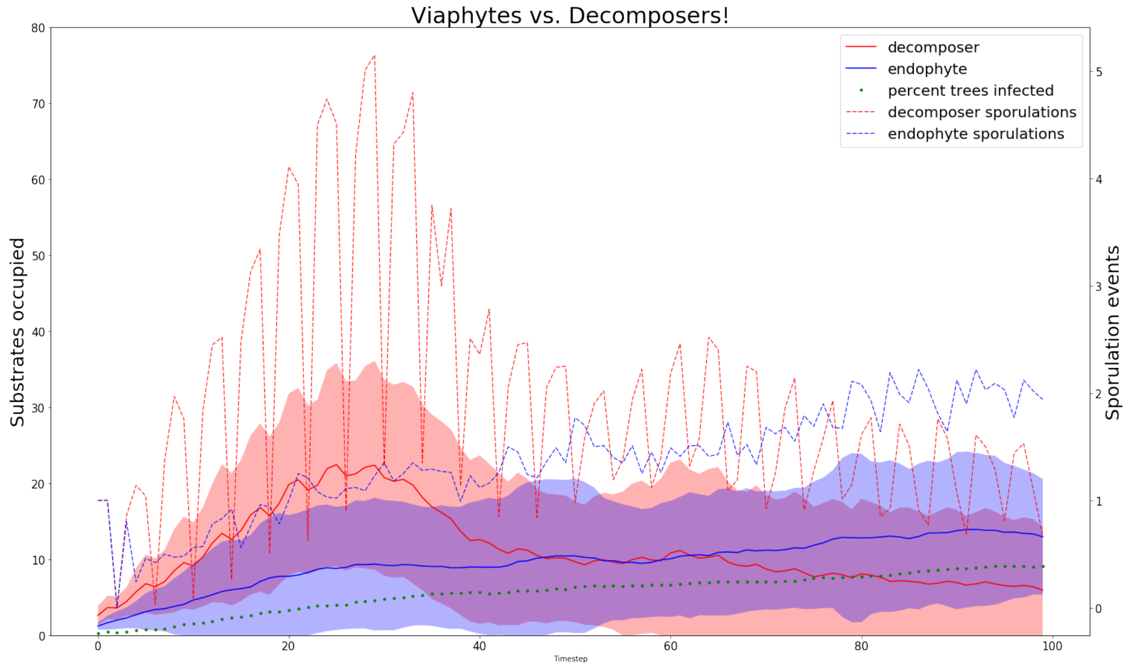
Section **??**

100-Step control run

Though I really wrote the model to handle short-term ecological simulations (~10-20 years), let's let it run this competition model little longer, and look at sporulation events, which are another way of measuring fitness besides number of substrates occupied. Will be useful for comparisons with deforestation runs.

```
In [73]: control = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/thinonce/contro

In [74]: runplotdata = pr.pldata_single(control,steps=100) ## use our single-level parser

In [76]: x = list(range(100))
         fig = plt.figure(figsize=(25, 15))
         z = fig.add_subplot(111)
         z2 = z.twinx()
         treepercent=[ (i/634)*100 for i in runplotdata['inf_trees_means'] ] ## convert mean t
         z.set_ylim(0,80) ## yaxis

         ## plot red fungus:
         z.plot(x, runplotdata['decomp_means'],
                 '-',
                c='red',
                 label=('decomposer'),
                 )
         ## error fill
         z.fill_between(x, runplotdata['decomp_updev'],
                         runplotdata['decomp_downdev'],
                         linewidth=0,
                         facecolor='red',
                         alpha = 0.3,
                         )
         ## plot blue fungus:
         z.plot(x, runplotdata['endo_means'],
                 '-',
                c='blue',
                 label=('endophyte'),
                 )

         ## error fill
         z.fill_between(x, runplotdata['endo_updev'],
                         runplotdata['endo_downdev'],
                         linewidth=0,
                         facecolor='blue',
                         alpha = 0.3,
                         )
         ## trees infected:
         z.plot(x, treepercent,
                 '.',
                 linewidth=1,
                 label=('percent trees infected'),
                 c='green',
               )
```

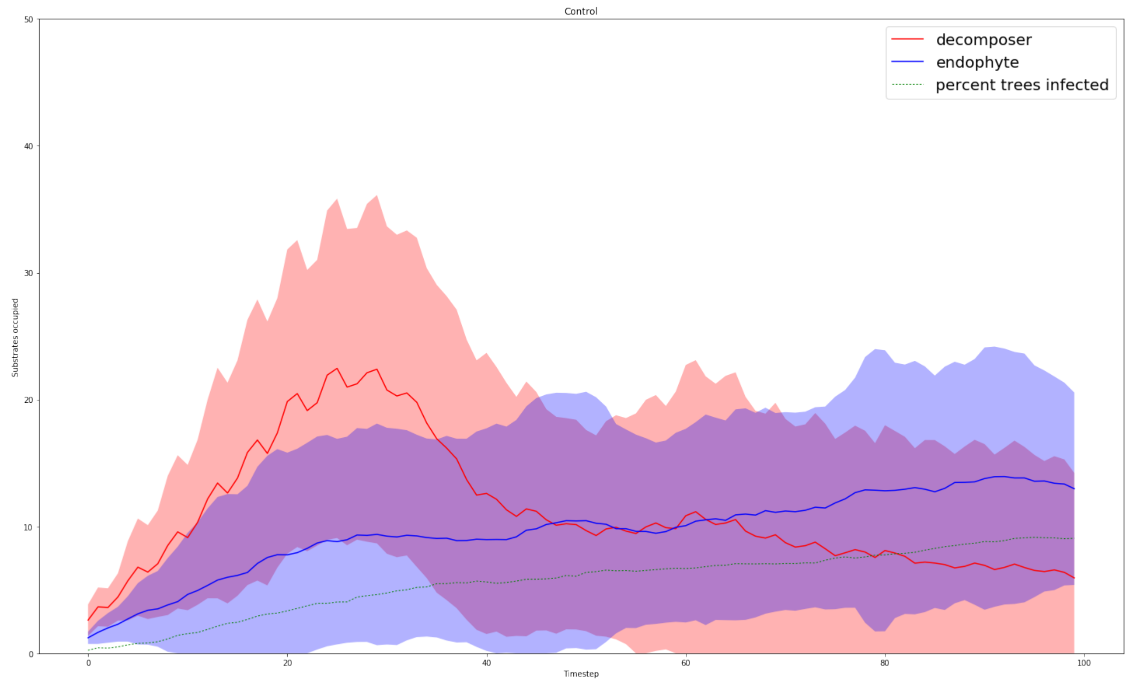
```
## decomposer sporulations
z2.plot(x, runplotdata['despo_means'],
        '--',
        linewidth=1,
        label=('decomposer sporulations'),
        c='red',
        )
## endo sporulations
z2.plot(x, runplotdata['espo_means'],
        '--',
        linewidth=1,
        label=('endophyte sporulations'),
        c='blue',
        )

## combine legend info from both axes
aa=z.get_legend_handles_labels()
bb=z2.get_legend_handles_labels()
handles = aa[0] + bb[0]
labels = aa[1] + bb[1]

z.legend(handles, labels, prop={'size':20})
z.set_ylabel("Substrates occupied", {'fontsize':25})
z2.set_ylabel("Sporulation events", {'fontsize':25})
z.set_xlabel("Timestep")
z.set_title('Viaphytes vs. Decomposers!', {'fontsize':30})
z.tick_params(labelsize=15)
z2.tick_params(labelsize=15)
```



A less cluttered version here, for the manuscript.

```
In [80]: x = list(range(100))
         fig = plt.figure(figsize=(25, 15))
         z = fig.add_subplot(111)
         treepercent=[ (i/634)*100 for i in runplotdata['inf_trees_means'] ] ## convert mean t
         z.set_ylim(0,50) ## yaxis

         ## plot red fungus:
         z.plot(x, runplotdata['decomp_means'],
                 '-',
                c='red',
                 label=('decomposer'),
                 )
         ## error fill
         z.fill_between(x, runplotdata['decomp_updev'],
                         runplotdata['decomp_downdev'],
                         linewidth=0,
                         facecolor='red',
                         alpha = 0.3,
                         )
         ## plot blue fungus:
         z.plot(x, runplotdata['endo_means'],
                 '-',
                c='blue',
                 label=('endophyte'),
                 )

         ## error fill
         z.fill_between(x, runplotdata['endo_updev'],
                         runplotdata['endo_downdev'],
                         linewidth=0,
                         facecolor='blue',
                         alpha = 0.3,
                         )
         ## trees infected:
         z.plot(x, treepercent,
                 ':',
                 linewidth=1,
                 label=('percent trees infected'),
                 c='green',
               )

         handles, labels = z.get_legend_handles_labels()
         z.legend(handles, labels, prop={'size':20})
         z.set_ylabel("Substrates occupied")
```

```
z.set_xlabel("Timestep")
z.set_title('Control')

plt.savefig('graphics/manuscript/control.svg')
```



Section **??**

2 Deforestation

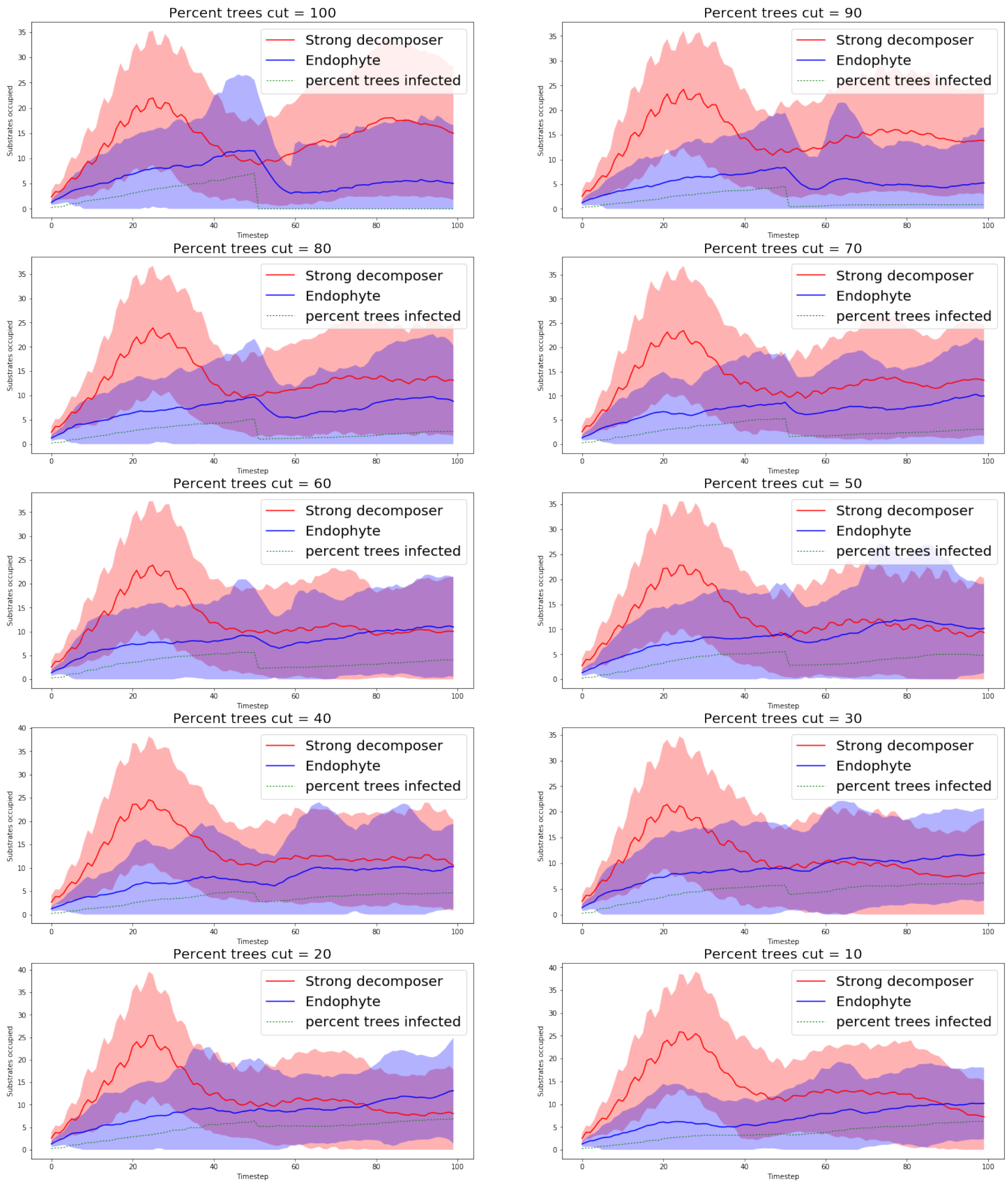
We'll look at three scenarios of deforestation (see notes here).

2.1 Single thin event

The first is a general thin of trees across the landscape. We'll sweep across intensities of thinning, invoking a single thin event at step 51 of 100:

```
In [ ]: mpiexec -n 10 python3 runFA.py -sims 10 -steps 100 -deforest_type thin -deforest_steps

In [35]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/thinonce/thinonce

In [36]: lvls = sorted(list(runs.keys()))[::-1] ########## reversed
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i, 100)
```

```
In [37]: x = list(range(100))
         fig, axes = plt.subplots(5,2, figsize=(25, 30)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ## c
             #z.set_ylim(0,80) ## yaxis

             ## plot red fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='red',
                     label=('Strong decomposer'),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='red',
                             alpha = 0.3,
                             )

                 ## plot blue fungus:
             z.plot(x, runplotdata[lvls[i]]['endo_means'],
                     '-',
                    c='blue',
                     label=('Endophyte'),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                             runplotdata[lvls[i]]['endo_downdev'],
                             linewidth=0,
                             facecolor='blue',
                             alpha = 0.3,
                             )

             ## trees infected:
             z.plot(x, treepercent,
                     ':',
                     linewidth=1,
                     label=('percent trees infected'),
                     c='green',
                   )

             handles, labels = z.get_legend_handles_labels()
             z.legend(handles, labels, prop={'size':20})
             z.set_ylabel("Substrates occupied")
             z.set_xlabel("Timestep")
             z.set_title('Percent trees cut = %s' %lvls[i], {'fontsize':20})
```



In this style of cut, endophytes seem to be able to sustain in up to perhaps a 70% reduction in canopy, even under fairly intense harvest. However, they don't prosper, persisting but not outcompeting viaphytes after reductions of tree agents larger than 30% or 40%.

Section **??**

Serial thinning

Let's take a look at the effects of high-grading timber repeatedly, as often occurs in state forest reserves.

```
In [42]: ##aciss
```

```
mpiexec -n 10 python3 runFA.py -sims 10 -steps 100 -deforest_type thin -deforest_steps
```

```
In [82]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/serialthin/serialt
```

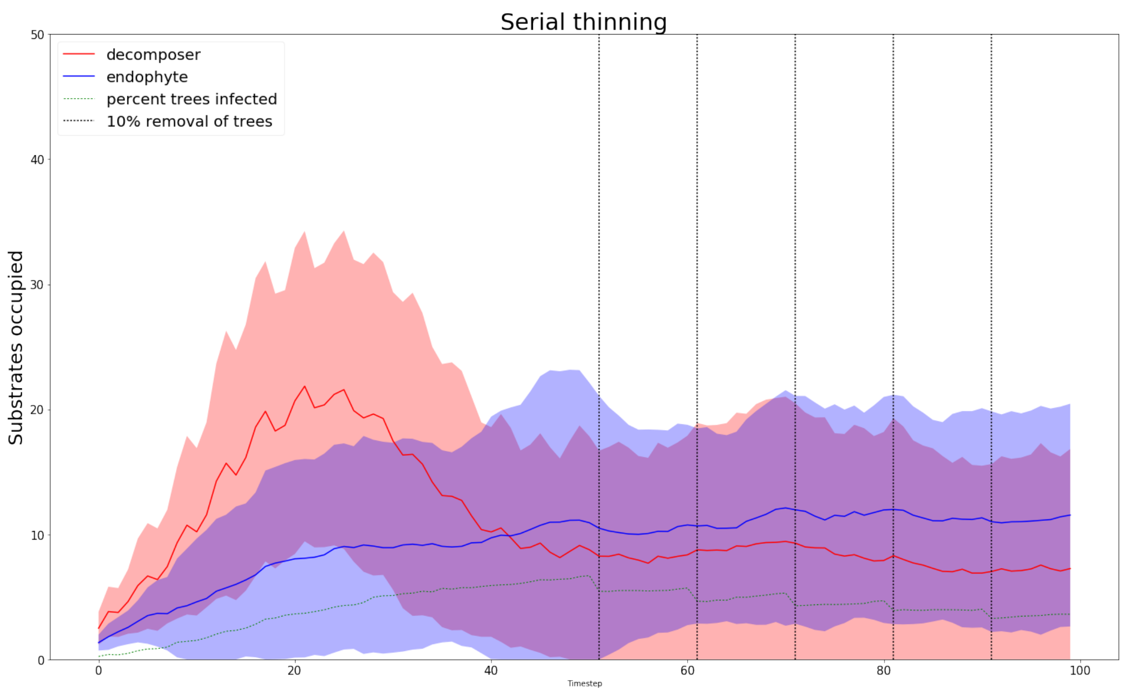
```
In [83]: runplotdata = pr.pldata_single(runs,100) ## use our single-level parser
```

```
In [84]: runplotdata.keys()
```

```
Out[84]: dict_keys(['despo_downdev', 'decomp_means', 'espo_means', 'inf_trees_means', 'despo_me
```

```
In [86]: x = list(range(100))
         fig = plt.figure(figsize=(25, 15))
         z = fig.add_subplot(111)
         inf_treepercent=[ (i/634)*100 for i in runplotdata['inf_trees_means'] ] ## convert in
         treepercent=[ (i/634)*100 for i in runplotdata['trees_means'] ] ## convert mean trees
         z.set_ylim(0,50) ## yaxis
         ## plot red fungus:
         z.plot(x, runplotdata['decomp_means'],
                 '-',
                c='red',
                 label=('decomposer'),
                 )
         ## error fill
         z.fill_between(x, runplotdata['decomp_updev'],
                         runplotdata['decomp_downdev'],
                         linewidth=0,
                         facecolor='red',
                         alpha = 0.3,
                         )
         ## plot blue fungus:
         z.plot(x, runplotdata['endo_means'],
                 '-',
                c='blue',
                 label=('endophyte'),
                 )

         ## error fill
         z.fill_between(x, runplotdata['endo_updev'],
                         runplotdata['endo_downdev'],
                         linewidth=0,
                         facecolor='blue',
                         alpha = 0.3,
                         )
         ## trees infected:
         z.plot(x, inf_treepercent,
                 ':',
                 linewidth=1,
                 label=('percent trees infected'),
                 c='green',
```

```
        )


    ## show times of tree removal with vertical bars

    z.plot((51,51),(0,50),":", c='black')
    z.plot((61,61),(0,50),":", c='black')
    z.plot((71,71),(0,50),":", c='black')
    z.plot((81,81),(0,50),":", c='black')
    z.plot((91,91),(0,50),":", c='black', label="10% removal of trees")

    handles, labels = z.get_legend_handles_labels()
    z.legend(handles, labels, prop={'size':20}, framealpha=0.3)
    z.set_ylabel("Substrates occupied", {'fontsize':25})
    z2.set_ylabel("Sporulation events", {'fontsize':25})
    z.set_xlabel("Timestep")
    z.set_title("Serial thinning", {'fontsize':30})
    z.tick_params(labelsize=15)
    z2.tick_params(labelsize=15)

    plt.savefig('graphics/manuscript//serialthin.svg')
```



Ultimately, this amounts to ~40% reduction in trees over time. Looks like a well established endophyte population can handle this kind of "gradual" thin better than the equivalent sudden reduction of all 70% at once.

Seems like this could only work if endophytes were well established on the landscape. What we've done here is let a poorly dispersing fungus get a leg up on its competitor for a decade through other means (viaphytism), and once dominance on the landscape is established, removed the crutch.

Section ??

Forest fragmentation

Let's take a look at the effects of removing large contiguous areas of forest, as often occurs in with land use conversions to agriculture, extraction, homesteading, etc.

```
In [ ]: ## aciss
       mpiexec -n 10 python3 runFA.py -sims 10 -steps 100 -deforest_type fragment -deforest_s
```

```
In [30]: runs = pd.read_pickle('/home/daniel/Documents/ABM/FA/sweeps/results/frag15/frag_rad15
```

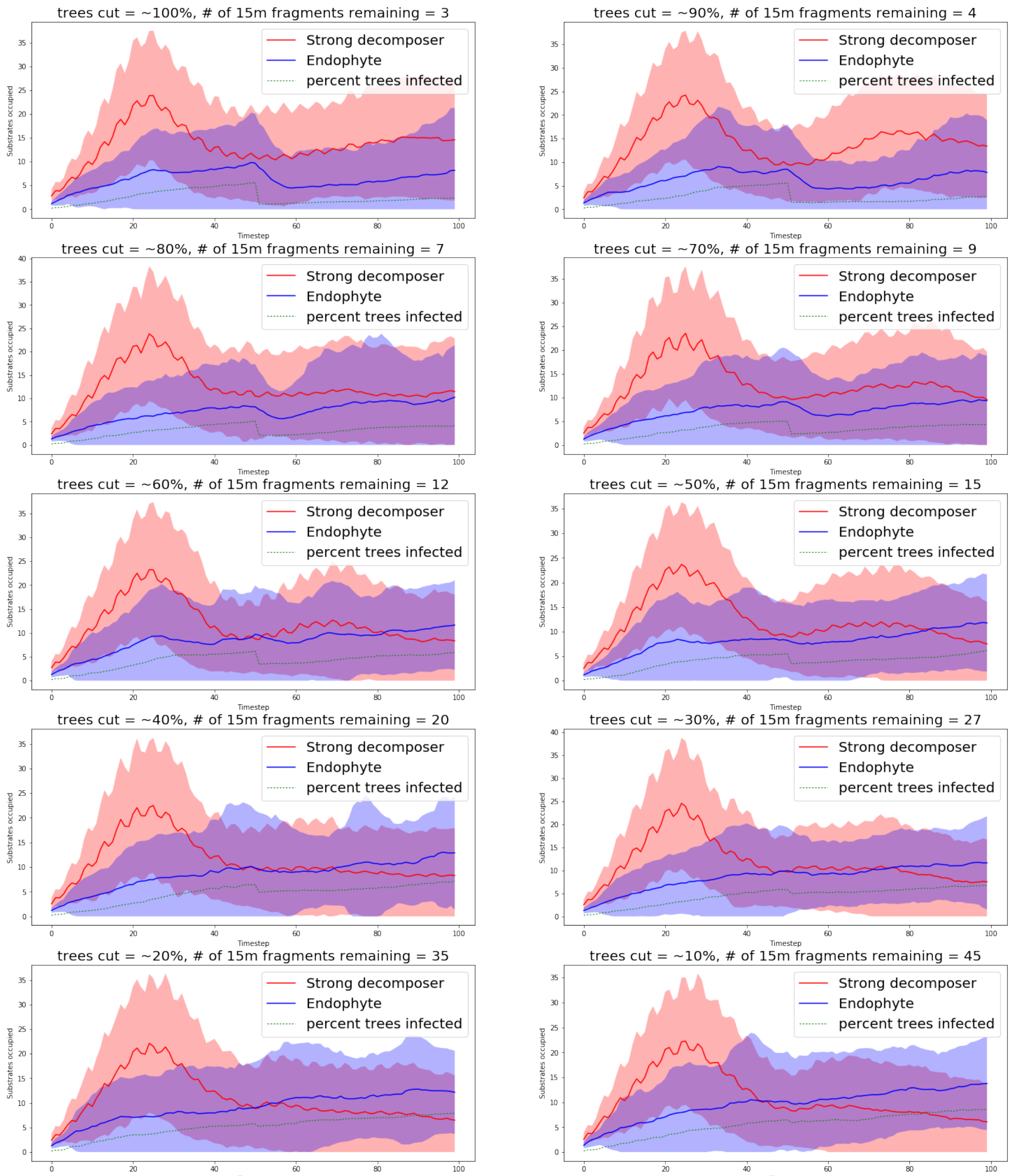
```
In [31]: lvls = sorted(list(runs.keys())) ## lvls of the run, sorted
         runplotdata = {}
         for i in lvls:
             runplotdata[i] = pr.pldata(runs, i, 100)
```

```
In [32]: lvls
```

```
Out[32]: [3, 4, 7, 9, 12, 15, 20, 27, 35, 45]
```

```
In [34]: x = list(range(100))
         fig, axes = plt.subplots(5,2, figsize=(25, 30)) ## set figure, nrows and ncols, sizes
         for i,z in enumerate(axes.flatten()): ## unroll our array of subplots, deal with them
             treepercent=[ (i/634)*100 for i in runplotdata[lvls[i]]['inf_trees_means'] ] ## c
             #z.set_ylim(0,80) ## yaxis

             ## plot red fungus:
             z.plot(x, runplotdata[lvls[i]]['decomp_means'],
                     '-',
                    c='red',
                     label=('Strong decomposer'),
                     )
             ## error fill
             z.fill_between(x, runplotdata[lvls[i]]['decomp_updev'],
                             runplotdata[lvls[i]]['decomp_downdev'],
                             linewidth=0,
                             facecolor='red',
                             alpha = 0.3,
                             )

                 ## plot blue fungus:
             z.plot(x, runplotdata[lvls[i]]['endo_means'],
                     '-',
                    c='blue',
                     label=('Endophyte'),
                     )
             ## error fill
```

```
z.fill_between(x, runplotdata[lvls[i]]['endo_updev'],
                runplotdata[lvls[i]]['endo_downdev'],
                linewidth=0,
                facecolor='blue',
                alpha = 0.3,
                )

## trees infected:
z.plot(x, treepercent,
        ':',
        linewidth=1,
        label=('percent trees infected'),
        c='green',
      )

handles, labels = z.get_legend_handles_labels()
z.legend(handles, labels, prop={'size':20})
z.set_ylabel("Substrates occupied")
z.set_xlabel("Timestep")
perc = [10,20,30,40,50,60,70,80,90,100][::-1]
z.set_title('trees cut = ~%s%%, # of 15m fragments remaining = %s' %(perc[i],lvls
```



Similar to thinning results above, in that viaphytes can often persist even through a 60%-70% loss of tree agents. The main difference seems to be that viaphytes do a little better, not just persisting, but also retaining a competitive advantage up to 60% loss.

Section **??**

```
In [ ]:
```