plotting (pnas)

January 19, 2021

 Jupyter Python 3 notebook for reproducing figures in PNAS manuscript, "Growth, death, and competition in sessile organisms" by ED Lee, CP Kempes, and GB West. In order to reproduce the figures, the corresponding pickles must be generated by running the code in `pipeline.py`.

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[36]:
```
%pylab inline
```

```
Populating the interactive namespace from numpy and matplotlib
```

[37]:
```
plt.rc('font', size=20)
```

[61]:
```
# import necessary Python modules
from pyutils import *
from statsmodels.distributions import ECDF
import os
from misc.plot import colorcycle
import pandas as pd
from matplotlib.patches import Circle
from matplotlib.collections import PatchCollection
from matplotlib.gridspec import GridSpec, GridSpecFromSubplotSpec
```

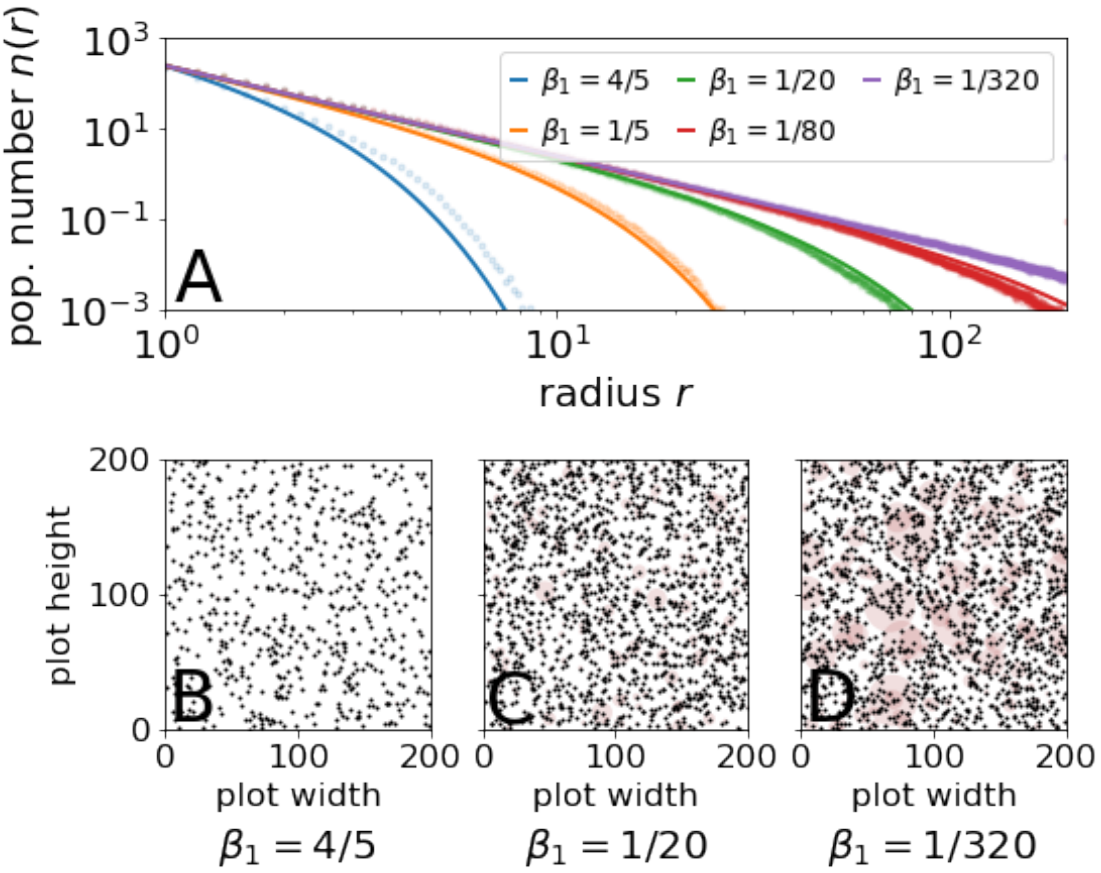
```
from matplotlib.offsetbox import OffsetImage, AnnotationBbox
from matplotlib.image import imread
from mpl_toolkits.axes_grid1.inset_locator import inset_axes

# set image save path
imgdr = os.path.expanduser('~') + '/Dropbox/Research/forests/writing/
 ↪20201130_pnas'
assert os.path.isdir(imgdr), "Directory in which to save images does not exist."
```

1 Figure 2

[602]:
```
# is the disagreement from the fact that the "core" of the tree is less likely␣
 ↪to have competitors
# such that you actually don't compete with all of you're area?
load_pickle('cache/biomass_scaling_w_compet_nu=2.5.p.bak')

for k in nk.keys():
    nk[k] = np.concatenate([i[-1000:,:,None] for i in nk[k]], axis=2).mean(2)

kappa = (1.8 - 4/3) * (nu-1)
f = forest.coeffs['sharing fraction']
rhobar = forest.coeffs['resource efficiency']
cr = forest.coeffs['root']**2 * np.pi

lastn = 1000

gs = GridSpec(2, 3, hspace=.55)
fig = plt.figure(figsize=(8,6.3))
ax = fig.add_subplot(gs[0,:])

h = []
for i, (rk_, nk_) in enumerate(zip(rk.values(), nk.values())):
    h.append(ax.plot(rk_[0], nk_[-lastn:].mean(0), '.', zorder=0, alpha=.14))

    beta1 = basalRange[i]
    vareps = forest.coeffs['resource efficiency']
    assert nu>2
    xi0 = (nu-2)**(1/(2-nu))

    B = (beta1 * xi0 / vareps / rhobar / cr / (1-f))**(nu-1) / (nu-1)
    s = forest.coeffs['area competition']
    dx = rk_[0][1] - rk_[0][0]
    n0 = g0 / (Abar + cg/dx + A * r0**kappa)

    y = (n0 * (rk_[0]/r0)**(-1/3 - Abar/cg) *
```

```
        np.exp(-B * s / cg / (kappa+2/3) * (rk_[0]**(kappa+2/3) - r0**(kappa+2/
↪3))))
    h.append(ax.loglog(rk_[0], y, '-', lw=2, c=f'C{i}', zorder=1)[0])

ax.text(1.05, 1.5e-3, 'A', fontsize=35)
ax.set(xlabel=r'radius $r$',
       ylabel=r'pop. number $n(r)$',
       ylim=(1e-3, 1e3),
       xlim=(1,199))
ax.legend(h[1::2],
          [r'$\beta_1=4/5$', r'$\beta_1=1/5$', r'$\beta_1=1/20$', r'$\beta_1=1/
↪80$', r'$\beta_1=1/320$'],
          fontsize='x-small',
          handlelength=.5, ncol=3, loc=1, columnspacing=1, handletextpad=.5)



load_pickle('plotting/biomass_scaling_w_compet_nu=2.5.p')

ax = [fig.add_subplot(gs[1,i]) for i in range(3)]
forest[basalRange[0]].plot(ax=ax[0],
                           show_canopy=False,
                           show_center=True)
ax[0].text(2, 6, 'B', fontsize=35)
[el.set_fontsize('small') for el in ax[0].yaxis.get_ticklabels()]
[el.set_fontsize('small') for el in ax[0].xaxis.get_ticklabels()]
ax[0].set_title(r'$\beta_1=4/5$', y=-.52, fontsize=20)
ax[0].set_xlabel('plot width', fontsize='small')
ax[0].set_ylabel('plot height', fontsize='small')

forest[basalRange[2]].plot(ax=ax[1],
                           show_canopy=False,
                           show_center=True,
                           plot_kw={'yticklabels':[]})
ax[1].text(2, 6, 'C', fontsize=35)
[el.set_fontsize('small') for el in ax[1].xaxis.get_ticklabels()]
ax[1].set_title(r'$\beta_1=1/20$', y=-.52, fontsize=20)
ax[1].set_xlabel('plot width', fontsize='small')

forest[basalRange[4]].plot(ax=ax[2],
                           show_canopy=False,
                           show_center=True,
                           plot_kw={'yticklabels':[]})
ax[2].text(2, 6, 'D', fontsize=35)
[el.set_fontsize('small') for el in ax[2].xaxis.get_ticklabels()]
ax[2].set_title(r'$\beta_1=1/320$', y=-.52, fontsize=20)
ax[2].set_xlabel('plot width', fontsize='small')
```

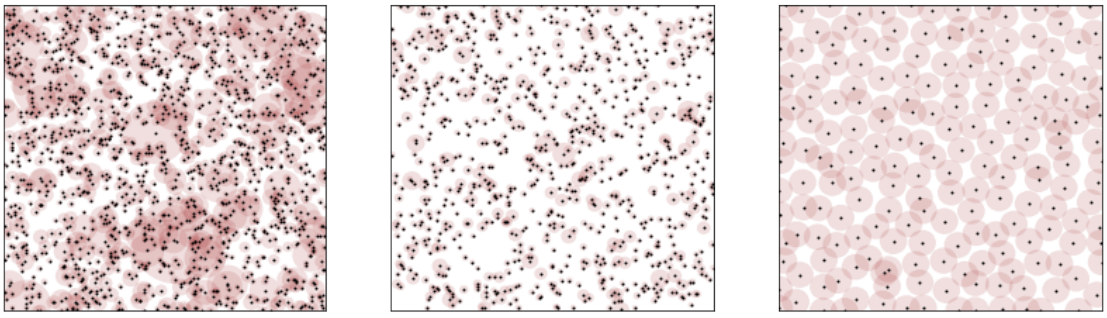
```
fig.savefig(f'{imgdr}/competition_example.pdf', bbox_inches='tight')
```



2 Figure 3

[27]:
```
fig, ax = plt.subplots(figsize=(14,4), ncols=3, sharex=True, sharey=True)
ax = ax[::-1]

load_pickle('cache/spacing_with_Abar_no_growth.p')
allxy = xy
xy = vstack(allxy[AbarRange[-1]][areaDeathRateRange[-1]][0])
data.plot(xy, [8.5]*len(xy), 200, ax=ax[0], show_center=True,
          plot_kw={'xticks':[],'yticks':[]});

load_pickle('plotting/biomass_scaling_w_compet_nu=2.0.p')
forest[basalRange[0]].plot(ax=ax[1],
                           show_canopy=False,
                           show_center=True,
```

```
                              plot_kw={'xticks':[], 'yticks':[]})

forest[basalRange[2]].plot(ax=ax[2],
                              show_canopy=False,
                              show_center=True,
                              plot_kw={'xticks':[], 'yticks':[]})

fig.subplots_adjust(wspace=.2)
fig.savefig(f'{imgdr}/spacing_examples.pdf', bbox_inches='tight')
```

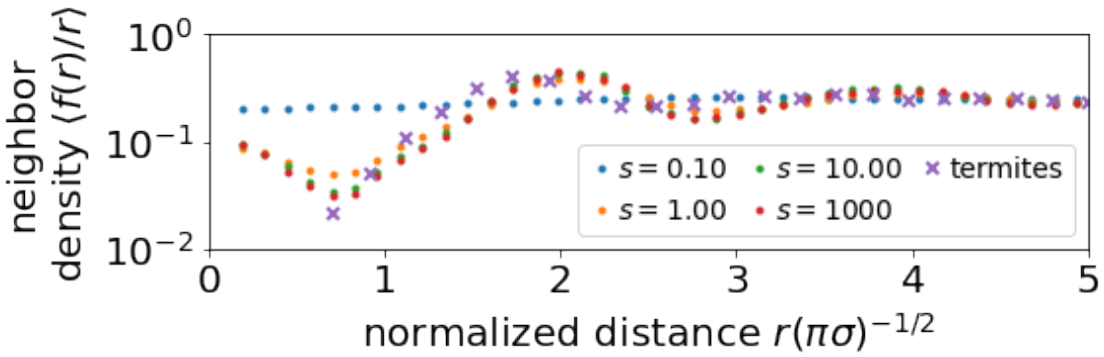


3 Figure 4

[492]:
```
load_pickle('plotting/spatial_correlation.p')

fig, ax = plt.subplots(figsize=(8,2))

for p_ in list(p.values())[::3]:
    # spatial autocorrelation function
    ax.semilogy(r, p_/r, '.')

namp, namr = data.namibia_corr_fcn()
drRatio = (namr[1]-namr[0]) / (r[1]-r[0])
ax.plot(namr, namp/namr / drRatio, 'x', mew=2)

ax.set(xlim=(0,5), yscale='log',
       xlabel=r"normalized distance $r(\pi\sigma)^{-1/2}$",␣
 ↪ylabel='neighbor\n'+r"density $\langle f(r)/r\rangle$")
ax.set(ylim=(1e-2,1), yticks=[1e-2,.1,1])
ax.legend([r'$s=%1.2f$'%i for i in areaDeathRateRange[::3]][:
 ↪-1]+[r'$s=1000$']+['termites'],
          ncol=3, fontsize='x-small', columnspacing=.6, handletextpad=.09,␣
 ↪handlelength=1)
```

```
fig.savefig(f'{imgdr}/spatial_corr.pdf', bbox_inches='tight')
```

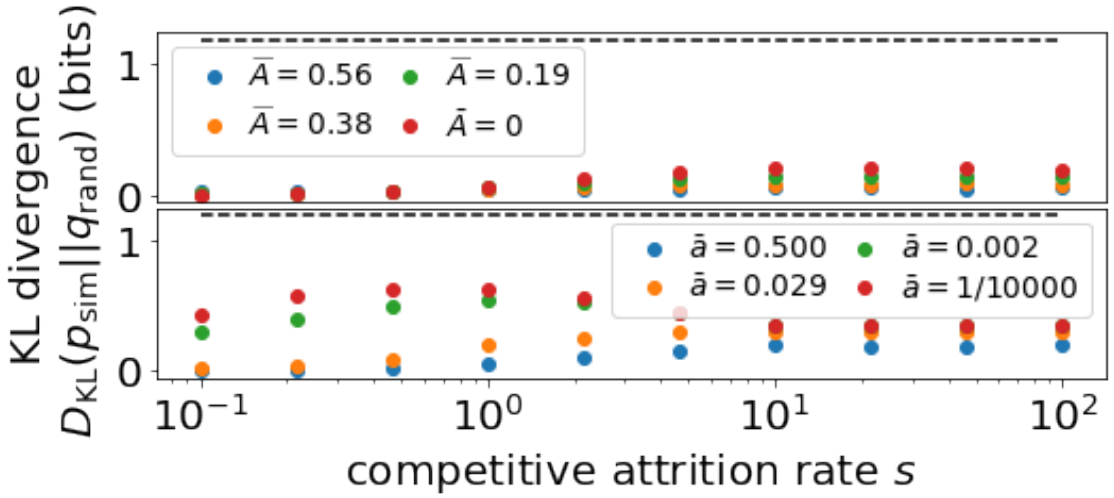
[492]:
```
<matplotlib.legend.Legend at 0x7f23d6c9c5b0>
```



[494]:
```
fig, ax = plt.subplots(figsize=(8,3), nrows=2, sharey=True,
                       gridspec_kw={'hspace':0.03})

load_pickle('plotting/dkl_Abar_range.p')
for kl_ in kl[1:]:
    ax[0].semilogx(areaDeathRateRange, kl_, 'o')

load_pickle('plotting/dkl_cg_range.p')
for kl_ in kl:
    ax[1].semilogx(areaDeathRateRange, kl_, 'o')

ax[0].hlines(1.19, areaDeathRateRange.min(), areaDeathRateRange.max(),
             linestyles='--')
ax[1].hlines(1.19, areaDeathRateRange.min(), areaDeathRateRange.max(),
             linestyles='--')

ax[1].set(xlabel=r'competitive attrition rate $s$',
          ylabel='            KL divergence\n'r'           $D_{\rm KL}(p_{\rm␣
 ↪sim}||q_{\rm rand})$ (bits)')
# ax[0].xaxis.set_tick_params(length=0)
ax[0].set(xticks=[])
ax[0].xaxis.set_ticks_position('none')
ax[1].set(ylim=ax[0].get_ylim())
ax[0].legend([r'$\widebar A=%1.2f$'%a for a in AbarRange[1:
 ↪-1]]+[r'$\bar{A}=0$'],
             fontsize='x-small', handletextpad=.2, ncol=2, loc=2,␣
 ↪columnspacing=.2)
ax[1].legend([r'$\bar{a}=%1.3f$'%a for a in cgRange[:-1]]+[r'$\bar{a}=1/
 ↪10000$'],
```

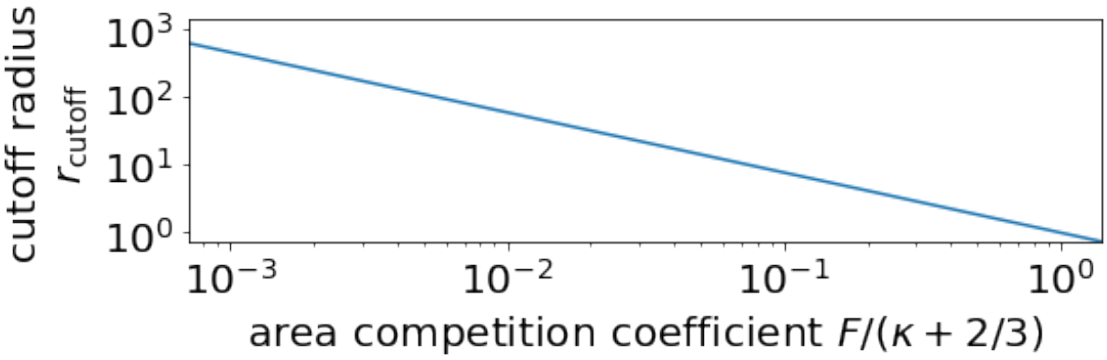
```
            fontsize='x-small', handletextpad=.2, ncol=2, loc=1,␣
↪columnspacing=.2, labelspacing=.2)

fig.savefig(f'{imgdr}/dkl.pdf', bbox_inches='tight')
```

[494]: <matplotlib.legend.Legend at 0x7f238551fbb0>



[572]:
```
fig, ax = plt.subplots(figsize=(8,2))

coeff = logspace(-4,1.1,10)
# coeff = linspace(1e-3,1,1000)
delta = 1.8 - 4/3

ax.loglog(coeff, coeff**(-1/(delta+2/3)), '-')

ax.set(xlabel=r'area competition coefficient $F/(\kappa+2/3)$',
       ylabel='cutoff radius\n'r'$r_{\rm cutoff}$',
       xlim=(0.000707945784384138, 1.4125375446227544),
       ylim=(0.7373047958716826, 1e3/0.7373047958716826))
ax.set(yticks=[1,10,100,1000])

fig.savefig(f'{imgdr}/cutoff_scaling.pdf', bbox_inches='tight')
```

[572]:
```
[[<matplotlib.axis.YTick at 0x7f235e7aaac0>,
  <matplotlib.axis.YTick at 0x7f2366134760>,
  <matplotlib.axis.YTick at 0x7f2365d2e460>,
  <matplotlib.axis.YTick at 0x7f23583e21c0>]]
```

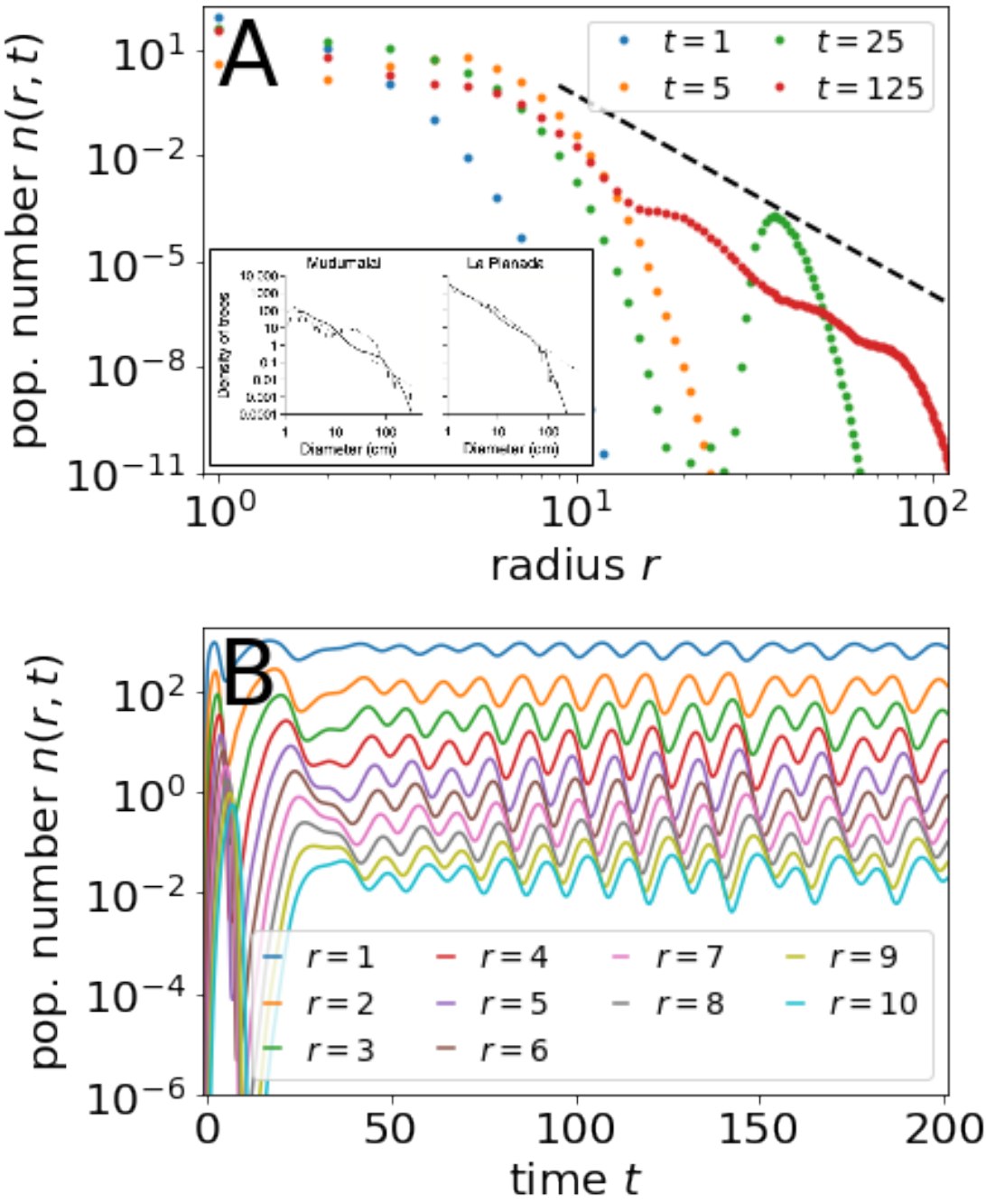


4 Figure 5

[518]:
```
fig, ax = plt.subplots(figsize=(6,9), nrows=2,
                       gridspec_kw={'hspace':.33})

tplot = [1, 5, 25, 125]
y = pd.read_csv('../mathematica/nk_oscillations.csv')
for i, t in enumerate(tplot):
    ax[0].plot(y.columns, y.iloc[i], '.')
x = array([9, 200])
y = x**(-6+1/3)
y *= 1 / y[0]
ax[0].loglog(x, y, 'k--', lw=2)

ax[0].set(xscale='log', yscale='log',
       xlabel=r'radius $r$', ylabel=r'pop. number $n(r,t)$')
ax[0].set(xlim=(.9, 100/.9), ylim=(1e-11, 2e2))
ax[0].legend([r'$t=%d$'%i for i in tplot],
             fontsize='x-small',
             ncol=2,
             handletextpad=.2,
             borderpad=.2,
             columnspacing=.5,
             loc=1)

forestex = imread('../writing/20200723_dynamics_draft/wave_example.png')
imagebox = OffsetImage(forestex, zoom=.11)
ab = AnnotationBbox(imagebox, (3.25, 2e-8), pad=.1)
ax[0].add_artist(ab)

y = pd.read_csv('../mathematica/curves.csv')
x = array(y.columns.values).astype(float)
```

```
for i in range(10):
    ax[1].semilogy(x, y.iloc[i], '-')
ax[1].set(ylim=(1e-6, 2e3), xlim=(-1,201),
          xlabel=r'time $t$', ylabel=r'pop. number $n(r,t)$')
ax[1].legend([r'$r=%d$'%r for r in range(1,11)],
             fontsize='x-small', handlelength=.5, ncol=4)

fig.text(.14, .825, 'A', fontsize='40')
fig.text(.14, .395, 'B', fontsize='40')

fig.savefig(f'{imgdr}/pop_waves.pdf', bbox_inches='tight', dpi=200)
```

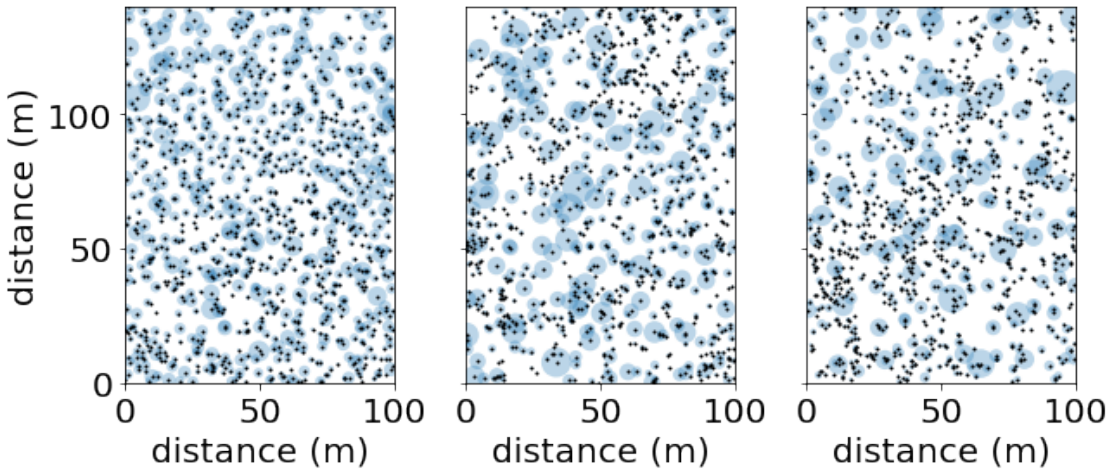
[518]: Text(0.14, 0.395, 'B')



5 Supplementary figures

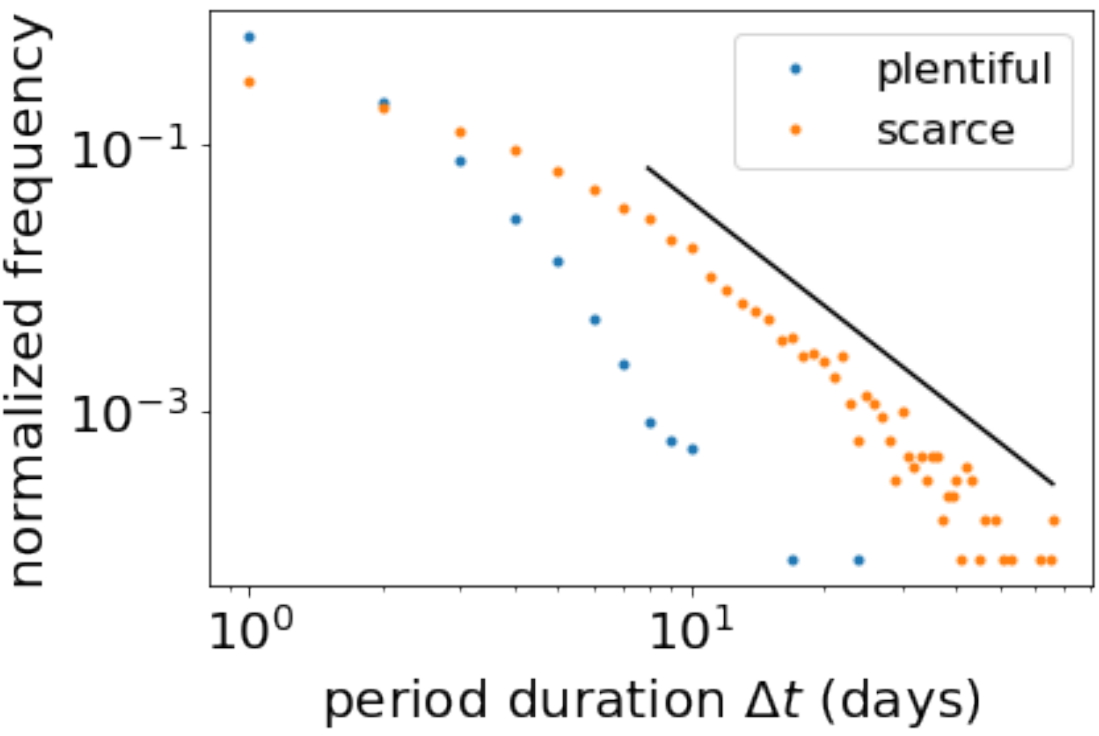
[56]:
```
def forest_plot(plotNo, ax):
    df = pd.read_csv('../data/uas/southeast_alaska/Data/Data.csv')
```

```
    ix = df['Plot ']==plotNo  # select a patch
    x, y = df['Xcoord.m'].loc[ix], df['Ycoord.m'].loc[ix]
    r = df['DBH.cm'].loc[ix] / 100 * 5

    # there are some weird outliers that must something wrong
    badix = (x<0) | (x>100)
    x = x[~badix]
    y = y[~badix]
    r = r[~badix]

    # create patches for plotting
    p = []
    for x_, y_, r_ in zip(x, y, r):
        p.append(Circle((x_,y_), r_))

    patches = PatchCollection(p, alpha=.3)

    ax.plot(x, y, 'k.', ms=2)
    ax.add_collection(patches)

fig, ax = plt.subplots(figsize=(10,4), ncols=3, sharex=True, sharey=True)
ax = ax.ravel()

forest_plot(32, ax[0])
forest_plot(76, ax[1])
forest_plot(130, ax[2])

ax[-1].set(xlim=(0,100), ylim=(0,140))
ax[0].set(ylabel='distance (m)')
for a in ax:
    a.set_aspect('equal')
    a.set(xlabel='distance (m)')

fig.savefig(f'{imgdr}/alaskan_forest.pdf', bbox_inches='tight')
```



Puerto Rico rainfall

[57]:
```
load_pickle('plotting/pr_rainfall.p')

abovedt = np.concatenate(list(abovedt.values()))
belowdt = np.concatenate(list(belowdt.values()))

fig, ax = plt.subplots()

na = bincount(abovedt)[1:]
xa = arange(1, na.size+1)

nb = bincount(belowdt)[1:]
xb = arange(1, nb.size+1)

na = na / na.sum()
nb = nb / nb.sum()

ax.loglog(xa, na, '.', c='C0')
ax.loglog(xb, nb, '.', c='C1')

# power law
x = array([8, xb[-1]])
ax.loglog(x, 15 * x**-2.6, 'k-')

ax.set(xlabel=r'period duration $\Delta t$ (days)', ylabel='normalized␣
 ↪frequency')
ax.legend(('plentiful', 'scarce'), fontsize='small')

fig.savefig(f'{imgdr}/pr_rainfall.pdf', bbox_inches='tight')
```



Automaton solution to WEB model

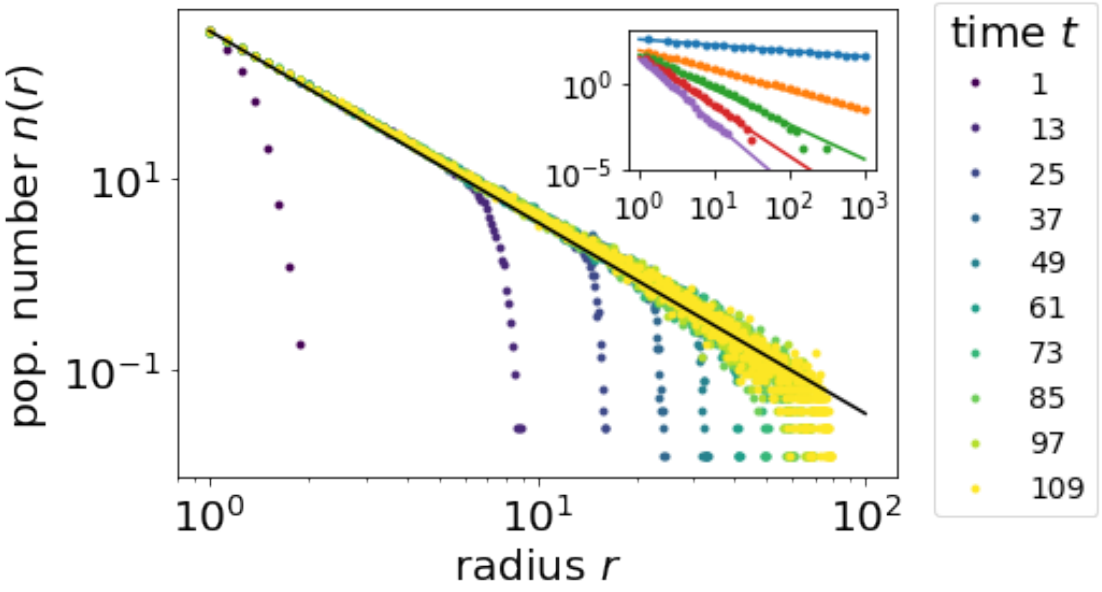
[37]:
```
load_pickle('cache/linear_model_exponent_transience.p')

rk = rk[0]
nk = np.concatenate([i[:,:,None] for i in nk], axis=2)
nk = nk.mean(2)
tRange = range(1, 112, 12)

fig, ax = plt.subplots()

h = []
cmap = colorcycle(10)
for i in tRange:
    h.append(ax.loglog(rk, nk[i], '.', c=next(cmap))[0])

dx = (rk[1]-rk[0])
y = rk**(-1/3 -cm/cg)
y *= g0 / (cg / dx * rk[0]**(2/3) + cm * rk[0]**(-2/3)) / y[0]
ix = rk<100
h.append(ax.loglog(rk[ix], y[ix], 'k-')[0])

ax.set(xlabel=r'radius $r$', ylabel=r'pop. number $n(r)$',
       xlim=(.8, 100/.8))
```

```
leg = ax.legend(h, tRange, title=r'time $t$',
                bbox_to_anchor=(1.3,1.05),
                loc=1,
                fontsize='x-small')



load_pickle('cache/linear_model_exponent.p')

# create log bins
nbins = arange(5) * 6 + 25
lognk, logrk, dx = {}, {}, {}

counter = 0
for (k, nk_), rk_ in zip(nk.items(), rk.values()):
    nk_ = nk_[-200:].mean(0)

    ix = np.digitize(rk_, np.logspace(0, np.log10(rk_[-1]), nbins[counter]))

    logrk[k] = np.logspace(0, np.log10(rk_[-1]), nbins[counter])
    lognk[k] = np.array([nk_[ix==i].sum() / (ix==i).sum() for i in range(ix.
 ↪max()+1)])
    dx[k] = rk_[1] - rk_[0]

    counter += 1

axins = inset_axes(ax, width=1.6, height=.9)
h = []

for i, (cm, rk_, nk_, dx_) in enumerate(zip(cmRange, logrk.values(), lognk.
 ↪values(), dx.values())):
    h.append(axins.loglog(rk_, nk_[:-1], '.')[0])

    # match up slope prediction to last point
    exponent = 1/3 + cm / cg
    y = rk_**(-exponent)
    y *= g0 / (cg / dx_ + cm) / y[0]
    h.append(axins.loglog(rk_, y, '-', c=f'C{i}')[0])

axins.set(ylim=(1e-5, 1e3), xticks=(1,10,100,1e3))
[el.set_fontsize('x-small') for el in axins.xaxis.get_ticklabels()]
[el.set_fontsize('x-small') for el in axins.yaxis.get_ticklabels()]

fig.savefig(f'{imgdr}/indpt_model.pdf', bbox_inches='tight')
```

```
<ipython-input-37-4431144a3497>:43: RuntimeWarning: invalid value encountered in
double_scalars
```

```
    lognk[k] = np.array([nk_[ix==i].sum() / (ix==i).sum() for i in
range(ix.max()+1)])
```

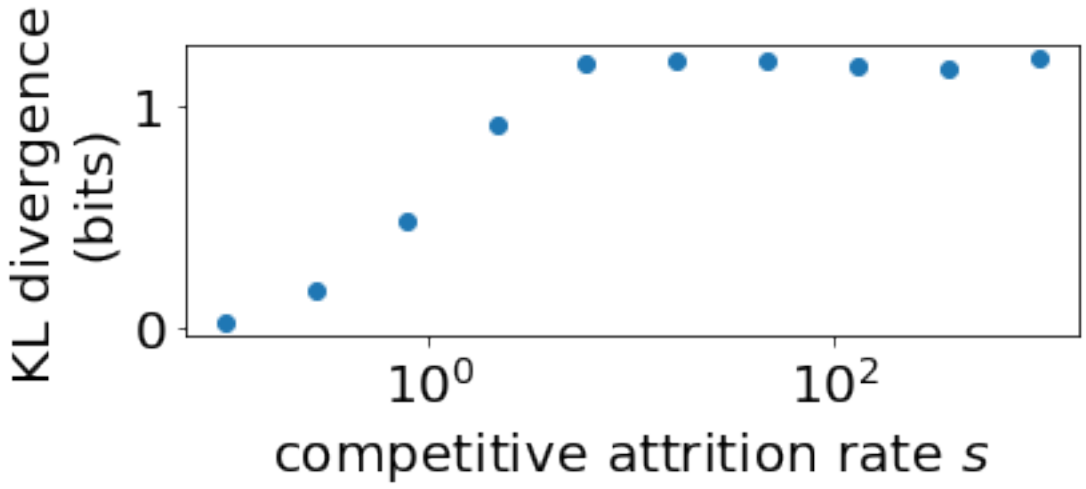
[37]:
```
[None, None, None, None, None, None, None]
```



KL divergence for solid phase

[58]:
```
load_pickle('cache/packing_example.p')

kl = np.zeros_like(areaDeathRateRange)
interpkl = zeros_like(areaDeathRateRange)
optbinWidth = zeros_like(areaDeathRateRange)

for j, adr in list(enumerate(areaDeathRateRange)):
    dr = concatenate([nn.dist(xy_) for xy_ in xy[adr]])
    N = mean([len(xy_) for xy_ in xy[adr]])

    # interpolate DKL curve to extrapolate value
    bins = logspace(log10(dr.max()/dr.size)+2, log10(dr.max()/dr.size)+5, 30)
    d = zeros_like(bins)
    for k in range(d.size):
        d[k] = nn.kl(dr, N, L, bins[k])
    optbinWidth[j] = bins[argmin(d)]

    kl[j] = nn.kl(dr, N, L, optbinWidth[j])

fig, ax = plt.subplots(figsize=(6,2))
ax.semilogx(areaDeathRateRange, kl, 'o')
```

```
ax.set(xlabel=r'competitive attrition rate $s$',
       ylabel='KL divergence\n(bits)')
fig.savefig(f'{imgdr}/dkl_ordering.pdf', bbox_inches='tight')
```

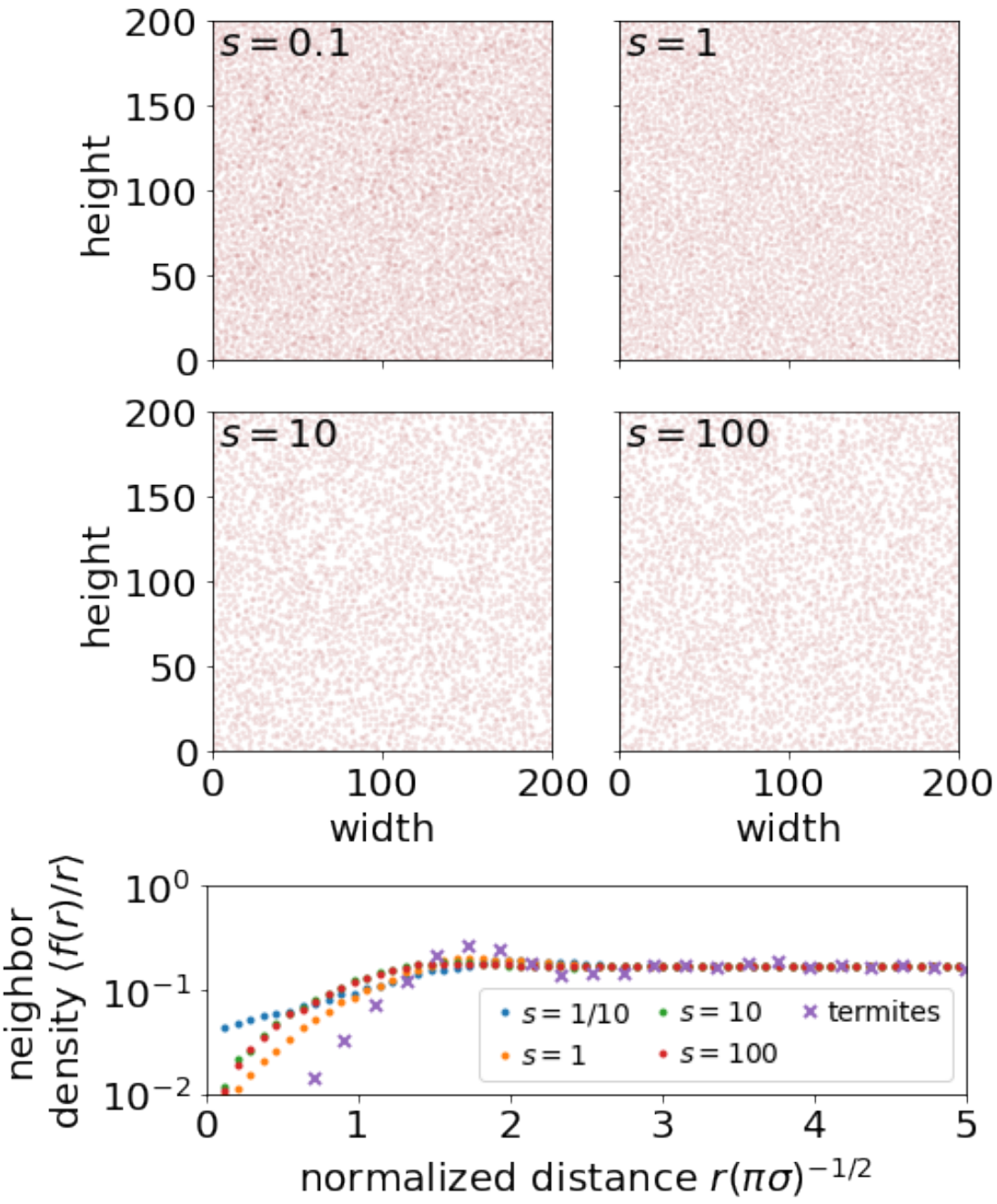


Examples of phase regions

[48]:
```
load_pickle('cache/spacing_with_cg.p')

allxy = xy

fig = plt.figure(figsize=(6.9,10))
gs = GridSpec(3, 2, wspace=.1, hspace=.5, height_ratios=(1,1,.7))
gsSub = GridSpecFromSubplotSpec(2,2, gs[:2,:], wspace=.15, hspace=.15)
ax = (fig.add_subplot(gsSub[0,0], aspect='equal'),
      fig.add_subplot(gsSub[0,1], aspect='equal'),
      fig.add_subplot(gsSub[1,0], aspect='equal'),
      fig.add_subplot(gsSub[1,1], aspect='equal'))

xy = vstack(allxy[cgRange[-1]][areaDeathRateRange[0]][0])
data.plot(xy, [1.5]*len(xy), 200, ax=ax[0])
ax[0].text(3, 180, r'$s=0.1$')

xy = vstack(allxy[cgRange[-1]][areaDeathRateRange[3]][0])
data.plot(xy, [1.5]*len(xy), 200, ax=ax[1])
ax[1].text(3, 180, r'$s=1$')

xy = vstack(allxy[cgRange[-1]][areaDeathRateRange[6]][0])
data.plot(xy, [1.5]*len(xy), 200, ax=ax[2])
ax[2].text(3, 180, r'$s=10$')
```

```
xy = vstack(allxy[cgRange[-1]][areaDeathRateRange[9]][0])
data.plot(xy, [1.5]*len(xy), 200, ax=ax[3])
ax[3].text(3, 180, r'$s=100$')

ax[0].set(xticklabels=[], ylabel='height')
ax[1].set(xticklabels=[], yticklabels=[])
ax[2].set(xlabel='width', ylabel='height')
ax[3].set(yticklabels=[], xlabel='width')


load_pickle('plotting/spatial_corr_liquid.p')
ax = fig.add_subplot(gs[2,:])

for p_ in list(p.values())[::3]:
    # spatial autocorrelation function
    ax.semilogy(r, p_/r, '.')

namp, namr = data.namibia_corr_fcn()
drRatio = (namr[1]-namr[0]) / (r[1]-r[0])
ax.plot(namr, namp/namr / drRatio, 'x', mew=2)

ax.set(xlim=(0,5), yscale='log',
       xlabel=r"normalized distance $r(\pi\sigma)^{-1/2}$",␣
 ↪ylabel='neighbor\n'+r"density $\langle f(r)/r\rangle$")
ax.set(ylim=(1e-2,1), yticks=[1e-2,.1,1])
ax.legend([r'$s=1/10$',r'$s=1$',r'$s=10$',r'$s=100$']+['termites'],
          ncol=3, fontsize='x-small', columnspacing=.6, handletextpad=.09,␣
 ↪handlelength=1, loc=4)

fig.savefig(f'{imgdr}/liquid_phase.pdf', bbox_inches='tight')
```

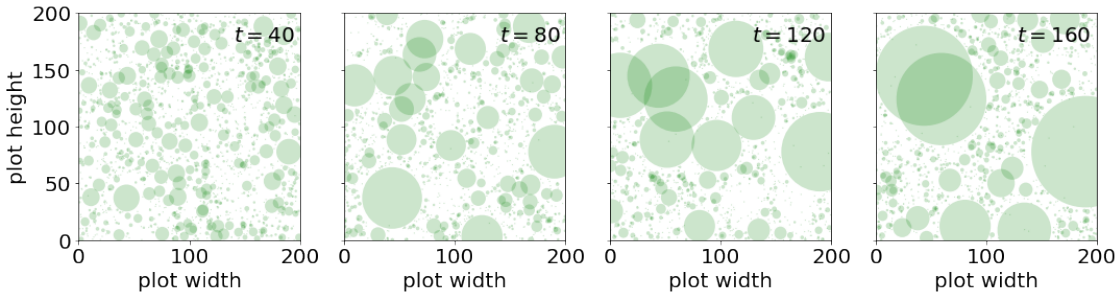
[48]: <matplotlib.legend.Legend at 0x7f3181c331c0>



Canopy simulation example

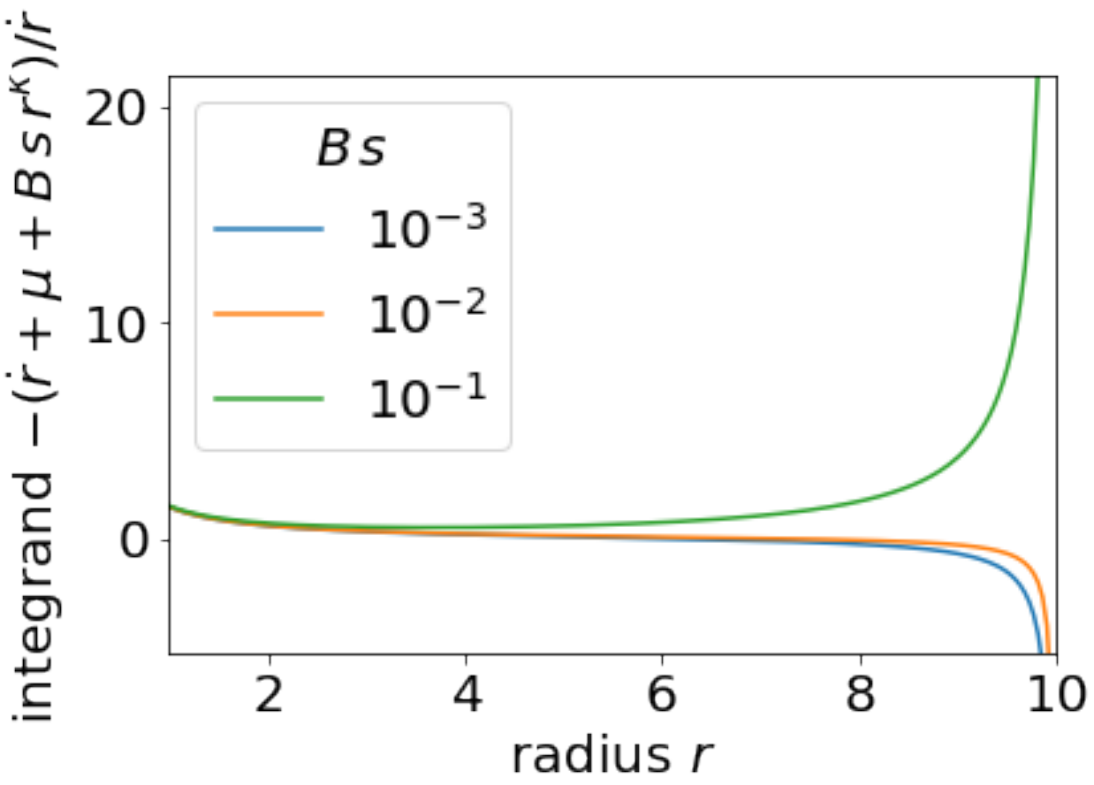
[396]:
```
load_pickle('plotting/oscillation_plot_examples.p')

fig, ax = plt.subplots(figsize=(17.5,4), ncols=4)
for i, (k, t) in enumerate(trees.items()):
    forest.plot(all_trees=t, ax=ax[i])
```

```
    ax[i].text(195, 175, r'$t=%d$'%k, ha='right')
    if i>0: ax[i].set(yticklabels=[])
    else: ax[i].set(ylabel='plot height')
    ax[i].set(xlabel='plot width')

fig.savefig(f'{imgdr}/oscillation_plots.pdf', bbox_inches='tight')
```



Non-power-law growth tail

[44]:
```
r0 = 1
rmax = 10
a = 1
thalf = 5
lam = 1
mu0 = 1
kappa = 2

rdot = lambda r: rmax * a / 2 * cosh(arctanh(2 * r / rmax - 1))**-2
drdot = lambda r: -2 * a * (2*r / rmax - 1)
mu = lambda r: mu0 * r**(-2/3)

bsrange = np.logspace(-3, -1, 3)
rRange = np.linspace(r0, rmax-.05, 200)

fig, ax = plt.subplots()

for bs in bsrange:
    ax.plot(rRange, (drdot(rRange) + mu(rRange) + bs * rRange**kappa)/
 ↪rdot(rRange))

ax.set(xlabel=r'radius $r$', ylabel='integrand $-(\dot{r}+\mu+ B\,s\,r^\kappa)/
 ↪\dot{r}$',
       xlim=(r0, rmax), ylim=(-5.308656142979472, 21.37184385702066))
ax.legend((r'$10^{-3}$',r'$10^{-2}$',r'$10^{-1}$'), title=r'$B\,s$')

fig.savefig(f'{imgdr}/pop_tail.pdf', bbox_inches='tight')
```

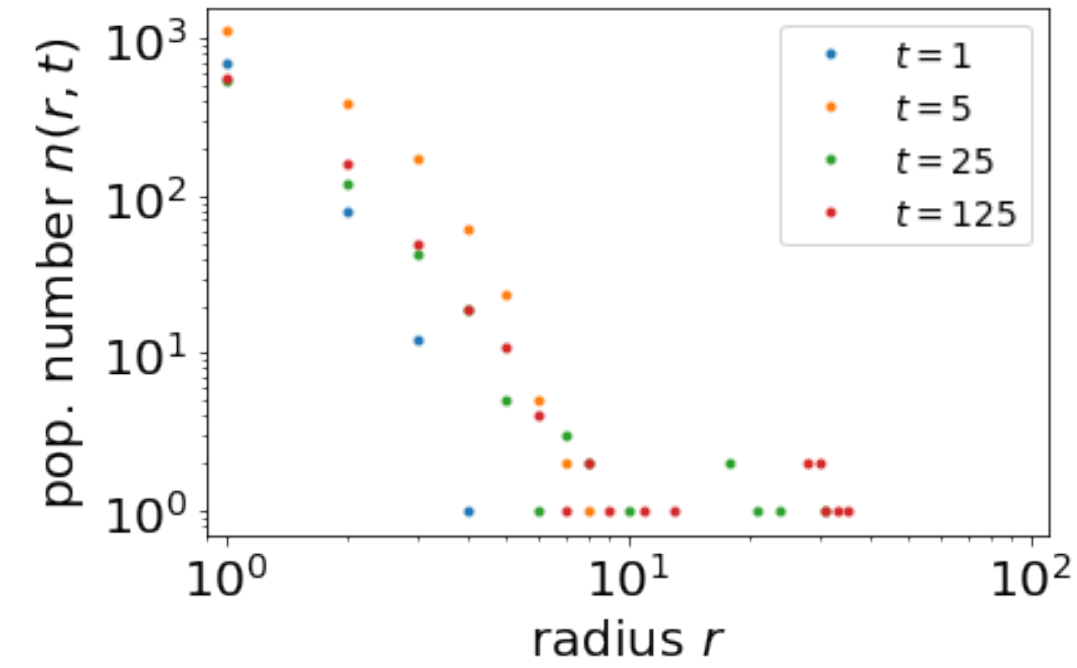


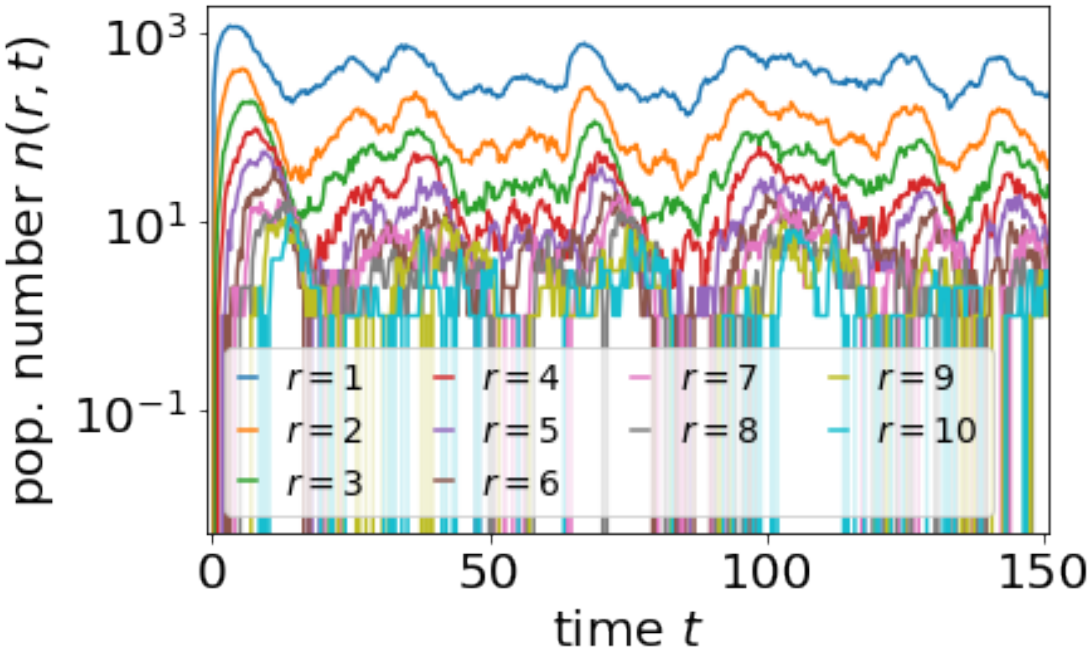
Automaton simulation of asymmetric competition

[53]:
```
load_pickle('cache/automaton_oscillation_example.p')

# average across forests
# thisnk = concatenate([i[:,:,None] for i in nk], axis=2).mean(2)
thisnk = nk[1]

fig, ax = plt.subplots(figsize=(6,9), nrows=2,
                       gridspec_kw={'hspace':.33})

for thist in [1, 5, 25, 125]:
    i = argmin((thist-t[0])**2)
    ax[0].loglog(forest.rRange, thisnk[i], '.')
ax[0].set(xlabel=r'radius $r$', ylabel=r'pop. number $n(r,t)$',
          xlim=(.9,100/.9))
ax[0].legend([r'$t=1$', r'$t=5$', r'$t=25$', r'$t=125$'], fontsize='x-small')

for i in range(10):
    ax[1].plot(t[0], thisnk[:,i])

ax[1].set(xlabel=r'time $t$', ylabel=r'pop. number $n(r,t)$',
```

```
          yscale='log', ylim=(1e-2/2, 2e3), xlim=(-1,151))
ax[1].legend([r'$r=%d$'%r for r in range(1,11)],
             fontsize='x-small', handlelength=.5, ncol=4)

fig.savefig(f'{imgdr}/2d_pop_waves.pdf', bbox_inches='tight')
```

[53]: <matplotlib.legend.Legend at 0x7f3182db28b0>





Spatial distribution comparison with termites

[295]:
```
df = pd.read_csv('../data/Tarnita/termite_mound_location_field_data/Namib_G1.
↪txt',
                 sep='\t',
                 header=None)
termitexy = df.values

load_pickle('cache/packing_example.p')

allxy = xy
xy = vstack(allxy[areaDeathRateRange[-1]][0])

fig = plt.figure(figsize=(10,4))
ax = fig.add_subplot(121, aspect='equal'), fig.add_subplot(122, aspect='equal')

data.plot(xy, [4.2]*len(xy), 200, ax=ax[0])
data.plot(termitexy, [10]*len(termitexy), 520, ax=ax[1])

ax[0].set(title='simulation', xlabel='width', ylabel='height')
ax[1].set(title='termite mound data', xlabel='width (m)', ylabel='height (m)')

fig.subplots_adjust(wspace=.3)
fig.savefig(f'{imgdr}/termite_mounds.pdf', bbox_inches='tight')
```