

UNIT 5: Competition

Outline

Introduction

Population model with competition

- Balanced competition

- Unbalanced competition

Population-level interactions

- Invasion theory

- Colonization and co-existence

Niches and coexistence

- The competitive exclusion principle

Inter-species interactions

- ▶ Competition: interaction hurts the growth rate of both species

Inter-species interactions

- ▶ Competition: interaction hurts the growth rate of both species
- ▶ Exploitation: interaction is good for one species but bad for the other

Inter-species interactions

- ▶ Competition: interaction hurts the growth rate of both species
- ▶ Exploitation: interaction is good for one species but bad for the other
- ▶ Mutualism: interaction is good for both species

Inter-species interactions

- ▶ Competition: interaction hurts the growth rate of both species
- ▶ Exploitation: interaction is good for one species but bad for the other
- ▶ Mutualism: interaction is good for both species
- ▶ Commensalism: interaction is good for one species, and close to neutral for the other

Inter-species interactions

- ▶ Competition: interaction hurts the growth rate of both species
- ▶ Exploitation: interaction is good for one species but bad for the other
- ▶ Mutualism: interaction is good for both species
- ▶ Commensalism: interaction is good for one species, and close to neutral for the other

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other



Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ *

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light
 - ▶ *

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light
 - ▶ * Ants and mammals competing for leaves

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light
 - ▶ * Ants and mammals competing for leaves
 - ▶ *

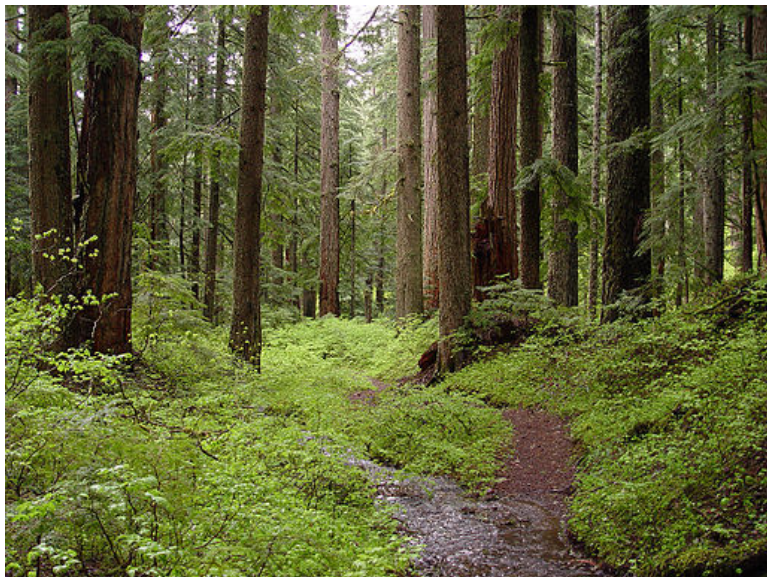
Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light
 - ▶ * Ants and mammals competing for leaves
 - ▶ * Mussels and algae competing for space in the intertidal zone

Competition

- ▶ Competition occurs when two species both depend on the same resource, or resources
- ▶ Each species ability to reproduce successfully is reduced by the presence of the other
 - ▶ * Survival, growth, producing offspring
- ▶ Species may be very similar, or very different
 - ▶ * Oaks and maples competing for light
 - ▶ * Ants and mammals competing for leaves
 - ▶ * Mussels and algae competing for space in the intertidal zone

Competition



Competition



Competition



Competition in ecology

- ▶ What factors determine which species survive in which habitats?

Competition in ecology

- ▶ What factors determine which species survive in which habitats?
- ▶ What factors determine how many similar species can co-exist?

Competition in ecology

- ▶ What factors determine which species survive in which habitats?
- ▶ What factors determine how many similar species can co-exist?
- ▶ Why do similar species coexist at all?

Competition in ecology

- ▶ What factors determine which species survive in which habitats?
- ▶ What factors determine how many similar species can co-exist?
- ▶ Why do similar species coexist at all?

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?



Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ *

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together
 - ▶ *

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together
 - ▶ * Sometimes one survives, and sometimes the other

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together
 - ▶ * Sometimes one survives, and sometimes the other
 - ▶ *

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together
 - ▶ * Sometimes one survives, and sometimes the other
 - ▶ * Whichever species got a “head start” would survive

Flour beetles

- ▶ There is a series of experiments where researchers allow two species of flour beetles to compete in different laboratory environments
- ▶ The larger species survives better in drier conditions, and the smaller species reproduces faster in moister conditions
- ▶ Poll: What outcomes do you expect under wet vs dry conditions?
 - ▶ * Each species wins when conditions are better for it
- ▶ Poll: What if I “tune” the conditions to something in between?
 - ▶ * The species could both survive together
 - ▶ * Sometimes one survives, and sometimes the other
 - ▶ * Whichever species got a “head start” would survive

Outcomes of competition



The confused flour beetle

Outcomes of competition

- ▶ In a given stable environment, we generally expect the competitive interaction between two species to have one of the following results

Outcomes of competition

- ▶ In a given stable environment, we generally expect the competitive interaction between two species to have one of the following results
 - ▶ **Dominance:** one species wins every time

Outcomes of competition

- ▶ In a given stable environment, we generally expect the competitive interaction between two species to have one of the following results
 - ▶ **Dominance**: one species wins every time
 - ▶ **Co-existence**: if both species are present, they will both persist

Outcomes of competition

- ▶ In a given stable environment, we generally expect the competitive interaction between two species to have one of the following results
 - ▶ **Dominance**: one species wins every time
 - ▶ **Co-existence**: if both species are present, they will both persist
 - ▶ **Founder control**: whichever species gets established first will exclude the other

Outcomes of competition

- ▶ In a given stable environment, we generally expect the competitive interaction between two species to have one of the following results
 - ▶ **Dominance**: one species wins every time
 - ▶ **Co-existence**: if both species are present, they will both persist
 - ▶ **Founder control**: whichever species gets established first will exclude the other

Outline

Introduction

Population model with competition

- Balanced competition

- Unbalanced competition

Population-level interactions

- Invasion theory

- Colonization and co-existence

Niches and coexistence

- The competitive exclusion principle

Population model with competition

- ▶ We modeled a single species using the equation:

Population model with competition

- ▶ We modeled a single species using the equation:

- ▶ $\frac{dN}{dt} = (b(N) - d(N))N$

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21} N_2$$

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?



Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?
 - ▶ * $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?
 - ▶ * $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
 - ▶ *

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?
 - ▶ * $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
 - ▶ * $\frac{dN_2}{dt} = (b_2(\tilde{N}_2) - d_2(\tilde{N}_2))N_2$

Population model with competition

- ▶ We modeled a single species using the equation:
 - ▶ $\frac{dN}{dt} = (b(N) - d(N))N$
- ▶ We want to modify this for a species which is competing with another species
 - ▶ $\frac{dN_1}{dt} = ?$
- ▶ The amount of competition seen by species 1 is
$$\tilde{N}_1 = N_1 + \alpha_{21}N_2$$
- ▶ How should our equation change?
 - ▶ * $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
 - ▶ * $\frac{dN_2}{dt} = (b_2(\tilde{N}_2) - d_2(\tilde{N}_2))N_2$

Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects

Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects
- ▶ Therefore, we expect each species to converge to its *carrying capacity* K (or K_1 and K_2) when it is alone

Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects
- ▶ Therefore, we expect each species to converge to its *carrying capacity* K (or K_1 and K_2) when it is alone
- ▶ How do we define carrying capacity in this system?

Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects
- ▶ Therefore, we expect each species to converge to its *carrying capacity* K (or K_1 and K_2) when it is alone
- ▶ How do we define carrying capacity in this system?



Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects
- ▶ Therefore, we expect each species to converge to its *carrying capacity* K (or K_1 and K_2) when it is alone
- ▶ How do we define carrying capacity in this system?
 - ▶ * The birth rate equals the death rate: $b(K) = d(K)$

Carrying capacity

- ▶ For this unit, we will mostly ignore Allee effects
- ▶ Therefore, we expect each species to converge to its *carrying capacity* K (or K_1 and K_2) when it is alone
- ▶ How do we define carrying capacity in this system?
 - ▶ * The birth rate equals the death rate: $b(K) = d(K)$

Carrying capacity with competition

$$\blacktriangleright \frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$$

Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$

- ▶ How can this population be at equilibrium?

Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
- ▶ How can this population be at equilibrium?



Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
- ▶ How can this population be at equilibrium?
 - ▶ * $\tilde{N}_1 = K_1$: the species has the right amount of competitive pressure to make $\mathcal{R} = 1$

Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
- ▶ How can this population be at equilibrium?
 - ▶ * $\tilde{N}_1 = K_1$: the species has the right amount of competitive pressure to make $\mathcal{R} = 1$
 - ▶ *

Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
- ▶ How can this population be at equilibrium?
 - ▶ * $\tilde{N}_1 = K_1$: the species has the right amount of competitive pressure to make $\mathcal{R} = 1$
 - ▶ * $N_1 = 0$: the species is not present

Carrying capacity with competition

- ▶ $\frac{dN_1}{dt} = (b_1(\tilde{N}_1) - d_1(\tilde{N}_1))N_1$
- ▶ How can this population be at equilibrium?
 - ▶ * $\tilde{N}_1 = K_1$: the species has the right amount of competitive pressure to make $\mathcal{R} = 1$
 - ▶ * $N_1 = 0$: the species is not present

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later
- ▶ This model is similar to the logistic model, except:

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later
- ▶ This model is similar to the logistic model, except:
 - ▶ Birth and death are tracked separately

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later
- ▶ This model is similar to the logistic model, except:
 - ▶ Birth and death are tracked separately
 - ▶ We don't assume functions are straight lines

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later
- ▶ This model is similar to the logistic model, except:
 - ▶ Birth and death are tracked separately
 - ▶ We don't assume functions are straight lines
- ▶ Everything we say about this model also applies to the logistic model

Logistic model

- ▶ You've probably learned about the logistic model, if not you may learn about it later
- ▶ This model is similar to the logistic model, except:
 - ▶ Birth and death are tracked separately
 - ▶ We don't assume functions are straight lines
- ▶ Everything we say about this model also applies to the logistic model

Subsection 1

Balanced competition

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?

▶ *

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .
 - ▶ *

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .
 - ▶ * Whichever species has a higher value of K can survive at a density where the other one can't

Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .
 - ▶ * Whichever species has a higher value of K can survive at a density where the other one can't
 - ▶ *

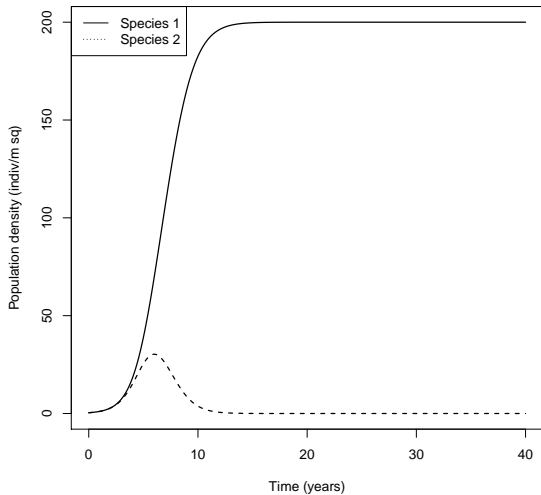
Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .
 - ▶ * Whichever species has a higher value of K can survive at a density where the other one can't
 - ▶ * Dominance!

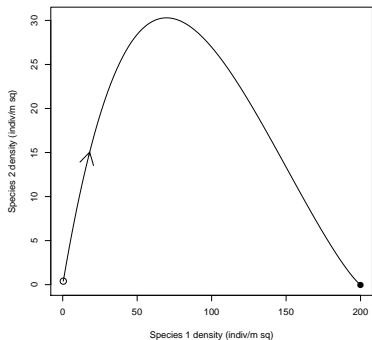
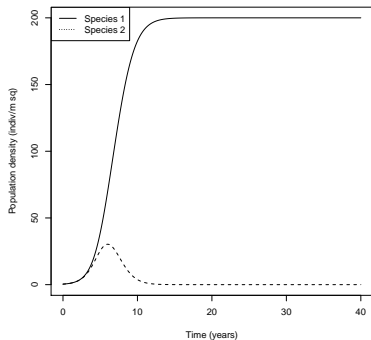
Equal competition

- ▶ If the α s are both equal to one, we have equal competition. This means that the competitive effect of an individual from either species is the same.
- ▶ If $\bar{N} = N_1 + N_2$, then:
 - ▶ $\frac{dN_1}{dt} = (b_1(\bar{N}) - d_1(\bar{N}))N_1$
 - ▶ $\frac{dN_2}{dt} = (b_2(\bar{N}) - d_2(\bar{N}))N_2$
- ▶ What happens in this case?
 - ▶ * Competition is mediated by only one quantity, \bar{N} .
 - ▶ * Whichever species has a higher value of K can survive at a density where the other one can't
 - ▶ * Dominance!

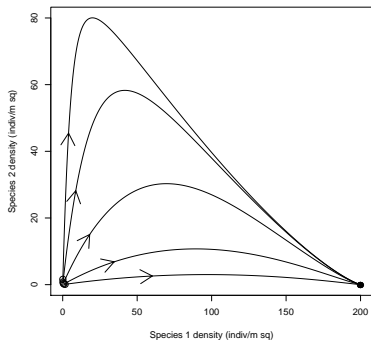
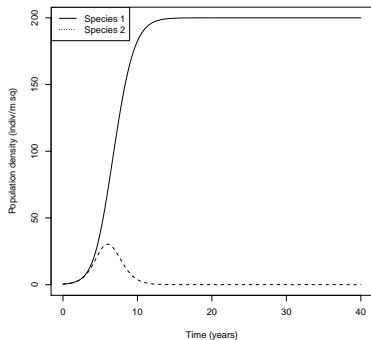
Dominance time plot



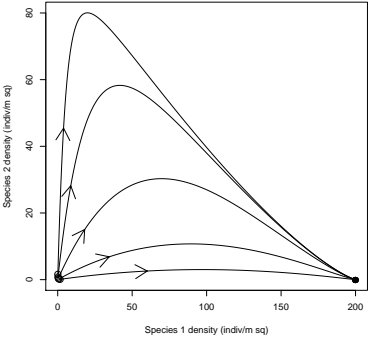
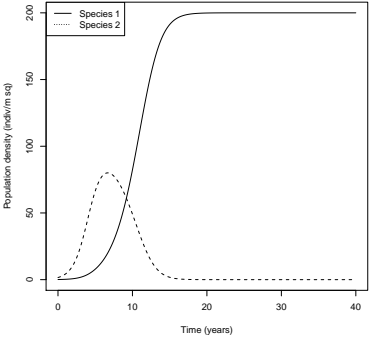
Dominance phase plot



Dominance



Dominance



Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ **Single starting points**

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes
 - ▶ Fixed parameters (usually)

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes
 - ▶ Fixed parameters (usually)
 - ▶ Multiple starting points (usually)

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes
 - ▶ Fixed parameters (usually)
 - ▶ Multiple starting points (usually)
 - ▶ Better for seeing overall pattern of results

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes
 - ▶ Fixed parameters (usually)
 - ▶ Multiple starting points (usually)
 - ▶ Better for seeing overall pattern of results
 - ▶ **Worse for seeing rates (how quickly things change)**

Time plots and phase plots

- ▶ *Time plots* have time on one axis and show population quantities on another
 - ▶ Fixed parameters (usually)
 - ▶ Single starting points
- ▶ *Phase plots* have population quantities on both axes
 - ▶ Fixed parameters (usually)
 - ▶ Multiple starting points (usually)
 - ▶ Better for seeing overall pattern of results
 - ▶ Worse for seeing rates (how quickly things change)

Reading phase plots

- ▶ Log or linear (per capita vs. total perspective)

Reading phase plots

- ▶ Log or linear (per capita vs. total perspective)
- ▶ Open circles are starting points

Reading phase plots

- ▶ Log or linear (per capita vs. total perspective)
- ▶ Open circles are starting points
- ▶ Closed circles are ending points

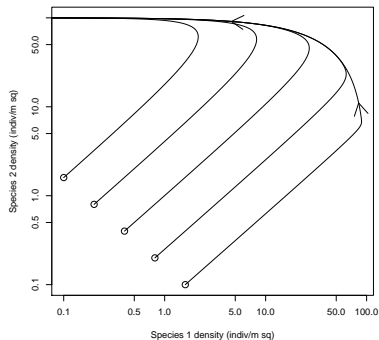
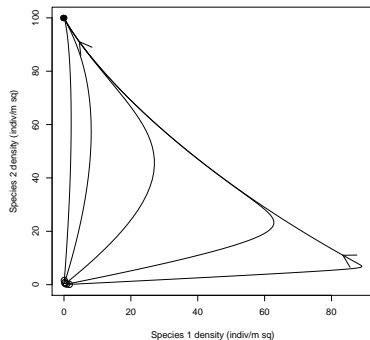
Reading phase plots

- ▶ Log or linear (per capita vs. total perspective)
- ▶ Open circles are starting points
- ▶ Closed circles are ending points
- ▶ **Arrows show direction of time**

Reading phase plots

- ▶ Log or linear (per capita vs. total perspective)
- ▶ Open circles are starting points
- ▶ Closed circles are ending points
- ▶ Arrows show direction of time

Dominance reversed



Log plots and linear plots

- We will look at *population* quantities on either a *log* or *linear* scale

Log plots and linear plots

- ▶ We will look at *population* quantities on either a *log* or *linear* scale
- ▶ Log plots show *proportional* differences

Log plots and linear plots

- ▶ We will look at *population* quantities on either a *log* or *linear* scale
- ▶ Log plots show *proportional* differences
- ▶ Linear plots show *absolute* differences

Log plots and linear plots

- ▶ We will look at *population* quantities on either a *log* or *linear* scale
- ▶ Log plots show *proportional* differences
- ▶ Linear plots show *absolute* differences

Units of α

► $\tilde{N}_1 = N_1 + \alpha_{21} N_2; \tilde{N}_2 = N_2 + \alpha_{12} N_1$

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect of individuals of species 2 on the growth rate of species 1.

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?



Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?
 - ▶ * $\text{indiv}_1 / \text{indiv}_2$

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?
 - ▶ * $\text{indiv}_1 / \text{indiv}_2$
- ▶ Since α has units, we don't expect there to be anything special about $\alpha = 1$

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?
 - ▶ * $\text{indiv}_1 / \text{indiv}_2$
- ▶ Since α has units, we don't expect there to be anything special about $\alpha = 1$
- ▶ Equal competition (both species have the same effect on each other) is a special case of balanced competition (both species have the same *relative* effect on each other)

Units of α

- ▶ $\tilde{N}_1 = N_1 + \alpha_{21}N_2$; $\tilde{N}_2 = N_2 + \alpha_{12}N_1$
- ▶ α_{21} measures the strength of the competitive effect *of* individuals of species 2 *on* the growth rate of species 1.
- ▶ What are the units of α_{21} ?
 - ▶ * $\text{indiv}_1 / \text{indiv}_2$
- ▶ Since α has units, we don't expect there to be anything special about $\alpha = 1$
- ▶ Equal competition (both species have the same effect on each other) is a special case of balanced competition (both species have the same *relative* effect on each other)

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?



Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?

▶ *

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?
 - ▶ * $\alpha_{12} = 1 \text{ indiv}_2 / 4 \text{ indiv}_1$

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?
 - ▶ * $\alpha_{12} = 1 \text{ indiv}_2 / 4 \text{ indiv}_1$
 - ▶ *

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?
 - ▶ * $\alpha_{12} = 1 \text{ indiv}_2 / 4 \text{ indiv}_1$
 - ▶ * In some sense this means the same thing: the larger plant has four times as much impact as the smaller one

Balanced competition example

- ▶ Two plants compete with each other for water. The value of α_{21} is $4 \text{ indiv}_1 / \text{indiv}_2$
- ▶ Poll: Which species is bigger?
 - ▶ * Species 2 individuals use as much water as 4 species 1 individuals
- ▶ If they're only competing for water, what's the value of α_{12} ?
 - ▶ * $\alpha_{12} = 1 \text{ indiv}_2 / 4 \text{ indiv}_1$
 - ▶ * In some sense this means the same thing: the larger plant has four times as much impact as the smaller one

Balanced competition example



Balanced competition

- ▶ **Poll:** What results do we expect from balanced competition?

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?



Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ *

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ *

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ * Both species experience total density in the same way

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ * Both species experience total density in the same way
 - ▶ *

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ * Both species experience total density in the same way
 - ▶ * So the species with the higher carrying capacity (compared using the same units) will dominate

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ * Both species experience total density in the same way
 - ▶ * So the species with the higher carrying capacity (compared using the same units) will dominate
- ▶ Balanced competition means (exactly) no tendency for founder control or for coexistence

Balanced competition

- ▶ Poll: What results do we expect from balanced competition?
 - ▶ * It seems like the bigger species should win
 - ▶ * But that's not always the case
- ▶ Balanced competition works just like equal competition
 - ▶ * Both species experience total density in the same way
 - ▶ * So the species with the higher carrying capacity (compared using the same units) will dominate
- ▶ Balanced competition means (exactly) no tendency for founder control or for coexistence

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?



Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$
- ▶ C measures the relative effect of between-species and within-species competition

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$
- ▶ C measures the relative effect of between-species and within-species competition
 - ▶ $C = 1$ means competition is balanced

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$
- ▶ C measures the relative effect of between-species and within-species competition
 - ▶ $C = 1$ means competition is balanced
 - ▶ $C < 1$ means there is more competition within species (tendency for coexistence)

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$
- ▶ C measures the relative effect of between-species and within-species competition
 - ▶ $C = 1$ means competition is balanced
 - ▶ $C < 1$ means there is more competition within species (tendency for coexistence)
 - ▶ $C > 1$ means there is more competition between species (tendency for founder control)

Measuring competitive effects

- ▶ It makes sense that we have a range of parameters that give us balanced competition, because we know qualitative changes in dynamics are explained by unitless parameters
- ▶ What's the unitless parameter here?
 - ▶ * $C = \alpha_{21}\alpha_{12}$
- ▶ C measures the relative effect of between-species and within-species competition
 - ▶ $C = 1$ means competition is balanced
 - ▶ $C < 1$ means there is more competition within species (tendency for coexistence)
 - ▶ $C > 1$ means there is more competition between species (tendency for founder control)

Subsection 2

Unbalanced competition

Unbalanced competition

- ▶ If two species are competing by using a simple resource, we expect competition to be balanced



Unbalanced competition

- ▶ If two species are competing by using a simple resource, we expect competition to be balanced
 - ▶ Both α s measure the relative effect of the two species on the resource



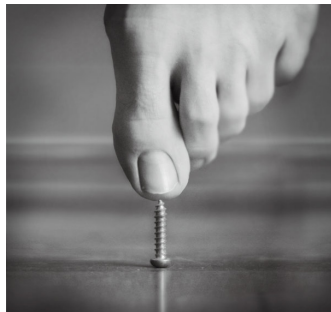
Unbalanced competition

- ▶ If two species are competing by using a simple resource, we expect competition to be balanced
 - ▶ Both α s measure the relative effect of the two species on the resource
- ▶ In more realistic situations, competition may not be balanced



Unbalanced competition

- ▶ If two species are competing by using a simple resource, we expect competition to be balanced
 - ▶ Both α s measure the relative effect of the two species on the resource
- ▶ In more realistic situations, competition may not be balanced



Coexistence

- ▶ Coexistence *may* occur when $C < 1$

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?



Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites



Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences

▶ *

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences
 - ▶ * Organisms may use resources in different ways

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences
 - ▶ * Organisms may use resources in different ways



Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences
 - ▶ * Organisms may use resources in different ways
 - ▶ * Trees may produce leaves at different times

Coexistence

- ▶ Coexistence *may* occur when $C < 1$
- ▶ Poll: Why might individuals have relatively weaker competitive interactions with members of the other species?
 - ▶ * They may compete for mates or mating sites
 - ▶ * Example: birds with different nesting preferences
 - ▶ * Organisms may use resources in different ways
 - ▶ * Trees may produce leaves at different times

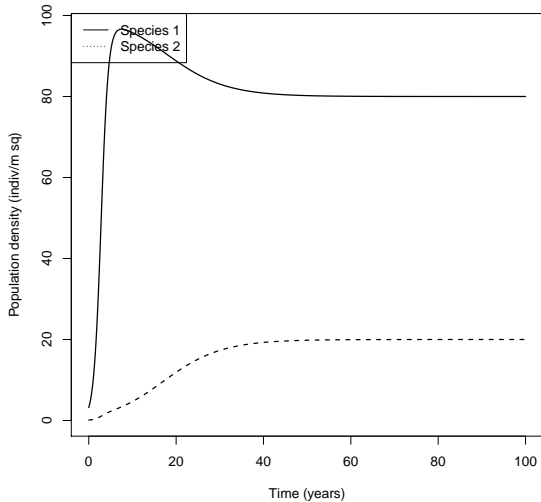
Coexistence



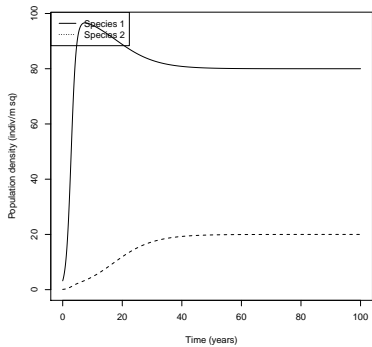
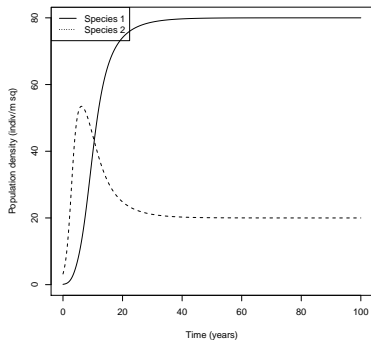
Coexistence



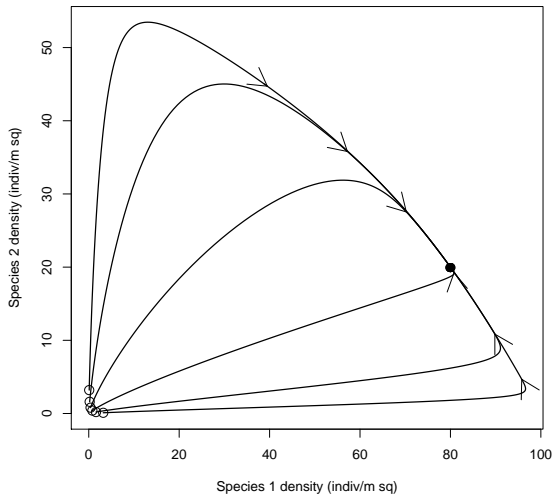
Coexistence



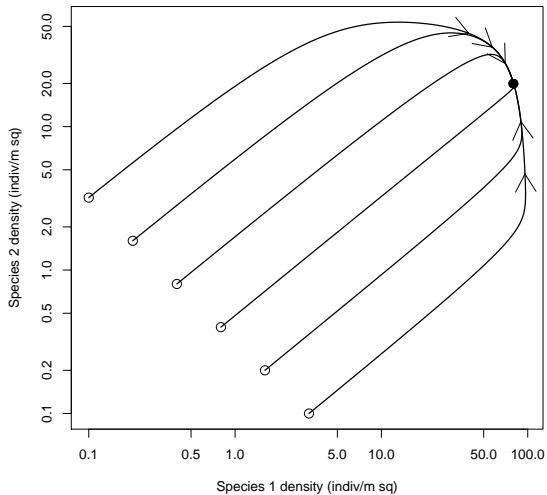
Coexistence



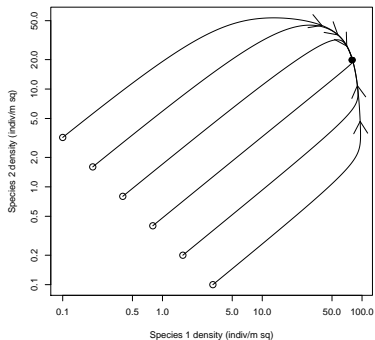
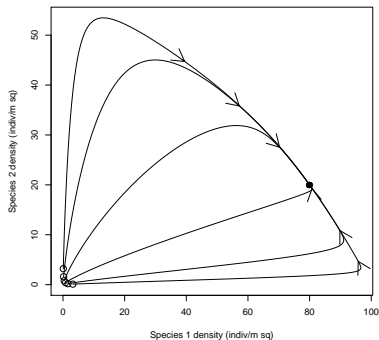
Coexistence phase plot



Coexistence phase plot (log scale)



Coexistence phase plots



Founder control

- ▶ Founder control *may* occur when $C > 1$

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ **Poll:** Why might individuals have relatively stronger competitive interactions with members of the other species?

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?



Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ *

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards
 - ▶ *

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards
 - ▶ * Organisms might change the environment in a way that favors their own species

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards
 - ▶ * Organisms might change the environment in a way that favors their own species
 - ▶ *

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards
 - ▶ * Organisms might change the environment in a way that favors their own species
 - ▶ * Example: trees and grasses

Founder control

- ▶ Founder control *may* occur when $C > 1$
- ▶ Poll: Why might individuals have relatively stronger competitive interactions with members of the other species?
 - ▶ * Conspecifics might co-operate to defend resources
 - ▶ * Example: dogs and leopards
 - ▶ * Organisms might change the environment in a way that favors their own species
 - ▶ * Example: trees and grasses

Founder control



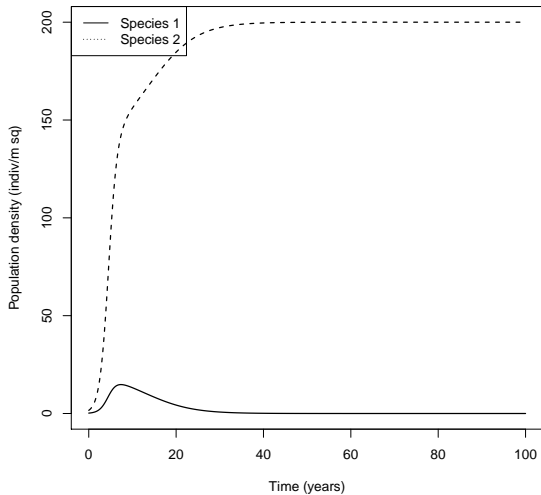
Co-operation

Founder control

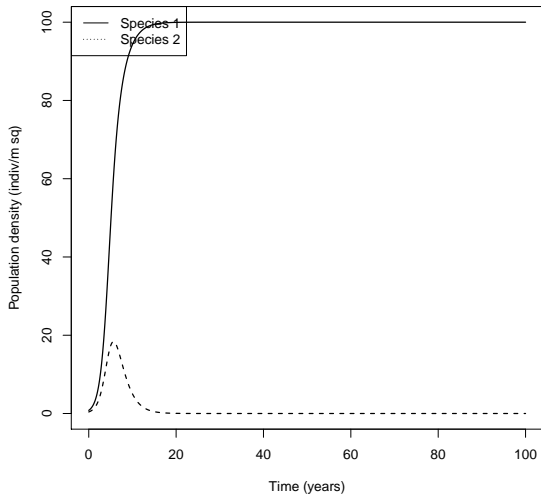


Changing the environment

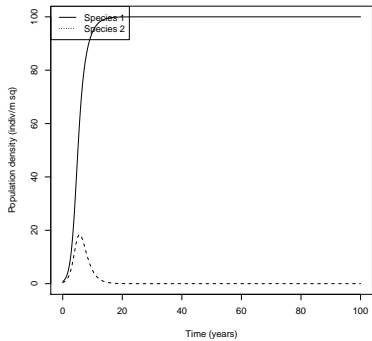
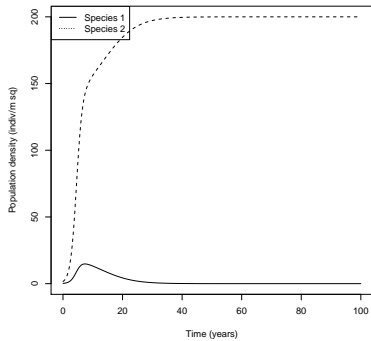
Founder control



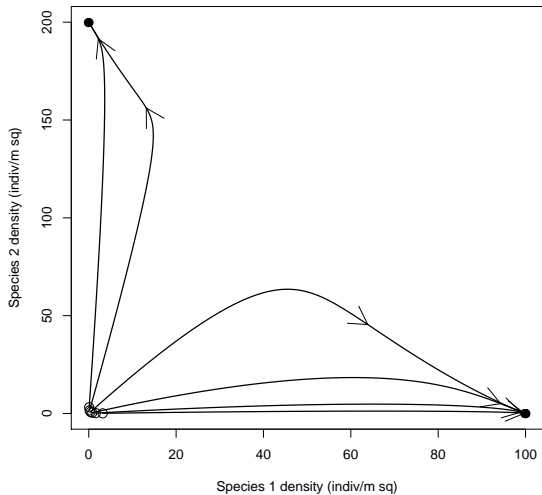
Founder control



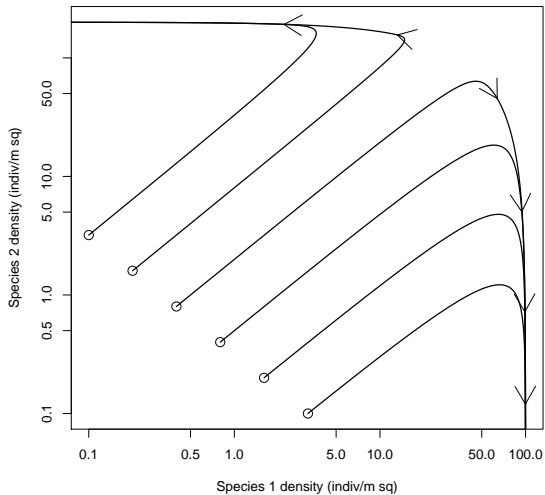
Founder control



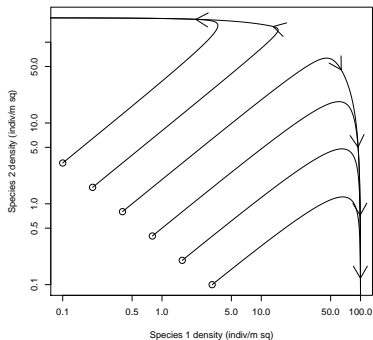
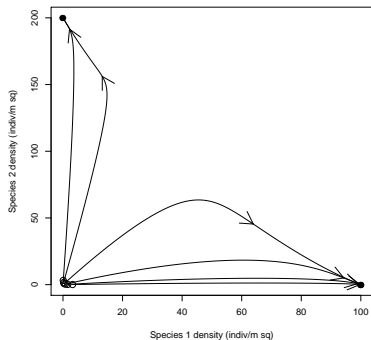
Founder control phase plot



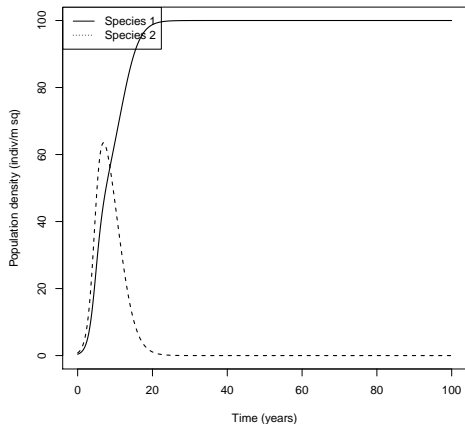
Founder control phase plot (log scale)



Founder control phase plots

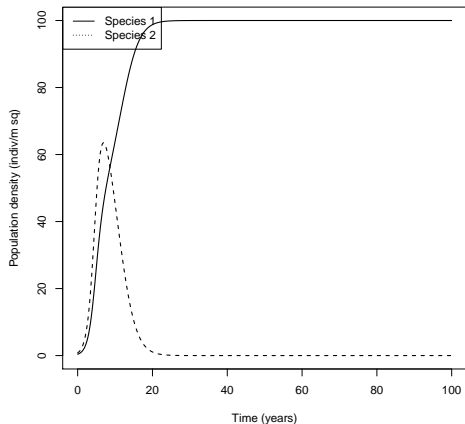


Founder control can be complicated



- Founder control really means each species can win with a *big enough* head start

Founder control can be complicated



- Founder control really means each species can win with a *big enough* head start

Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition

Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition
- ▶ C may stay (about) the same, even as we switch conditions so that one or the other species dominates

Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition
- ▶ C may stay (about) the same, even as we switch conditions so that one or the other species dominates
- ▶ Poll: C tells us what will happen *if* neither species is dominating.

Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition
- ▶ C may stay (about) the same, even as we switch conditions so that one or the other species dominates
- ▶ Poll: C tells us what will happen *if* neither species is dominating.



Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition
- ▶ C may stay (about) the same, even as we switch conditions so that one or the other species dominates
- ▶ Poll: C tells us what will happen *if* neither species is dominating.
 - ▶ * Founder effects, neutrality or coexistence

Results of competition

- ▶ C measures the relative effect of each species on each other, but it doesn't reflect growth rates or how strongly each species is affected by competition
- ▶ C may stay (about) the same, even as we switch conditions so that one or the other species dominates
- ▶ Poll: C tells us what will happen *if* neither species is dominating.
 - ▶ * Founder effects, neutrality or coexistence

Outline

Introduction

Population model with competition

Balanced competition

Unbalanced competition

Population-level interactions

Invasion theory

Colonization and co-existence

Niches and coexistence

The competitive exclusion principle

Subsection 1

Invasion theory

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?



Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other
 - ▶ *

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other
 - ▶ * Coexistence occurs when each species can invade the other

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other
 - ▶ * Coexistence occurs when each species can invade the other



Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other
 - ▶ * Coexistence occurs when each species can invade the other
 - ▶ * Founder control occurs when neither species can invade the other

Invasion theory

- ▶ The competitive relationship between two species can be investigated by studying two **invasion** scenarios:
- ▶ What happens if one species is established, and the other one tries to invade (ie., some individuals are introduced)?
 - ▶ * Dominance occurs when one species can invade the other
 - ▶ * Coexistence occurs when each species can invade the other
 - ▶ * Founder control occurs when neither species can invade the other

Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment

Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment
- ▶ That is, it neglects Allee effects

Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment
- ▶ That is, it neglects Allee effects
- ▶ Would this assumption work with Allee effects?

Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment
- ▶ That is, it neglects Allee effects
- ▶ Would this assumption work with Allee effects?



Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment
- ▶ That is, it neglects Allee effects
- ▶ Would this assumption work with Allee effects?
 - ▶ * No. With Allee effects a species may be able to do well if established, but not be able to “invade” if it’s rare

Allee effects

- ▶ This analysis assumes that species that can be successful under a certain competitive environment can also invade that environment
- ▶ That is, it neglects Allee effects
- ▶ Would this assumption work with Allee effects?
 - ▶ * No. With Allee effects a species may be able to do well if established, but not be able to “invade” if it’s rare

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:

▶ *

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ *

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ * $\tilde{N}_1 = \alpha_{21} N_2$

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ * $\tilde{N}_1 = \alpha_{21} N_2$
 - ▶ *

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ * $\tilde{N}_1 = \alpha_{21} N_2$
 - ▶ * $= \alpha_{21} K_2$, if species 2 is at equilibrium

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ * $\tilde{N}_1 = \alpha_{21} N_2$
 - ▶ * $= \alpha_{21} K_2$, if species 2 is at equilibrium
- ▶ If species 1 feels more competition from invading species two than it feels at its own equilibrium, it cannot invade. And **conversely**.

Competitive results

- ▶ The competitive effect felt by species 1 is measured by \tilde{N}_1
- ▶ The *amount* of competition needed for species 1 to be at equilibrium is:
 - ▶ * $\tilde{N}_1 = K_1$
- ▶ The amount of competition species 1 feels when trying to invade a population of species 2 is:
 - ▶ * $\tilde{N}_1 = \alpha_{21} N_2$
 - ▶ * $= \alpha_{21} K_2$, if species 2 is at equilibrium
- ▶ If species 1 feels more competition from invading species two than it feels at its own equilibrium, it cannot invade. And **conversely**.

Population-level competitive effects

- ▶ The population-level competitive effect of species 2 on species one is $E_{21} \equiv \alpha_{21} K_2 / K_1$

Population-level competitive effects

- ▶ The population-level competitive effect of species 2 on species one is $E_{21} \equiv \alpha_{21}K_2/K_1$
- ▶ This is the unitless ratio of the two measures of effect on species 1 from the previous slide.

Population-level competitive effects

- ▶ The population-level competitive effect of species 2 on species one is $E_{21} \equiv \alpha_{21}K_2/K_1$
- ▶ This is the unitless ratio of the two measures of effect on species 1 from the previous slide.
- ▶ The two values of E determine the competitive dynamics between the two species.

Population-level competitive effects

- ▶ The population-level competitive effect of species 2 on species one is $E_{21} \equiv \alpha_{21}K_2/K_1$
- ▶ This is the unitless ratio of the two measures of effect on species 1 from the previous slide.
- ▶ The two values of E determine the competitive dynamics between the two species.
- ▶ If $E_{21} > 1$ species 2 can exclude species 1 (species 1 cannot invade). And **conversely**.

Population-level competitive effects

- ▶ The population-level competitive effect of species 2 on species one is $E_{21} \equiv \alpha_{21}K_2/K_1$
- ▶ This is the unitless ratio of the two measures of effect on species 1 from the previous slide.
- ▶ The two values of E determine the competitive dynamics between the two species.
- ▶ If $E_{21} > 1$ species 2 can exclude species 1 (species 1 cannot invade). And **conversely**.

Results of competition

- ▶ If both E_s are < 1 , neither can exclude the other

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other



Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ *

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions: founder control

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions:
founder control
- ▶ If one E is > 1 , the large- E species can exclude the other

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions: founder control
- ▶ If one E is > 1 , the large- E species can exclude the other
 - ▶ *

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions: founder control
- ▶ If one E is > 1 , the large- E species can exclude the other
 - ▶ * We expect that species to always win: dominance

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions: founder control
- ▶ If one E is > 1 , the large- E species can exclude the other
 - ▶ * We expect that species to always win: dominance
- ▶ DIAGRAM

Results of competition

- ▶ If both E s are < 1 , neither can exclude the other
 - ▶ * We expect coexistence
- ▶ If both E s are > 1 , they both exclude each other
 - ▶ * which species wins will depend on starting conditions: founder control
- ▶ If one E is > 1 , the large- E species can exclude the other
 - ▶ * We expect that species to always win: dominance
- ▶ DIAGRAM

Measuring competition

- ▶ α measures competitive effects at the individual level

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ **unitless**

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$
 - ▶ C tells us: do the species have a *tendency* for founder control or coexistence?

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$
 - ▶ C tells us: do the species have a *tendency* for founder control or coexistence?
- ▶ For specific conditions, we would need to also know values of E

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$
 - ▶ C tells us: do the species have a *tendency* for founder control or coexistence?
- ▶ For specific conditions, we would need to also know values of E
 - ▶ Each species may dominate when conditions are good for it

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$
 - ▶ C tells us: do the species have a *tendency* for founder control or coexistence?
- ▶ For specific conditions, we would need to also know values of E
 - ▶ Each species may dominate when conditions are good for it
 - ▶ We see the tendency for founder control or coexistence in intermediate conditions

Measuring competition

- ▶ α measures competitive effects at the individual level
 - ▶ has units (ratios of types of individuals)
- ▶ E measures competitive effects at the population level, using equilibrium populations
 - ▶ unitless
- ▶ $C = \alpha_{21}\alpha_{12} = E_{21}E_{12}$
 - ▶ C tells us: do the species have a *tendency* for founder control or coexistence?
- ▶ For specific conditions, we would need to also know values of E
 - ▶ Each species may dominate when conditions are good for it
 - ▶ We see the tendency for founder control or coexistence in intermediate conditions

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition
- ▶ No tendency for either species to win

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition
- ▶ No tendency for either species to win
- ▶ No tendency for founder control or for coexistence

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition
- ▶ No tendency for either species to win
- ▶ No tendency for founder control or for coexistence
- ▶ If there's any small difference between the species, one may dominate

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition
- ▶ No tendency for either species to win
- ▶ No tendency for founder control or for coexistence
- ▶ If there's any small difference between the species, one may dominate
- ▶ Even if there's no difference, one should win eventually, by random "drift"

Neutral competition

- ▶ If competition is balanced, and neither species dominates, this is called neutral competition
- ▶ No tendency for either species to win
- ▶ No tendency for founder control or for coexistence
- ▶ If there's any small difference between the species, one may dominate
- ▶ Even if there's no difference, one should win eventually, by random "drift"

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?



Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first
 - ▶ *

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first
 - ▶ * Initial maximum growth rate

Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first
 - ▶ * Initial maximum growth rate
 - ▶ *

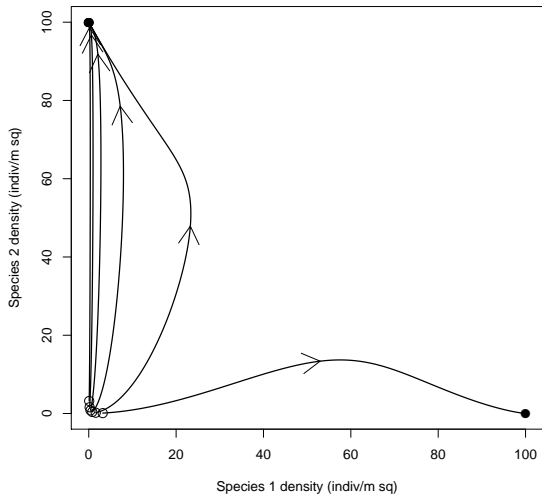
Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first
 - ▶ * Initial maximum growth rate
 - ▶ * How strongly they affect each other

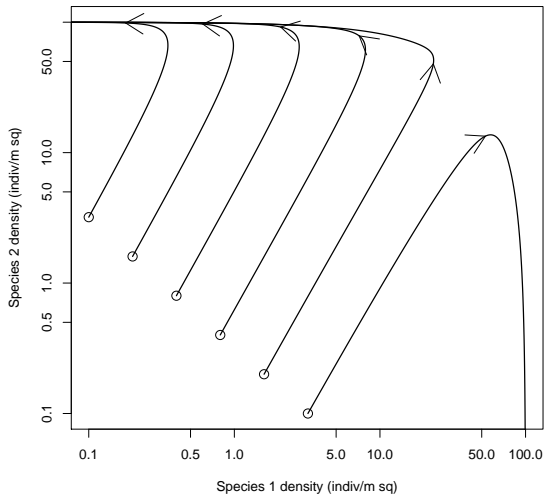
Founder control

- ▶ Up until now, we've thought of founder control as a single outcome
- ▶ But from the point of view of the competing species, it's pretty important which one of them gets control
- ▶ Poll: What factors determine who gets control?
 - ▶ * Who gets there first
 - ▶ * Initial maximum growth rate
 - ▶ * How strongly they affect each other

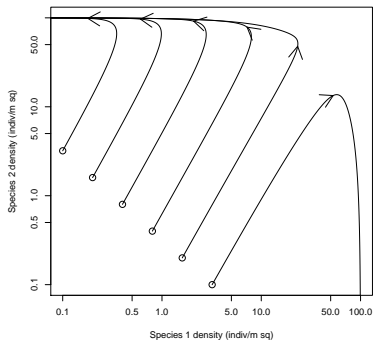
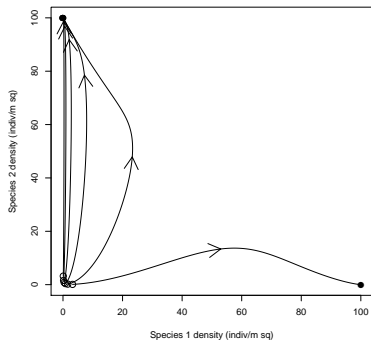
Growth rate and founder control



Growth rate and founder control



Growth rate and founder control



Subsection 2

Colonization and co-existence

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff
 - ▶ r strategists do better in the short term; K strategists do better in the long term

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff
 - ▶ r strategists do better in the short term; K strategists do better in the long term
- ▶ Poll: When can you survive by doing better in the short term?

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff
 - ▶ r strategists do better in the short term; K strategists do better in the long term
- ▶ Poll: When can you survive by doing better in the short term?



Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff
 - ▶ r strategists do better in the short term; K strategists do better in the long term
- ▶ Poll: When can you survive by doing better in the short term?
 - ▶ * When new opportunities (empty habitat) keep coming available

Colonization and co-existence

- ▶ Up until now, we've thought about the question of which species controls a particular area in the long term
- ▶ But if available habitat is changing, it also matters what happens in the short term
- ▶ rK tradeoff
 - ▶ r strategists do better in the short term; K strategists do better in the long term
- ▶ Poll: When can you survive by doing better in the short term?
 - ▶ * When new opportunities (empty habitat) keep coming available

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:



Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run
 - ▶ Faster exponential growth

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run
 - ▶ Faster exponential growth
- ▶ If patches are very stable, then K species wins

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run
 - ▶ Faster exponential growth
- ▶ If patches are very stable, then K species wins
- ▶ If they are very unstable, then r species wins

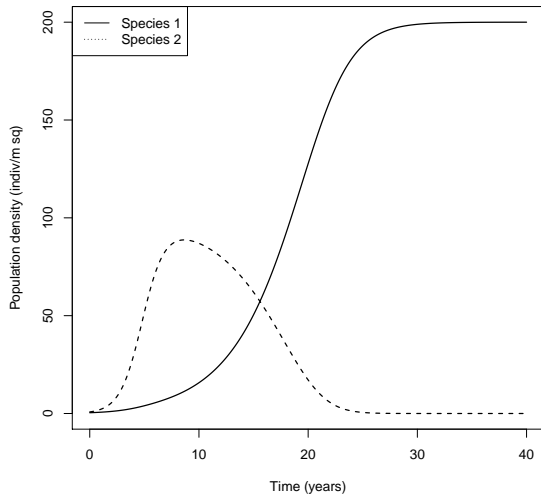
Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run
 - ▶ Faster exponential growth
- ▶ If patches are very stable, then K species wins
- ▶ If they are very unstable, then r species wins
- ▶ In between, we get coexistence at the level of multiple populations

Growth rates

- ▶ The maximum growth rate (for each species) is $r_0 = (b(0) - d(0))$:
 - ▶ * The net growth rate when crowding pressure is very low
- ▶ The species with the better r_0 should do better in the short run
 - ▶ Faster exponential growth
- ▶ If patches are very stable, then K species wins
- ▶ If they are very unstable, then r species wins
- ▶ In between, we get coexistence at the level of multiple populations

rK tradeoff



Outline

Introduction

Population model with competition

- Balanced competition

- Unbalanced competition

Population-level interactions

- Invasion theory

- Colonization and co-existence

Niches and coexistence

- The competitive exclusion principle

Ecological niches

- ▶ An ecological niche refers to the way an organism makes a living:

Ecological niches

- ▶ An ecological niche refers to the way an organism makes a living:
 - ▶ What resources does it need?

Ecological niches

- ▶ An ecological niche refers to the way an organism makes a living:
 - ▶ What resources does it need?
 - ▶ What sort of environmental conditions does it need?

Ecological niches

- ▶ An ecological niche refers to the way an organism makes a living:
 - ▶ What resources does it need?
 - ▶ What sort of environmental conditions does it need?

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.
- ▶ Many plants have very large fundamental niches

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.
- ▶ Many plants have very large fundamental niches
 - ▶ The reason spruce trees don't grow in Cootes Paradise is not that they can't grow there

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.
- ▶ Many plants have very large fundamental niches
 - ▶ The reason spruce trees don't grow in Cootes Paradise is not that they can't grow there



*

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.
- ▶ Many plants have very large fundamental niches
 - ▶ The reason spruce trees don't grow in Cootes Paradise is not that they can't grow there
 - ▶ * They can't compete with the other trees that grow there

Fundamental niches

- ▶ A **fundamental** niche is defined as the conditions under which an organism could make a living (in other words, survive with $\mathcal{R} > 1$) *in the absence of competition*.
- ▶ Many plants have very large fundamental niches
 - ▶ The reason spruce trees don't grow in Cootes Paradise is not that they can't grow there
 - ▶ * They can't compete with the other trees that grow there

Realized niche

- ▶ The realized niche is defined as the conditions under which an organism can make a living, including the effects of competing species



Realized niche

- ▶ The realized niche is defined as the conditions under which an organism can make a living, including the effects of competing species
 - ▶ The realized niche of spruce trees does not include Cootes Paradise



Realized niche

- ▶ The realized niche is defined as the conditions under which an organism can make a living, including the effects of competing species
 - ▶ The realized niche of spruce trees does not include Cootes Paradise



Example: chipmunks



Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?



Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?
 - ▶ * The aggressive species has the same fundamental and realized niches: the places where rainfall is good

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?
 - ▶ * The aggressive species has the same fundamental and realized niches: the places where rainfall is good
 - ▶ *

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?
 - ▶ * The aggressive species has the same fundamental and realized niches: the places where rainfall is good
 - ▶ * The mild-mannered species has a large fundamental niche, but its realized niche is the area that's too dry for the other species

Example: chipmunks

- ▶ There are several species of chipmunks in the Sierra Nevada mountains
 - ▶ The most aggressive can only survive where the rainfall is good, and it out-competes all the other species
 - ▶ The least aggressive can survive anywhere in the mountain range, but it cannot co-exist with any of the other species
- ▶ What are the fundamental and realized niches of these species?
 - ▶ * The aggressive species has the same fundamental and realized niches: the places where rainfall is good
 - ▶ * The mild-mannered species has a large fundamental niche, but its realized niche is the area that's too dry for the other species

Subsection 1

The competitive exclusion principle

The competitive exclusion principle

- ▶ If two species use resources in the same way, we expect that $C = 1$.

The competitive exclusion principle

- ▶ If two species use resources in the same way, we expect that $C = 1$.
 - ▶ The effect of an individual of each species can be measured by its impact on resources. If individuals of species one have (e.g.) twice the impact, this should be seen by both species equally.

The competitive exclusion principle

- ▶ If two species use resources in the same way, we expect that $C = 1$.
 - ▶ The effect of an individual of each species can be measured by its impact on resources. If individuals of species one have (e.g.) twice the impact, this should be seen by both species equally.
- ▶ If two species use resources in the same way, we do not expect them to co-exist

The competitive exclusion principle

- ▶ If two species use resources in the same way, we expect that $C = 1$.
 - ▶ The effect of an individual of each species can be measured by its impact on resources. If individuals of species one have (e.g.) twice the impact, this should be seen by both species equally.
- ▶ If two species use resources in the same way, we do not expect them to co-exist
 - ▶ One species will use the resources more efficiently (nothing in biology is exactly equal)

The competitive exclusion principle

- ▶ If two species use resources in the same way, we expect that $C = 1$.
 - ▶ The effect of an individual of each species can be measured by its impact on resources. If individuals of species one have (e.g.) twice the impact, this should be seen by both species equally.
- ▶ If two species use resources in the same way, we do not expect them to co-exist
 - ▶ One species will use the resources more efficiently (nothing in biology is exactly equal)

Exclusion and drift

- ▶ Even if the two species were *exactly* equal in efficiency, we expect one species to go extinct at random

Exclusion and drift

- ▶ Even if the two species were *exactly* equal in efficiency, we expect one species to go extinct at random
- ▶ Due to the randomness of births and deaths, we expect the proportions to fluctuate at random until one proportion reaches 0 and gets stuck there

Exclusion and drift

- ▶ Even if the two species were *exactly* equal in efficiency, we expect one species to go extinct at random
- ▶ Due to the randomness of births and deaths, we expect the proportions to fluctuate at random until one proportion reaches 0 and gets stuck there
 - ▶ We call this process “drift”, and it is strongly analogous to genetic drift

Exclusion and drift

- ▶ Even if the two species were *exactly* equal in efficiency, we expect one species to go extinct at random
- ▶ Due to the randomness of births and deaths, we expect the proportions to fluctuate at random until one proportion reaches 0 and gets stuck there
 - ▶ We call this process “drift”, and it is strongly analogous to genetic drift

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . .but it must also break down
- ▶ Poll: How?

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: How?



Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ *

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable
 - ▶ *

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable
 - ▶ * Co-existence may not be "long term"!

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable
 - ▶ * Co-existence may not be “long term”!
 - ▶ *

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable
 - ▶ * Co-existence may not be “long term”!
 - ▶ * There may be stabilizing factors outside competitive dynamics (e.g., natural enemies)

Competitive exclusion and biodiversity

- ▶ Two species that use resources the same way cannot co-exist in a stable environment in the long term due to their competitive dynamics
- ▶ This statement can be justified mathematically, and it has important implications for real populations . . .
- ▶ . . . but it must also break down
- ▶ Poll: **How?**
 - ▶ * Species may not use resources in the same way
 - ▶ * The environment may not be stable
 - ▶ * Co-existence may not be “long term”!
 - ▶ * There may be stabilizing factors outside competitive dynamics (e.g., natural enemies)