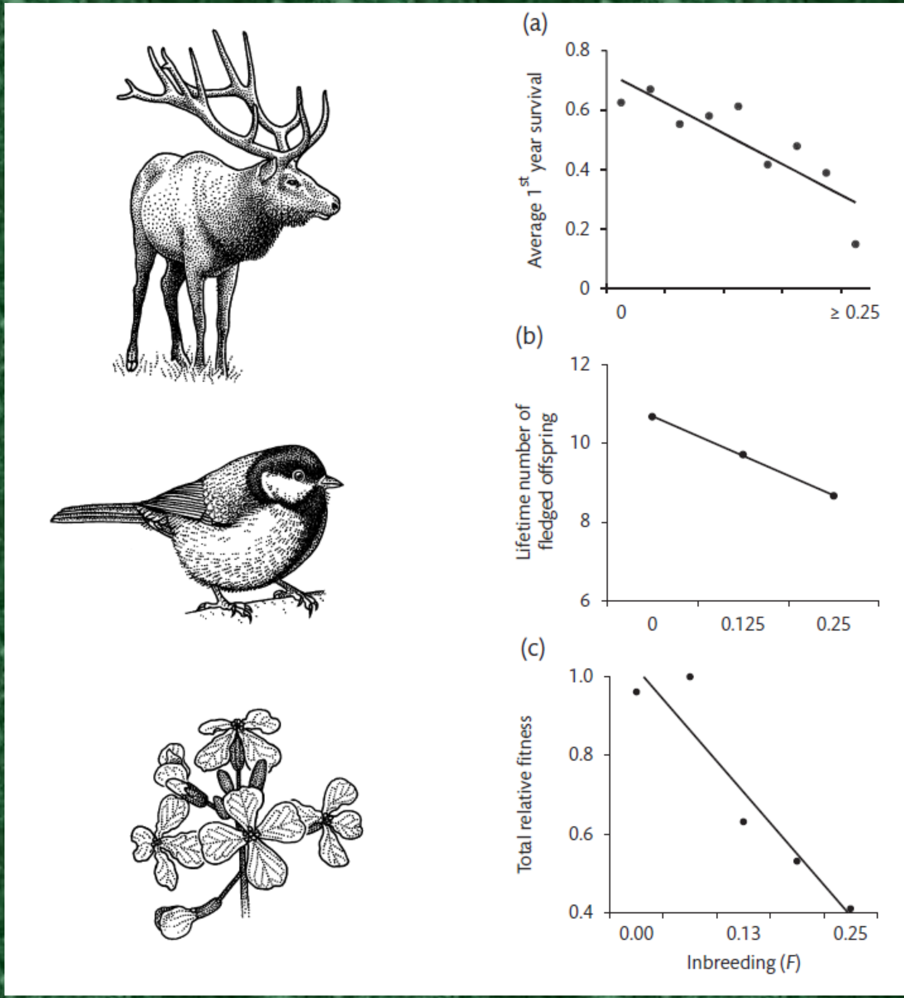
Inbreeding depression



Assumed background: Inbreeding

- Inbreeding is the mating of individuals related by descent
- Inbreeding increases homozygosity and exposes harmful recessives
- Inbreeding occurs through either non-random mating or small pop size
- Inbreeding is unavoidable in small isolated populations and accumulates over time
- Inbreeding coefficient (*F*) is Pr that 2 alleles in an indiv are i.b.d

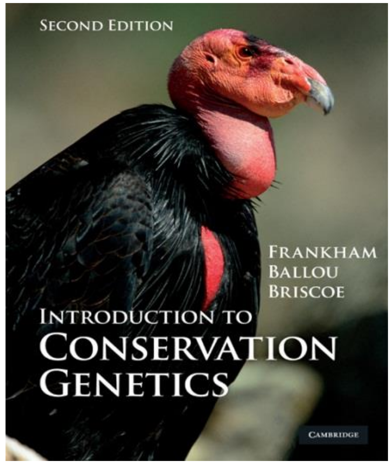
This lecture:

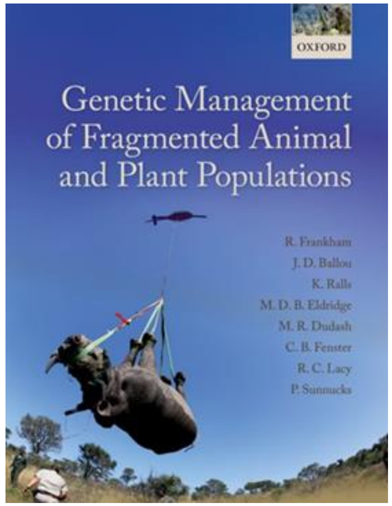
Inbreeding depression

- What is inbreeding depression (ID)?
- Why is ID important in conservation?
- How large are its effects?
- What are its characteristics?
- How does ID and its characteristics arise?
- How does it vary and change?
- How do we detect & measure it?
- What can we do about ID?

References: Text Ch 13

Frankham et al. (2017) GMFAPP Ch3





What is inbreeding depression?

Inbreeding depression is a reduction in mean due to inbreeding, especially for reproductive fitness characters

Inbreeding depression

Effects of inbreeding by selfing (I) versus outcrossing (O) on several characters in 57 species of plants (Darwin 1876)

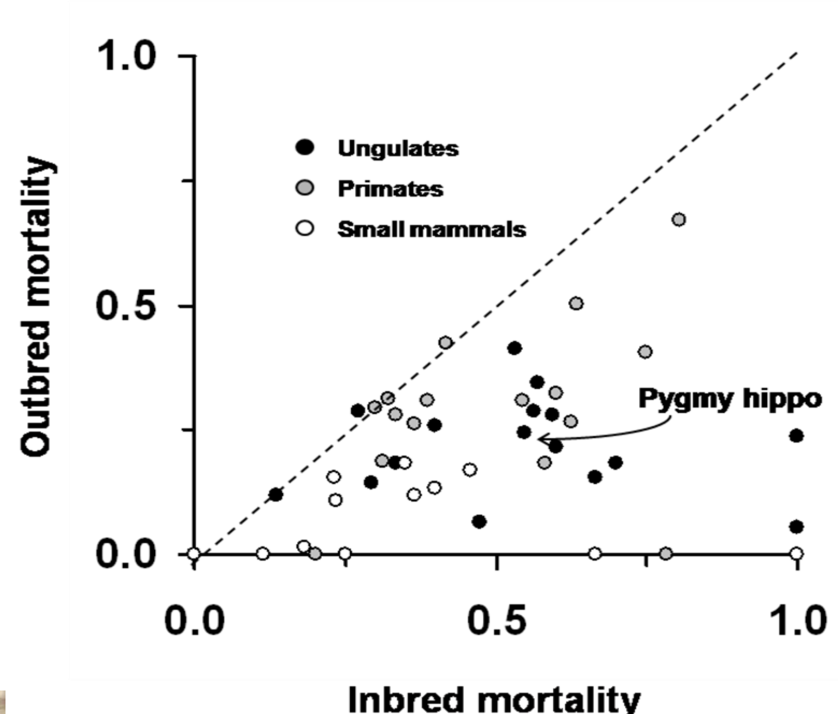
Characters	Species	O > I	O < I	Similar	Difference (O – I)
Height	54	57	8	18	13%
Weight	8	8	1	2	
Flowering time	32	44	9	5	
Seed production	23	26	2	5	41%

Inbreeding depression

Similar conclusions for laboratory and domestic animals and plants & humans

Inbreeding depression in captive mammals

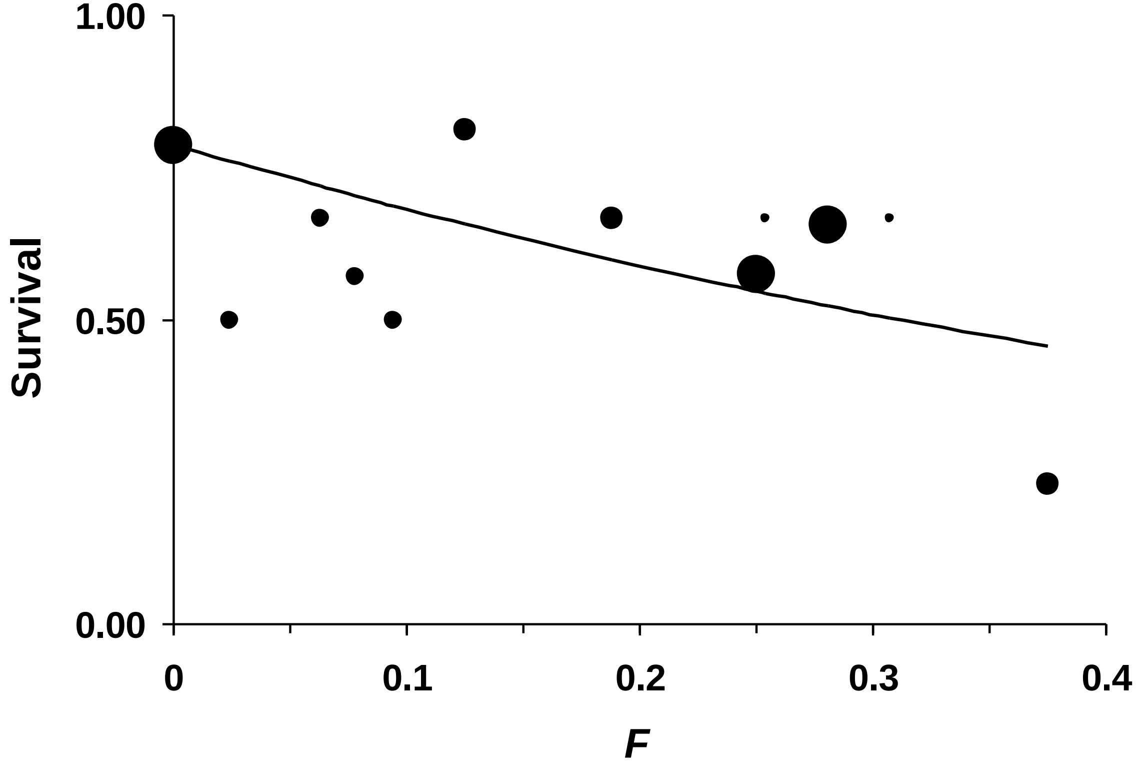
- 41/44 mammal populations showed inbreeding depression
- Juvenile mortality 32% higher in progeny of full-sibs



(Ralls & Ballou 83)

Pygmy hippos
Inbreds : 55% mortality
Outbreds : 25% mortality

Inbreeding depression



Inbreeding depression in the wild

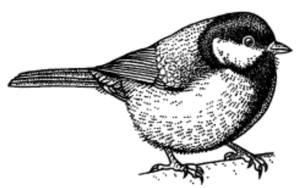
- 141/157 inbreeding harmful (90%)

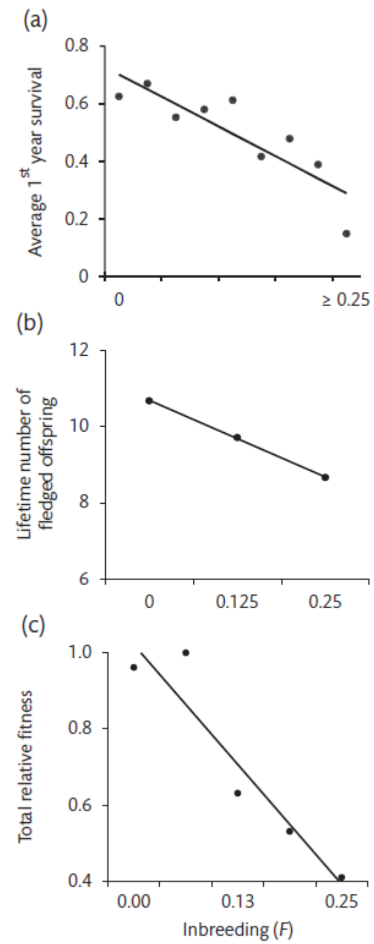
  91.2% cases harmful for fitness

- 2 equal
- 14 inbreds best

(Crnokrak & Roff 99)

ID is ubiquitous



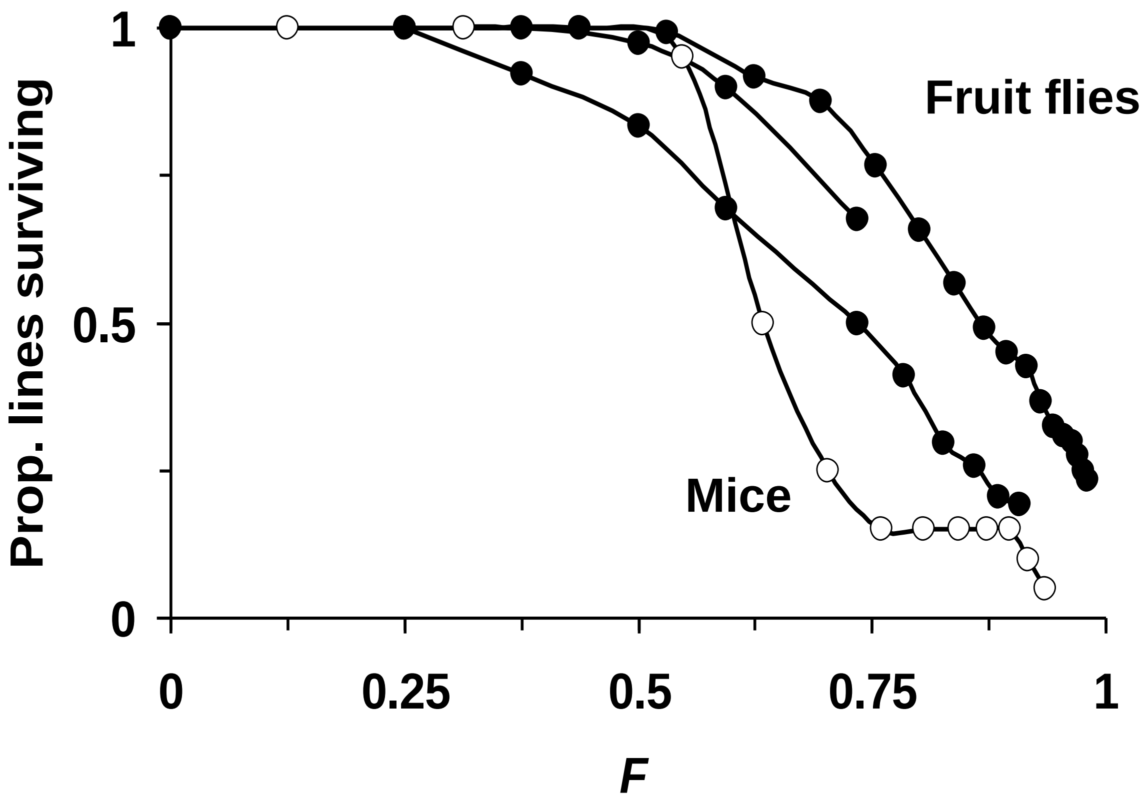


Why is ID important in conservation?

Inbreeding reduces reproductive fitness and adversely affects population persistence i.e. it increases the risk of extinctions

Inbreeding & extinction

Inbreeding causes extinctions in small captive populations



(Frankham 1995 CB)

Extinctions due to inbreeding in wild populations

- Butterflies I > O

  (Saccheri et al. 98)

  (Niemenen et al. 01)

- Plants I > O

  (Newman & Pilson 97)

  (Vilas et al. 2006)

Extinctions due to inbreeding in wild populations

- Butterflies
- Plants

- Are these general, or exceptional cases?

Computer projections for real species: +/- inbreeding depression

Computer projections for real species:
+/- inbreeding depression

Predict without bias

Computer projections for real species: +/- inbreeding depression

Predict without bias

30 vertebrate species using VORTEX

- *ID* as found in the wild (6 haploid lethal equivalents)
- Included natural selection (purging): 50% lethals
- Isolated random mating populations

Computer projections for real species: +/- inbreeding depression

Predict without bias

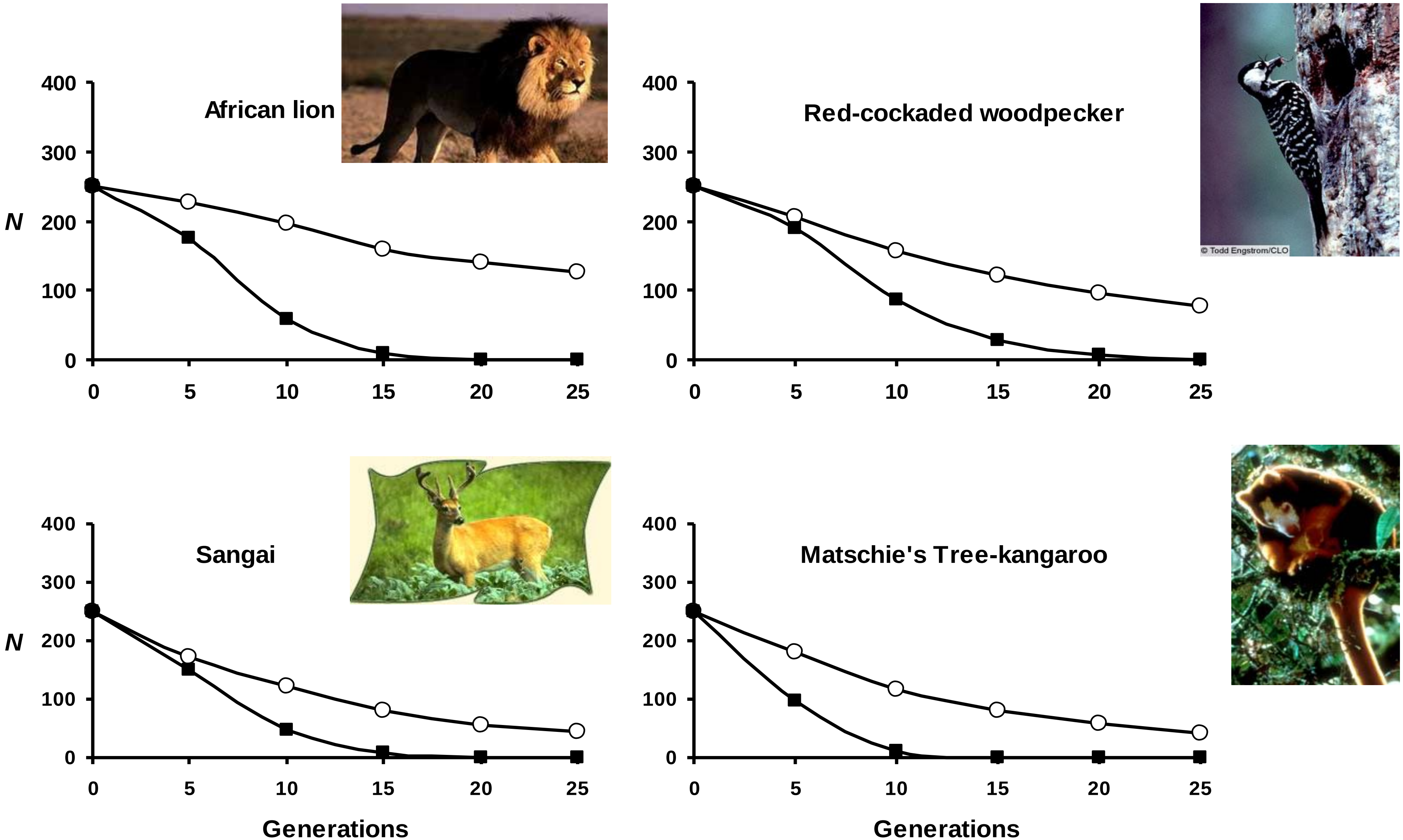
30 threatened species using VORTEX

- ID as found in the wild (12 lethal equivalents)
- purging: 50% lethals

Regimes based on IUCN categories:

- N_{initial} = 50, 250 and 1,000 (~ CE, EN & VU)

1000 reps & all threatening factors included



O’Grady et al. 2006 BC

Findings

- Inbreeding depression markedly decreased median times to extinction
  - 31% for K = 100
  - 39% for K = 500
  - 41% for K = 2,000
- Impacts were similar across major vertebrate taxa

(O'Grady et al. 2006 BC)

Results for butterflies and plants are not special cases:

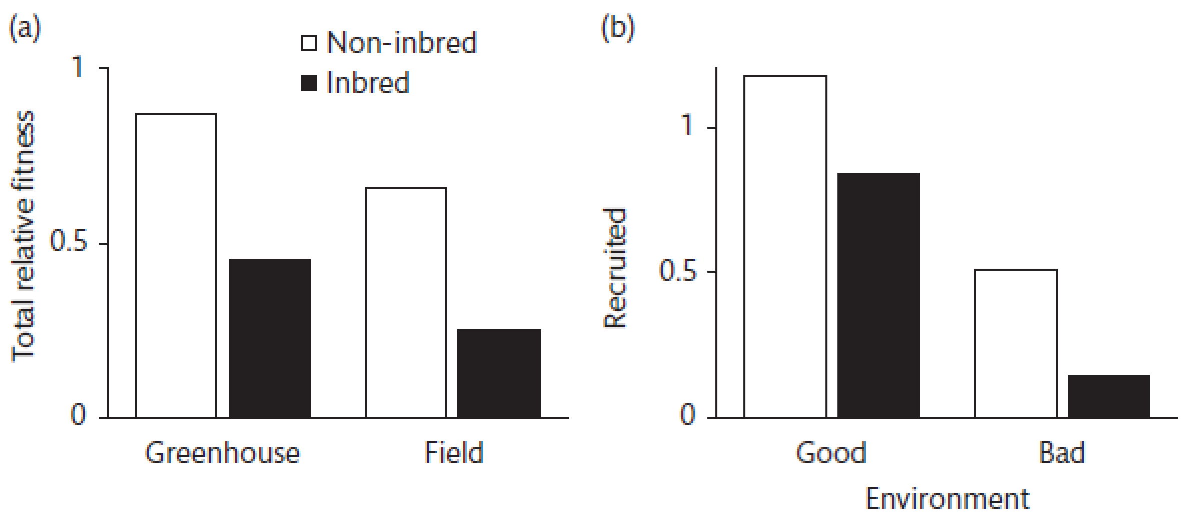
inbreeding generally increases extinction risk

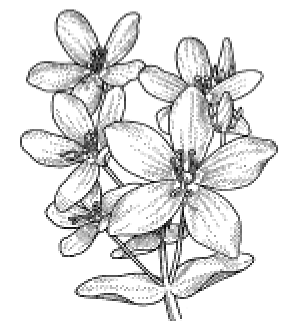
What are the characteristics of ID?

Characteristics of inbreeding depression

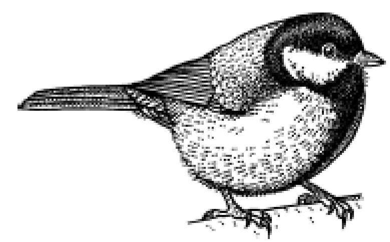
- Ubiquitous
- Natural outbreeders > inbreeders
- No ID in haploids or asexuals
- Fitness characters > those peripheral to fitness
- All components of reproductive fitness subject to ID
- Total fitness > its components
- Stressful/wild > benign/greenhouse or lab
- ID is highly variable (has a large stochastic components)

ID is greater in more stressful environments





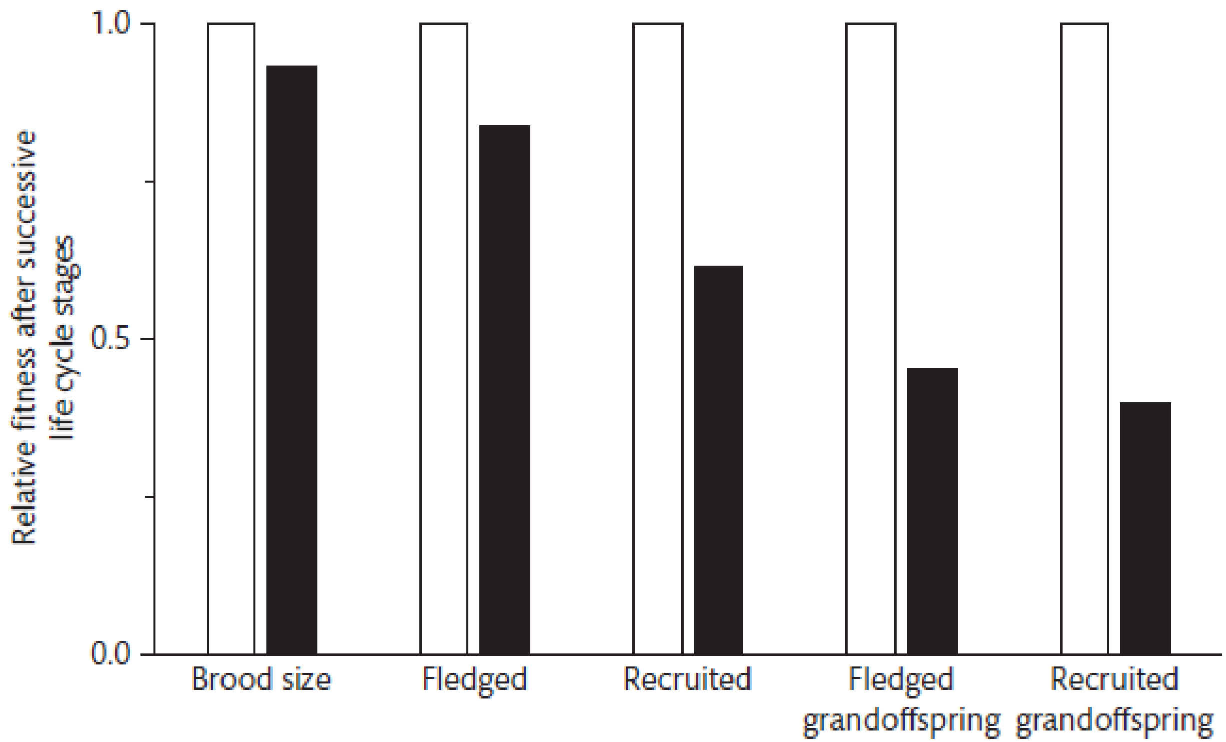
Rose pink plant (USA)



Great tit (UK)

$ID_{stressful} > ID_{benign}$ by 69%

Inbreeding affects all fitness components and accumulates across the life cycle



Devastating effects of FS inbreeding on total fitness in wild

Common name	**ID %**
Red deer	99
Collared flycatcher	94[a]
Great tit	55
Song sparrow	79
Takahe	88
Deerhorn clarkia	100[a]
Rose pink plant	38[a]
Wild radish	56[a]

How does ID and its characteristics arise?

½ way

Genetic basis of ID

- populations contain a load of harmful recessive alleles
- inbreeding increases the frequency of homozygotes and exposes recessive alleles in the phenotype
- this is occurring throughout the genome (~ 20K loci in vertebrates)

Impact of inbreeding on the mean of a population: single locus model

Genotype	Value	Genotype frequencies		Genotype frequency x value	
		Random mating	Inbred	Random mating	Inbred
A_1A_1	a	p^2	$p^2 + Fpq$		
A_1A_2	d	$2pq$	$2pq(1 - F)$		
A_2A_2	$-a$	q^2	$q^2 + Fpq$		

Impact of inbreeding on the mean of a population: single locus model

		Genotype frequencies		Genotype frequency x value	
Genotype	Value	Random mating	Inbred	Random mating	Inbred
A_1A_1	a	p^2	$p^2 + Fpq$	p^2a	$p^2a+Fpqa$
A_1A_2	d	$2pq$	$2pq(1 - F)$	$2pqd$	$2pq(1 - F)d$
A_2A_2	$- a$	q^2	$q^2 + Fpq$	$- q^2a$	$- q^2a - Fpqa$

Impact of inbreeding on the mean of a population: single locus model

		Genotype frequencies		Genotype frequency x value	
Genotype	Value	Random mating	Inbred	Random mating	Inbred
A_1A_1	a	p^2	$p^2 + Fpq$	p^2a	$p^2a+Fpqa$
A_1A_2	d	$2pq$	$2pq(1 - F)$	$2pqd$	$2pq(1 - F)d$
A_2A_2	$-a$	q^2	$q^2 + Fpq$	$-q^2a$	$-q^2a - Fpqa$
		Means		$Mo = a(p - q) + 2pqd$ $M_F = a(p - q) + 2pqd - 2pqdF$	

$$\boldsymbol{M_F = M_O - 2pqdF}$$

$$\boldsymbol{ID = 2pqdF}$$

What do the terms mean?

ID = $\sum 2pqdF$

$\sum$ = sum over all loci with segregating alleles that are harmful when homozygous

more for total fitness than for components

What do the terms mean?

2pq heterozygosity for harmful alleles

no ID in haploids

less with selfing

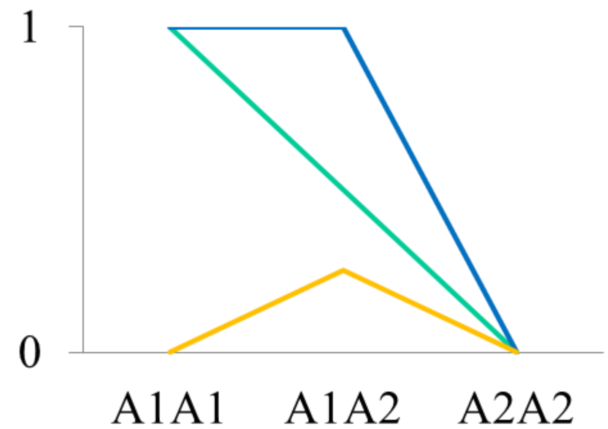
2pq*F* loss of heterozygosity

No ID in asexual species

less ID in selfing species

less ID in haplodiploids

What does the d term mean?



d = dominance of harmful alleles

ID when d = +ve recessive on average or heterozygote adv

directional dominance (as for fitness)

not for stabilising seln (non-fitness)

no ID when *d* = 0 hets intermediate

What does this equation predict?

$ID = \sum 2pqdF$

predicts linear decline in fitness with F

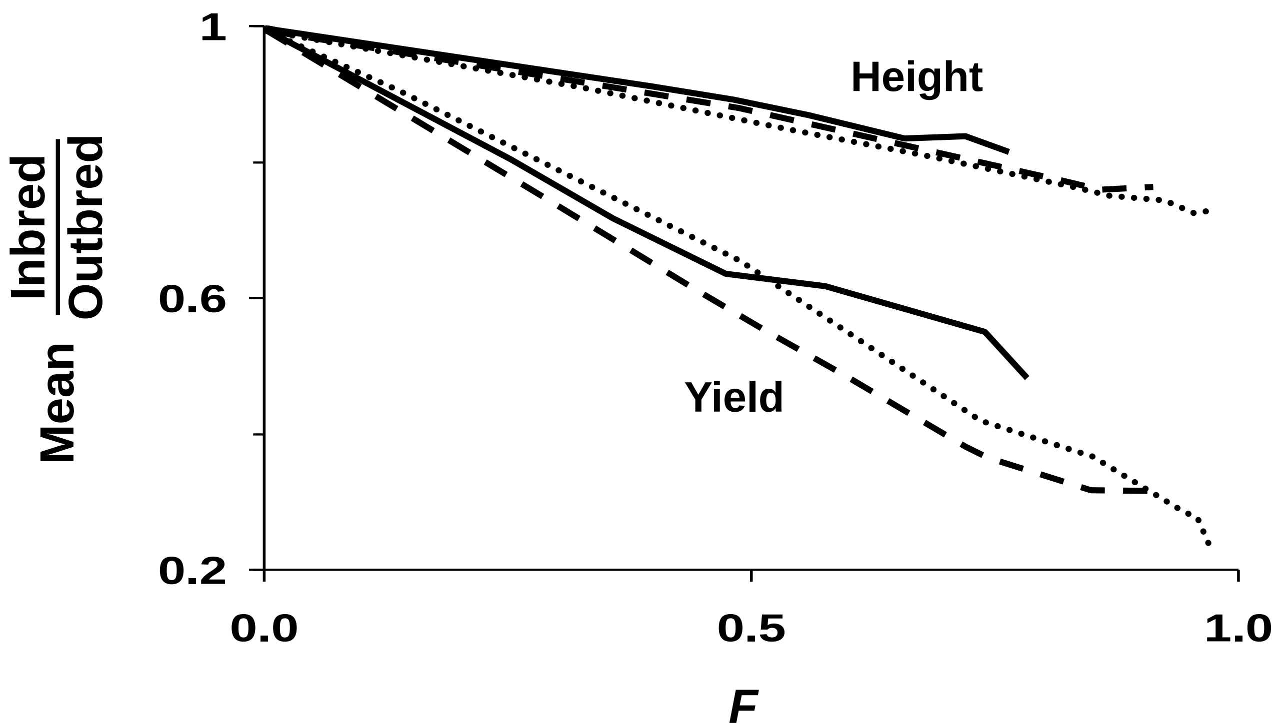


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Fig 13.4 ID in maize.ppt

How does ID vary and change?

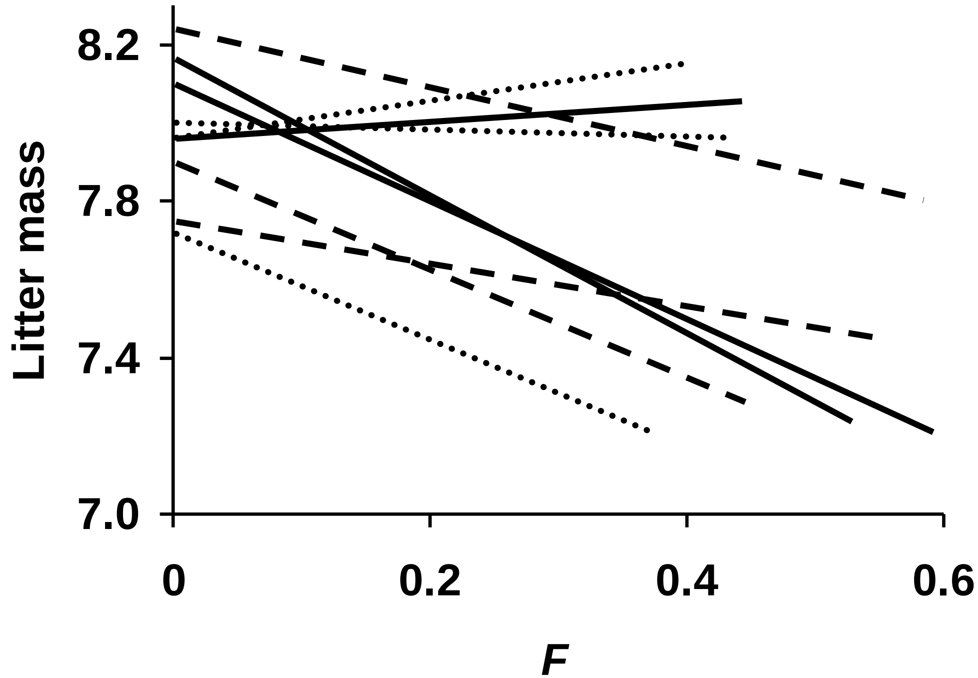

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Fig 13.3 Inbreeding in Peromyscus.ppt

How does natural selection affect ID (purging)?

Reduction in inbreeding depression caused by natural selection reducing frequency of harmful recessive alleles

Purging

- ID may be reduced by selection against harmful recessives under inbreeding
- Harmful recessives can be purged, but not loci with het advantage
- In small populations some harmful alleles become fixed through drift
- Purging more effective in large populations with some inbreeding (e.g. selfing)

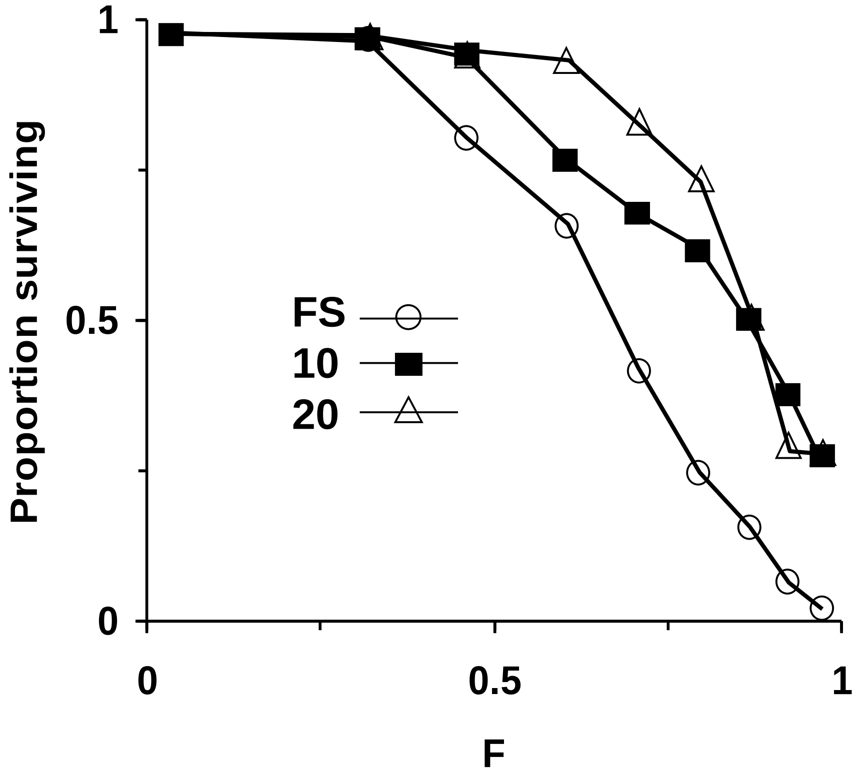

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Fig 13.5 F and Population Survival

How we detect and measure ID?

How do we detect ID?

- Compare inbreds & outbreds contemporaneously

  in same environment

- Compare I & O with same controls
- Regression of fitness on *F*

Measuring ID using delta (δ)

$$\delta = 1 - \frac{\text{fitness inbred offspring}}{\text{fitness of outbred offspring}}$$

Example: rose pink plant

Total fitness O = 0.99; I = 0.25*

$$\delta = 1 - \frac{0.25}{0.99} = 0.747$$

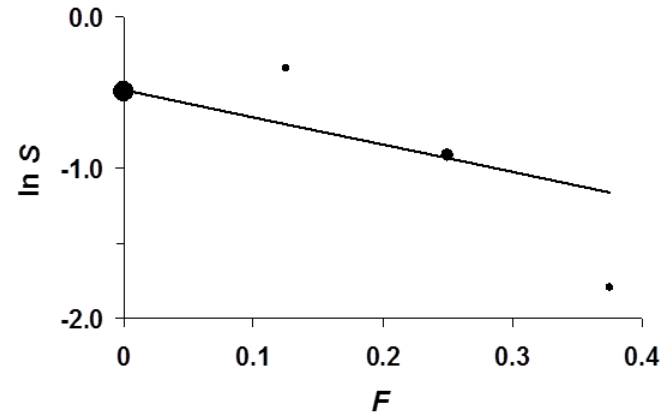
Measuring ID using lethal equivalents (*B*)

Regress ln(survival) on F

$S_l = e^{A - BF}$

$\ln S = A - BF$

$= -0.48 - 1.80\,F$ (Okapi)



B = haploid lethal equivalents = 1.80

$2B$ = diploid lethal equivalents = 3.60

Extent of inbreeding depression (lethal equivalents)

- Captive mammals juvenile survival $B = 1.57$

  FS have 32% lower juv survival ($1 - e^{-FB}$)

- Verts & plants total fitness in wild B ~ 6.85

  FS have 82% lower total fitness than outbreds

- Why do we need LE values?
  - To predict ID for any F values.

Extent of inbreeding depression for total fitness in the wild (lethal equivalents)

Common name	Genus and species	δ %	L.E.
Red deer	*Cervus elaphus*	99	18.7
Collared flycatcher	*Ficedula albicollis*	94[a]	7.5[a]
Great tit	*Parus major*	55	3.2
Song sparrow	*Melospiza melodia*	79	6.2
Takahe	*Porphyrio hochstetteri*	88	8.0
Deerhorn clarkia	*Clarkia pulchella*	100[a]	39.2[a]
Rose pink plant	*Sabatia angularis*	38[a]	1.9[a]
Wild radish	*Raphanus sativus*	58[a]	3.3[a]

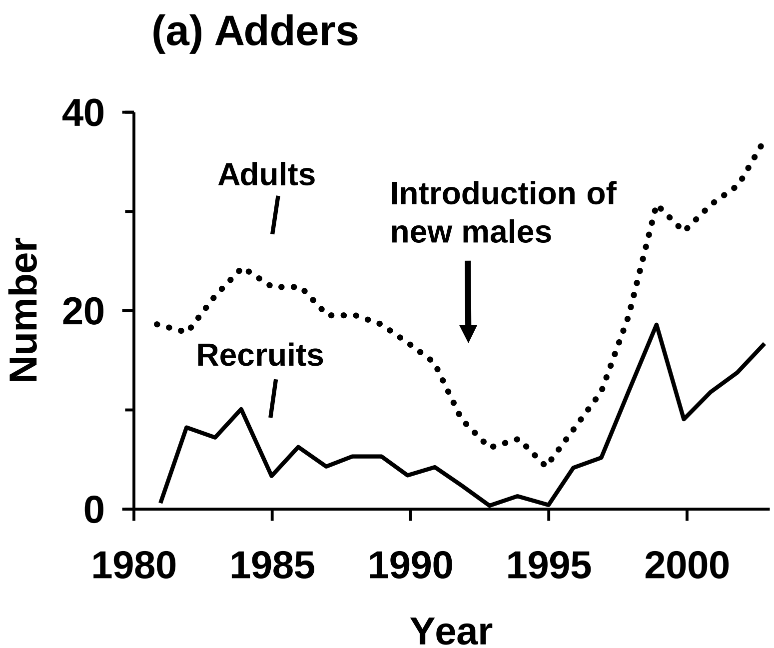
[a] No maternal ID

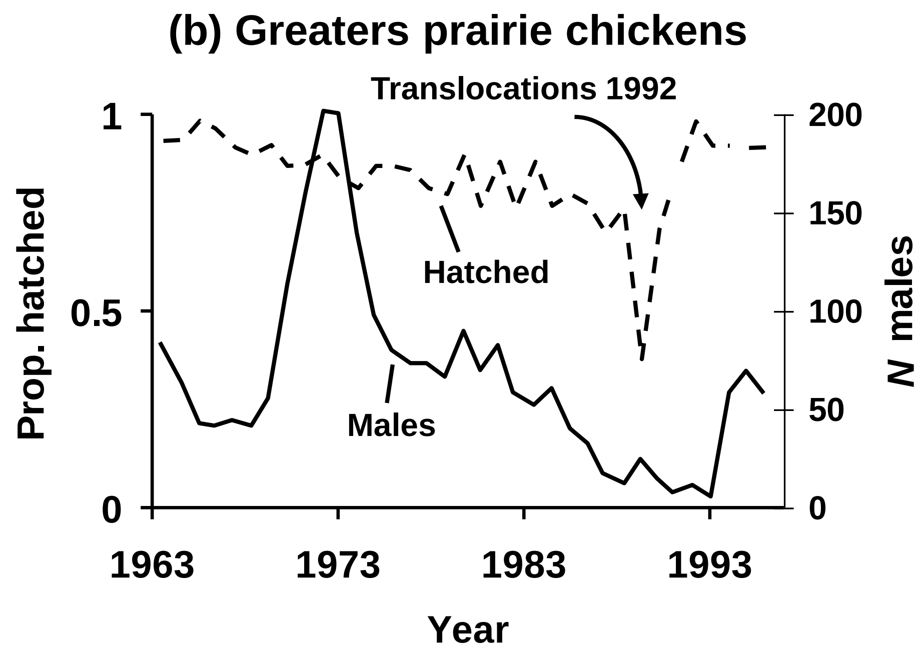
What can we do about inbreeding depression?

Genetic rescues of small inbred populations by outcrossing

SPECIES SPOTLIGHT...

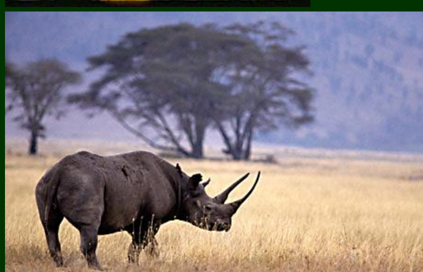
Genetic Rescue





Genetic rescue meta-analysis:
How consistent?
How large?

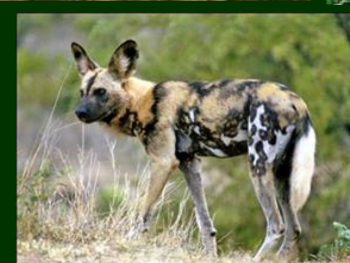










Consistency of genetic rescue:
(Frankham 2015)

- Data: 145 +: 2 =: 9 – (156)
- X^2 test of 145: 9 for equality = 139.1 ***
- Highly consistently beneficial effects

Magnitude of GR: composite fitness in outbreeding species

- Data: 67 cf
  - Median benefits

    Wild 165%: Captive 51%

    (likely underestimates)

    Benefits persisted across generation for outbreeders

- Have been very few genetic rescues. Why?

Messages

- Inbreeding reduces reproductive fitness (ID) and increases extinction risks
- This arises because inbreeding makes harmful alleles homozygous
- ID increases with F, is greater in more stressful environments & is greater in outbreeding than inbreeding species
- Natural selection can reduce ID by removing harmful recessive alleles
- Populations can usually be rescued from ID by outcrossing (genetic rescue)

Questions?

Variables affecting magnitude of genetic rescue

- Inbreeding (ΔF)
- Stressful > benign env
- Br system (outcrossing > selfing)
- Immigrants outbred > inbred
- Major taxa (vert, invert & plants) ns
- (ploidy; purging)

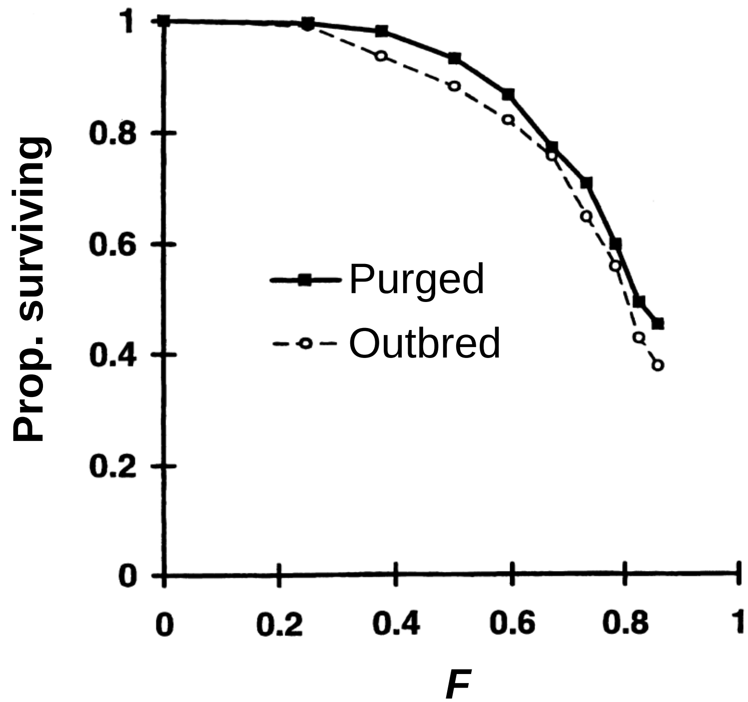


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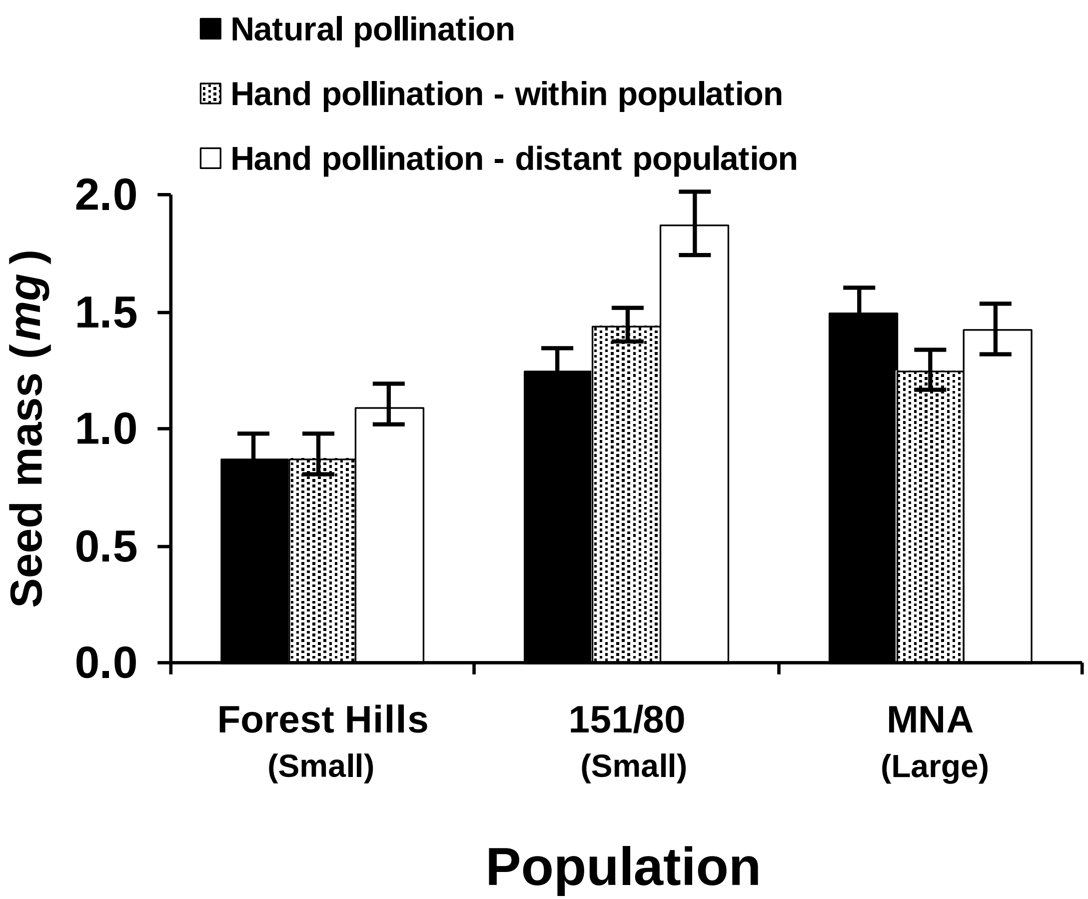
Fig 13.6 Purged and outbred.ppt

Alleviating inbreeding depression by outcrossing (scarlet gilia)



Case study: Inbreeding depression & rescue in desert topminnow fish (Vrjenhoek, 1994)