BIOL3110

Genetically viable populations

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This lecture:
Genetically viable populations

- Why do we need to define the size of genetically viable populations?
- How large to they need to be?
  - Avoid fitness loss in short term?
  - Retain evolutionary potential in perpetuity?
    - Quantitative genetic variation
    - Single locus diversity
  - Avoiding accumulation of harmful mutations?
- How large are populations in practice?
- Captive populations: a compromise
- Fallacy of small isolated surviving populations
- Reference: Text Ch15*
- + Frankham et al. (2014) Biological Conservation 170, 56-63

Reference

Biological Conservation 170 (2014) 56–63

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Perspective

Genetics in conservation management: Revised recommendations for the 50/500 rules, Red List criteria and population viability analyses

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Why do we need to define the size of genetically viable populations?

- Resources for conservation are limited
- Opportunistic funding
- *Crisis discipline*: require decisions to be made promptly with limited information
- Need for rules of thumb e.g. IUCN Red List, 50/500 etc

Resources limited

- Captivity
  - 2K species require captive breeding
  - Space in zoos for ~ 1K species
- Wild
  - Severe shortage of habitat & $
  - Even the largest reserves are too small for large species

How large must population be to retain their genetic health?

How large must populations be to retain genetic ‘health’? 50/500

Goal	N_e	References
1. Retain fitness in short term by avoiding ID	50	Franklin (1980); Soule (1980)
2. Retain evolutionary potential in perpetuity	500	Franklin (1980)

1. How large must isolated populations be to retain fitness in the short-term by avoiding ID?

Retaining reproductive fitness: avoiding ID in short-term

(Franklin 1980; Soulé 1980)

- Opinion of animal breeders
  - short term $N_e = 50 \sim F = 5\%$

What evidence has accumulated since 1980? avoiding ID in short-term

Exptal data

- House flies lab
  - 14% ID for N_e = 90 for 5G* (Bryant et al. 99)
- Plants wild
  - N_e = 50 results in 16% ID over 5 gens (F = 5%) (3.4 haploid LE)
  - ΔF = 4% lowered fitness by 79% & increased extns from 25% to 69% (Newman & Pilson 97)

- Vertebrates wild (7.6 haploid LE)
  - N_e = 50 results in 32% ID over 5 gens (F = 5%) (O'Grady et al. 2006; Frankham et al. 2022)

N_e = 50 is inadequate

Realistic simulations

Simulations

- N_e ~ 70 required to avoid 10% ID (Caballero et al. 2016)

Likely an underestimate

– assumed 6 LE

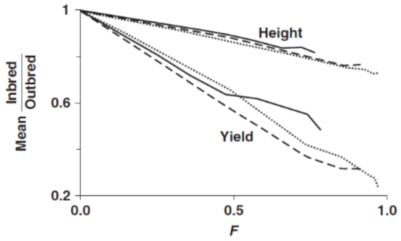
– actual median 7.6 in vertebrates (Frankham et al. 2022)

– maternal ID not included in half of estimates

Revised guidelines for retaining fitness in wild

(Frankham et al. 2014)

- Specify short term = 5G
- Linear decline in fitness with *F*, so can't totally avoid ID keep to <10%
- With 7.6 LE N_e = 179 required, but allowing for some mild purging
- In plants with LE = 3.4, N_e = 79 needed



Recommend

$N_e \geq 100$ over 5G required to keep ID < 10% in wild

What are N_e in practice?

What are N_e of TH sp in practice?

- Captive pops of TH sp

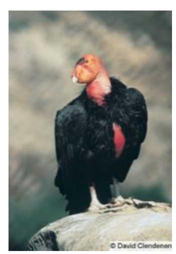
  Av N_e ~ 33

- Wild TH sp: IUCN criterion D
  - CE $N_e \leq 8$
  - EN $N_e \leq 39$
  - VU $N_e \leq 156$

- In many thr sp N_e is too small to prevent ID

N for de-listing thr species: wild

Species	N for de-listing	N_e
USA 475 sp (vert, inv & pl)	2,400	~ 240
17 delisted sp	2,360	~ 236



2. How large must isolated populations be to retain the ability to evolve in perpetuity?

Retaining evolutionary potential

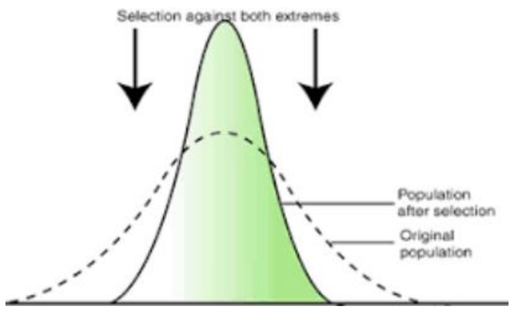
(Franklin (1980))

Assumptions:

1. Quantitative genetic variation
2. Heterozygosity not allelic diversity
3. Characters peripheral to fitness

Retaining evolutionary potential

- Quantitative genetic variation
- Heterozygosity not allelic diversity
- Equilibrium: mutation & drift
  - N_e = 500 (Franklin 1980)
- Equilibrium: mutation, drift & stabilising selection (Lande & Barrowclough 1987)
  - N_e ~ 500



Retaining evolutionary potential: derivation

Mutation-drift equilibrium (Franklin 1980)

$$\Delta V_A = V_m - V_A / (2N_e) = 0$$

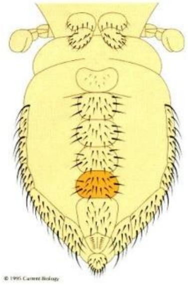
$$N_e = V_A / 2V_m$$

Substituting $V_m \sim 10^{-3}\ V_E$ per generation

$$N_e = V_A / [2 \times 10^{-3} \times V_E] = 500\ V_A / V_E$$

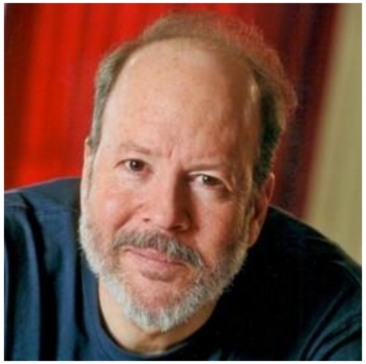
With $V_A / V_E \sim \dfrac{h^2}{1 - h^2} = 1$, $(h^2 = 0.5)$

$N_e = 500$



What has changed since 1980: evolutionary potential?

Adjusting for 90% harmful mutations (Lande 1995)



$V_m = 10^{-4} V_E$ (~ plant fitness in wild)

$N_e = V_A / [2 \times 10^{-4} \times V_E] = 5000\ V_A / V_E$

Assuming $V_A/V_E = 1$ ($h^2 = 0.5$),

$N_e = 5{,}000$

With $V_A / V_E = 1/4$, ($h^2 = 0.2$) (Franklin & Frankham 1998)

$N_e = 1{,}250$

What has changed since 1980? evolutionary potential

- Other quantitative genetic models
  - $N_e > 10$K (Keightley & Hill 1987)
  - $N_e = 10$K ~ ∞, 1K close (Weber & Diggins 1990)
  - $N_e \geq 1$K (Lynch & Lande 1998)
  - N_e a few K sufficient (Willi et al. 2006)

$N_e = 500$ inadequate

What has changed since 1980? evolutionary potential

However, we should consider

Quantitative genetic variation for total fitness,

not for peripheral traits

Retaining evolution potential for fitness: theory

- Mildly harmful

  $N_e \geq 1K$ (Falconer & Mackay 1996; Bataillon & Kirkpatrick 2000)

- Lethals

  $N_e \geq 1K$ (Nei 1968; Hedrick 2002)

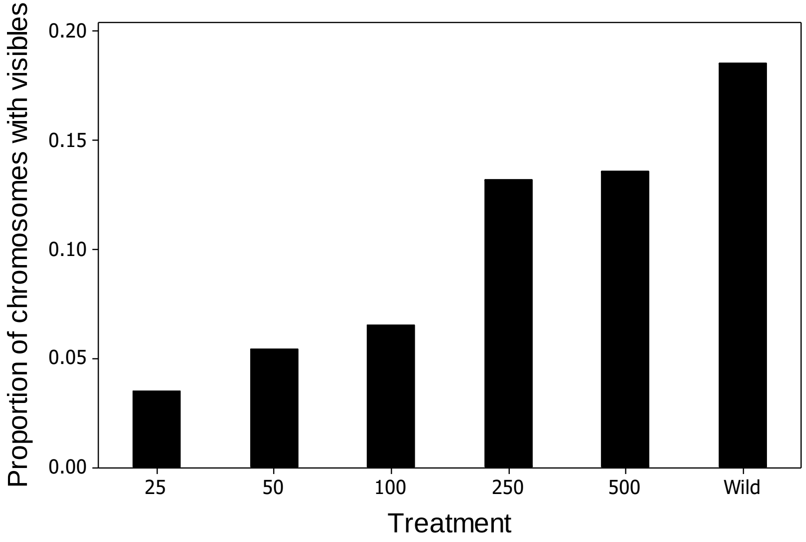
- Balancing selection

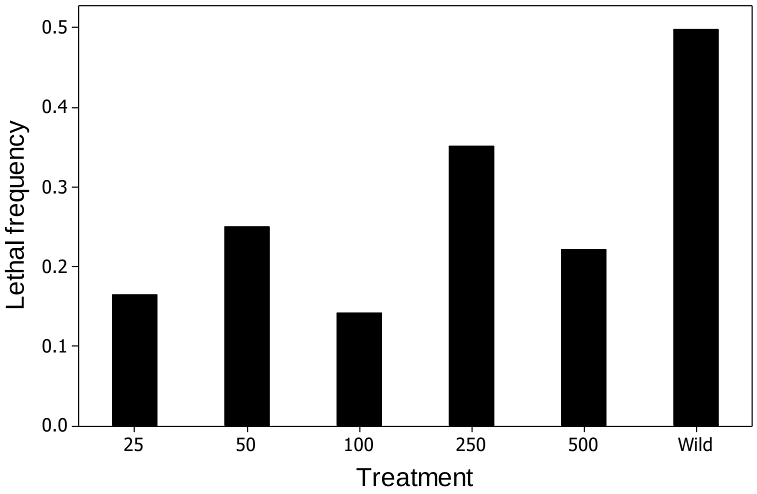
  Heterozygote advantage $N_e \geq 1K$ (Robertson 1962)

  Frequency dependent selection $N_e \geq 5K$ (Roff 1998)

N_e = 500 inadequate

Retaining evolution potential for fitness: Empirical data





Frankham et al. (2014)

Revisions: retaining evolutionary potential in perpetuity

(Frankham et al. 2014)

1. Specify retain QGV for total fitness
2. $N_e \geq 1000$ required

N_e in most thr species are too small to avoid loss evol potential

½ way

3. How large do populations need to be to retain single locus genetic diversity in perpetuity?

Retaining single loci GD

Lande & Barrowclough 1987

- Why are we concerned about indiv loci?
  - MHC in vertebrates
  - SI alleles in plants
  - Sex locus in Hymenoptera

- $N_e = 10^5$-10^6 to retain
- No thr sp this large, nor are many non-thr sp (including humans)

What happens if N_e < 1000?

- Extinction? Not necessarily soon
- Slow and continuous genetic deterioration
- ‘Fragility’
- Higher risk of eventual extinction, especially with catastrophic environmental change

Can we just wait for genetic diversity to be regenerated by mutation?

How long does this take?

It takes many generations to regenerating GD by mutation?

(Lande & Barrowclough 1987)

GD	Regeneration (G)
Quantitative confirmed in empirical studies	10^2-10^3
Single-locus	10^5-10^7

Must preserved GD, not rely on mutation to regenerate it in eukaryotes

4. Avoid accumulation of harmful mutations

- Chance fixation of harmful alleles is elevated in small populations
- Can lead to extinctions “mutational meltdown”

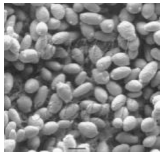
Avoiding mutational accumulation: Theory

- Outbreeders
  - $N_e < 12$ (Charlesworth et al. 93)
  - $N_e < 100$ (Lynch et al. 95)
  - $N_e < 1000$ (Lande 95)
  - Depends on effects of harmful mutations
    - (Garcia-Dorado 2003)
- Asexuals
  - Worse

Avoiding mutation accumulation Empirical data

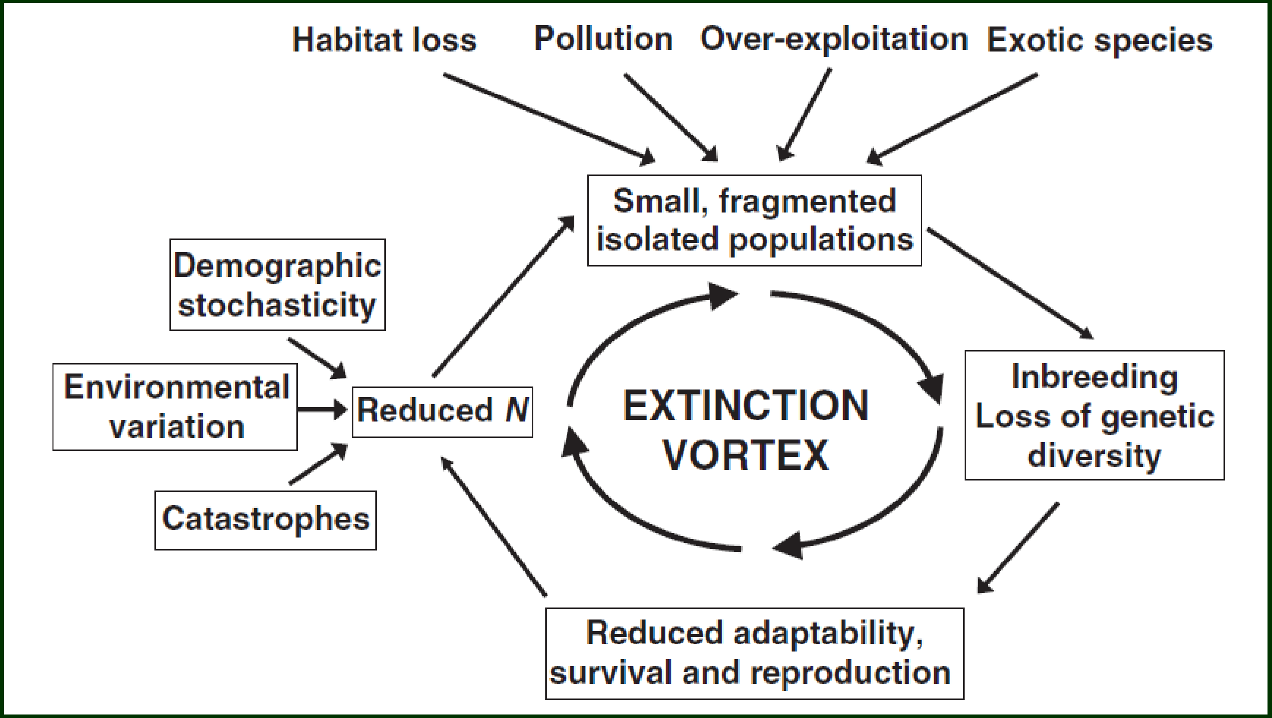
- No mut accum in *Dros* 45-50G N_e 25-500
  (Gilligan et al 1997)
- No mut accum in 2900G asex yeast N_e 250
  (Zeyl et al 2001)
- Nematodes N_e = 1 lost <1% fitness/G

  (Vassilieva et al. 2000; Estes et al. 2004)



- Conclusion:
  – Appears to be a minor threat << ID

What population sizes are required to cope with all threats (MVP)?



Sizes required for long-term viability to cope with different threats

Threat	N_e	N
Theory (Frankham et al. 2014; Nunney & Campbell 1993)		
Retaining QGV	1K	~10K
Demographic stochasticity		10s – 100
Environmental stochasticity		1K+
Catastrophes		1K+
Empirical data (Reed et al. 2003; Traill et al. 2007; Harcourt et al. 2002)		
PVA for 100 vertebrate species: 99% persistence for 40 G		>6K
PVA for 212 species: 99% probability of persistence for 40 G		4.2K
Primates in Sunda Islands		>16K

What are the population size targets for threatened species in captivity?

Goal: Retain 90% of genetic diversity for 100 yrs

How was this arrived at?

- Tradeoff between # species conserved & how well each is conserved
- Scenario: human pop will peak and decline within 100-200yrs & release habitat for reintro of thr sp

How large do thr species need to be to meet this target?

Aim: Retain 90% of genetic diversity for 100 yrs

Required N_e depends on generation length (L)

$$H_t/H_0 = [1 - 1/(2N_e)]^t \sim e^{-t/2Ne} = 0.9$$

let $t = 100 / L$

$$0.9 = e^{-100/2LNe}$$

take ln & rearrange

$$N_e \sim 475 / L$$

Endangered species in captivity

$N_e \sim 475 / L$

Examples:

Elephant $L = 35$

$N_e = 475/35 = 14$

White-footed mouse $L = 0.27$

$N_e = 475/0.27 = 1759$

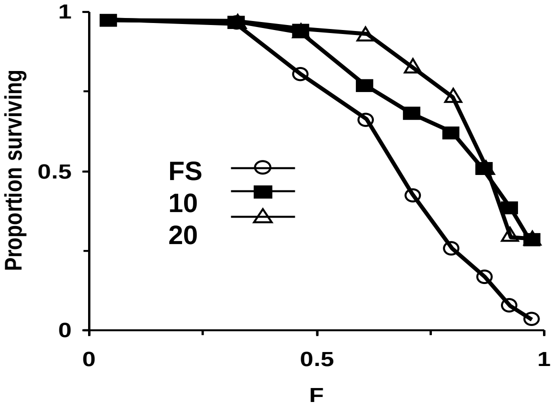
Fallacy of small wild isolated surviving populations

Fallacy of small wild surviving populations

- Small/bottlenecked surviving populations
  - Mauritius kestrel, golden hamster, Catham Is black robin, Seychelles warbler, Mauritius pink pigeon, Socorro Is red-tailed hawk, N elephant seal, California Islands foxes, Chillingham cattle
- Fallacy to argue from a few & generalise
  - ‘Grandad smoked 30 a day & lived to 80, so smoking does not contribute to cancer’

Fallacy of small wild surviving populations

- Selected sample – most small isolated pops go extinct in long-term
- Some highly inbred (*F* ~ 1) populations of mice, guinea pigs, *Drosophila* & plants persist
  - All surviving ones have low fitness when tested



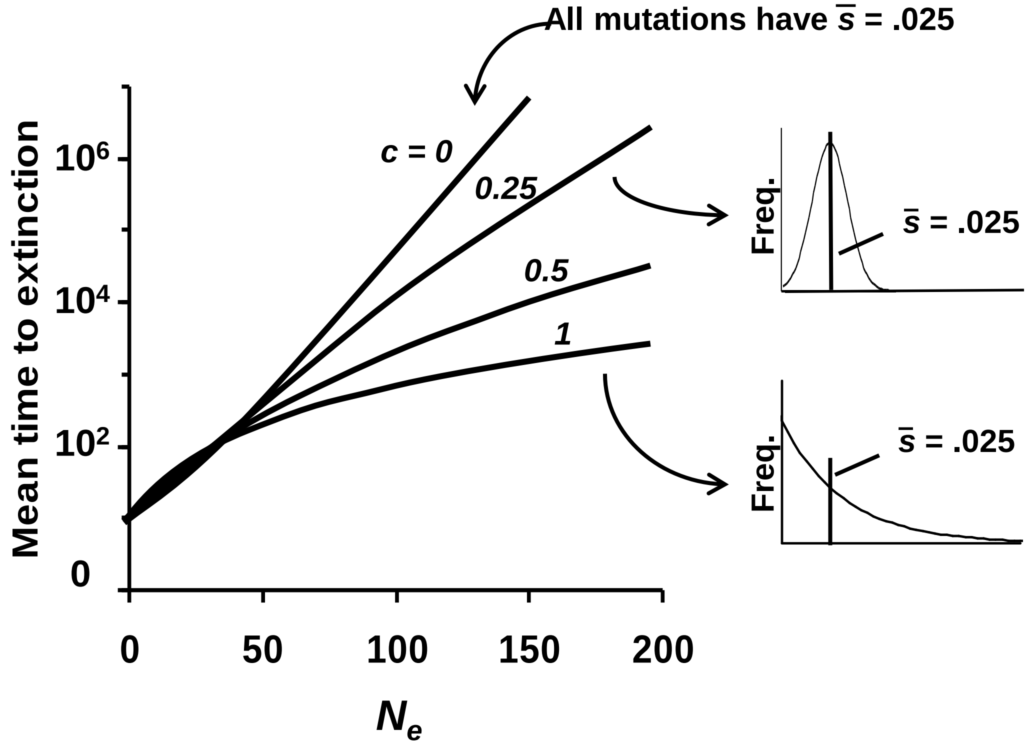
Fallacy of small wild surviving populations

- Claims of no fitness declines have been based on no firm evidence (Ch cattle & Ca Is foxes)
- Most small persisting wild population have improved environments (M kestrel, NE seal)
- Some have not been totally isolated (IR gray wolf, Ca Island foxes)
- Some have gone extinct & been re-established? (Cape Verde kite & several NZ populations)

Messages

- Resources limited for threatened species
- Need to define the minimum *N* to retain genetic ‘health’
- To retain wild fitness & minimise ID for 5 gens requires $N_e \geq 100$
- To permanently retain evol potential requires $N_\mathrm{e} \geq 1000$
- Current population sizes of thr species too small to avoid genetic deterioration
- Captive populations of thr species typically managed to retain 90% GD for 100 years

Questions?


All mutations have $\bar{s}$ = .025
Mean time to extinction
10^6
10^4
10^2
0
c = 0
0.25
0.5
1
0
50
100
150
200
N_e
Freq.
$\bar{s}$ = .025
Freq.
$\bar{s}$ = .025

Translating from N_e to N

(Frankham 2021)

N_e/N ratios from meta-analyses

- Only multigenerational estimates for ~ 47 species in 2021

- Average ~ 1/10

 (vary according to life-history)

$N \sim 10 \times N_e$