Genetic adaptation to captivity in species conservation programs

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Why captive breed?

- 4-6K species of terrestrial vertebrates cannot survive in the wild

Extent of captive breeding

- 245 threatened vertebrate species
- Few invertebrates
- Many threatened plants
  - Kew Gardens 2.7K species
  - Center for Plant Conservation, USA 600 sp

Eventual aim of most captive breeding programs is to return species to the wild

but many species will spend long periods in captivity

Genetic deterioration in captivity

- Inbreeding depression
- Loss of genetic diversity
- Mutation accumulation
- Genetic adaptation to captivity

Genetic adaptation to captivity unavoidable

- Rats > 3x
- Turkeys
- Fish – many species
- Biocontrol insects
- Butterfly 13x
- *Drosophila* 2x, x3 & 3x
- Plants ~ 2x

Genetic adaptation to captivity overwhelmingly deleterious in wild

- Biocontrol insects
- Fish – many species
- Rabbits & birds
- *Drosophila* populations

GADC involves rare alleles, deleterious & recessive in wild

- Decline in wild fitness (deleterious)
- Outbreeding depression in captivity N_e= 500 X (rare)
- Partial recovery of 'wild' fitness in 500P & 250P (rare & recessive)
- Increased null allele freq in captive fish pops (Leary et al. 93) (rare & recessive)
- Rare α-GPDH allele q_0 = .01 $\Rightarrow$ 1 in captive screwworms (Bush et al. 76) (rare, deleterious & recessive)
- ADH allele in olive fruit fly q_0 = .01 $\Rightarrow$ .32 captivity (Zouros et al. 82) (rare)

- Expect selective sweeps for neutral variation

GADC causes selective sweeps: faster than neutral loss of microsatellite GD

Original
unpublished
data omitted

(Montgomery, Woodworth, England, Briscoe & Frankham, unpub)

Selective sweeps: individual microsatelite loci

Locus	b	Chr

Original unpublished data omitted

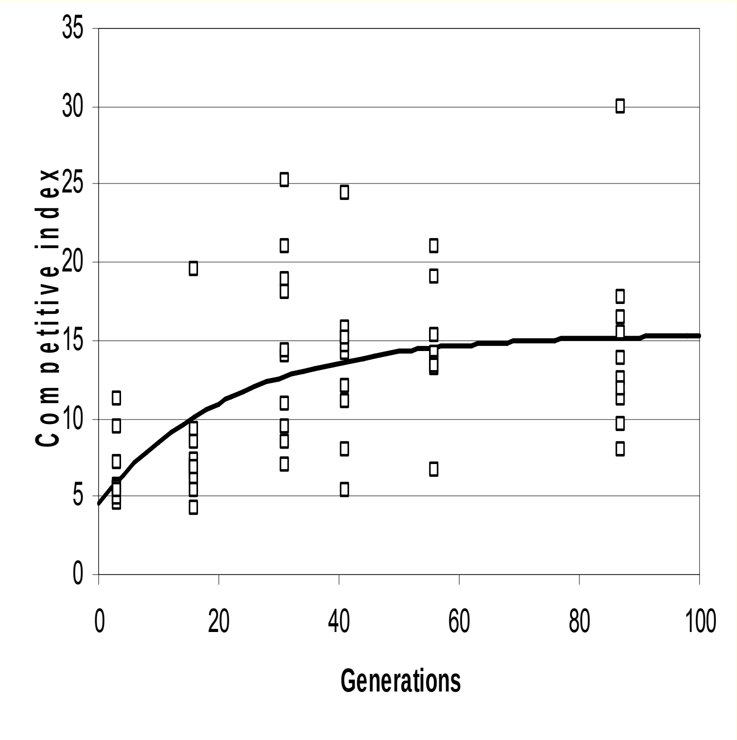
Factors determining genetic adaptation

$$GA_t \sim S\, h^2 \Sigma\left(1 - \frac{1}{2N_e}\right)^{t-1}$$

- generations in captivity (t)
- selection (S)
- genetic diversity (h^2)
- N_e

Generations effect

Modest crowding (25pr/b), N_e ~ 300



(Gilligan et al. 2003)

+ other *Drosophila* species + fish + plants

Selection differential effect

Environment	GA / generation
• Extreme crowding 8G	12.5%
• Modest crowding 25 pr/ B	9.0%
(Frankham & Loebel 92; Gilligan 2003)	
• Low crowding + Cu 25G	
• VFS	0.7%
• EFS	0.35%
(Frankham et al. 2000)	

Genetic diversity effect

(Reed et al. 2003)

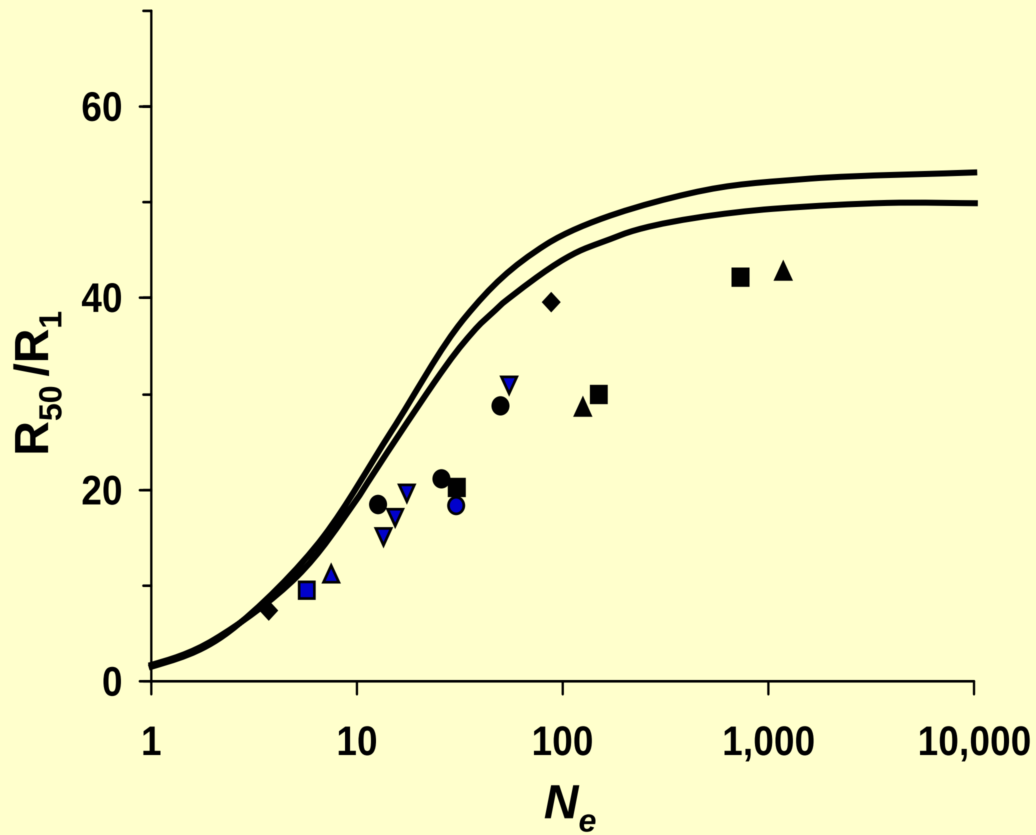
GADC: Δ # offspring over 7 gens

- Outbred > FS inbred (*F* = .59)

  60 > 29 # offspring

GADC: x strains > single in *D. serrata & D. birchii* (Ayala (1965a,b)

N_e effect



(Weber & Diggins 1990)

Predicted effects of generations, S, genetic diversity and N_e on genetic adaptation have all been verified

Minimizing GADC

$GA_t \sim S\ h^2\ \Sigma[1 - (1/2N_e)]^{t-1}$

Minimize

- generations in captivity
- selection (EFS)
- genetic diversity
- N_e (fragmentation)
- [immigration from the wild]
- [crossing replicate captive populations]

Minimizing generations in captivity

- Seed storage in plants
- Cryopreservation in plants
- Impractical for most animals
  - Semen cryopreservation in few species
  - Embryo cryopreservation in few species
  - Delaying reproduction risky

Minimizing selection: equalizing family sizes

- Halves selection
- Doubles N_e
- Recommended for captive management of endangered species

Equalizing family sizes

N_e = 100, 1 pr/ vial $CuSO_4$ in medium, 25G

	# O
EFS	+ 8.8% **
VFS	+ 17.5%
T94	113

(Frankham et al. 2000)

Equalizing family sizes

N_e = 100, 1 pr/ vial $CuSO_4$ in medium 25G

	# O	'Wild' [no Cu]
EFS	+ 8.8% **	- 38% ns
VFS	+ 17.5%	- 43%
Base	113	

(Frankham et al. 2000)

No 'wild' fitness benefits of MK or EFR

EFS reduces genetic adaptation
but
has little impact on reintroduction success

Minimizing N_e: fragmentation

Faster loss of genetic diversity

Captive populations already fragmented

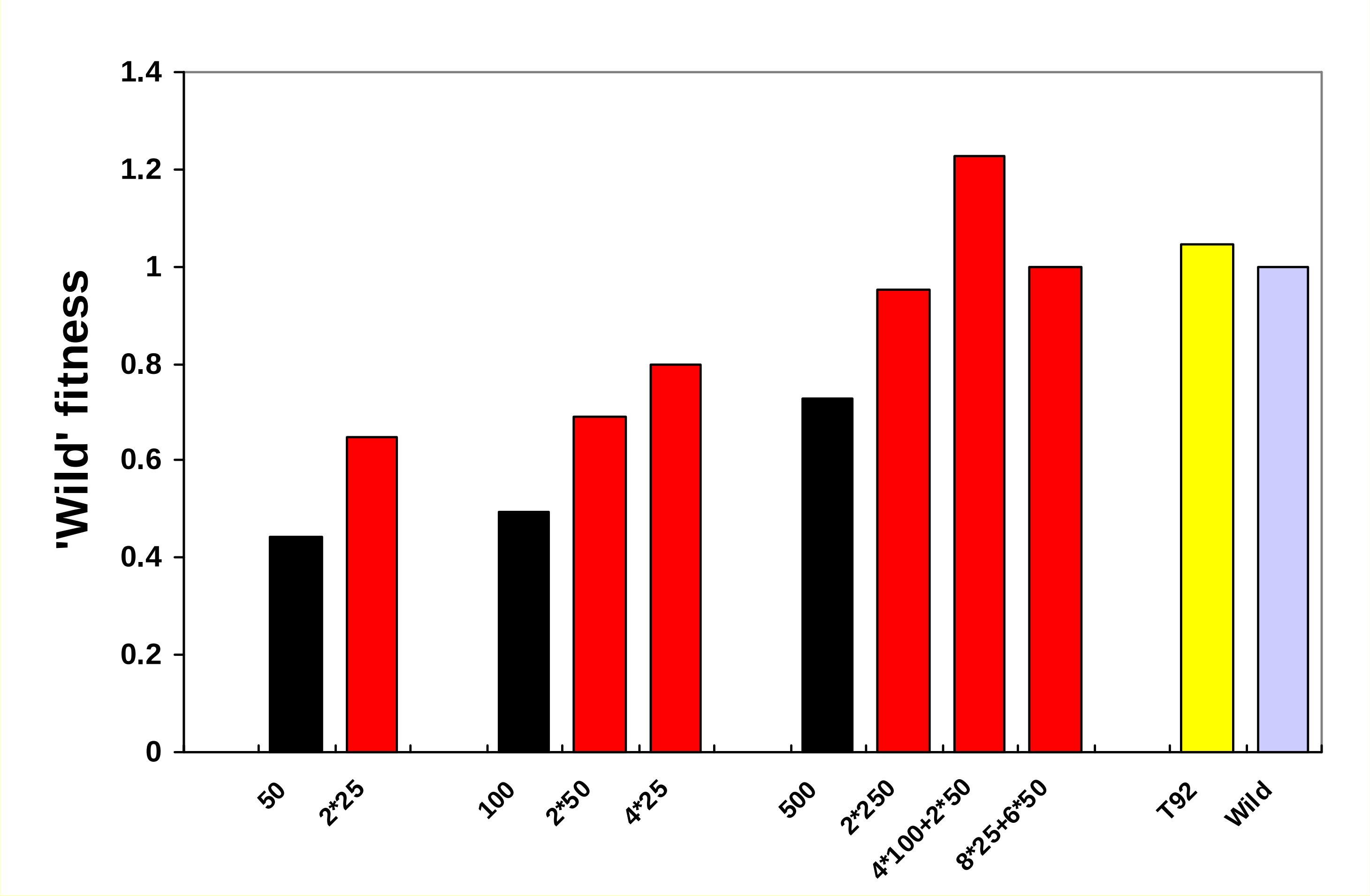
Minimizing GADC:
fragmenting population

Test of fragmentation strategy: SL v SS

- 50 v 2x25
- 100 v 2x50 v 4x25
- 500 v 2x250 v
- 50 gens
- ‘wild’ fitness
- genetic diversity

Fitness of SL v SS (pooled)

(Margan et al. 98)



Fragmentation reduces deleterious effects of GADC in reintroduced populations

Other benefits of fragmenting captive populations

- Retains more genetic diversity
- Reduces inbreeding
- Captive populations already fragmented
  - Reduces costs of translocations
  - Reduced risk of disease transfer

Managing a fragmented population

- Problem: inbreeding depression
- Solution: cross replicates after inbreeding has accumulated to say *F* ~.2

Recovery of fitness in reintroduced populations

- ‘Wild’ fitness = .14 of N_e= 500s at G50
- $\Rightarrow$ .7 in 12 G in ‘wild’

(Woodworth et al. 2002; Margan et al. 98)

Conclusions

- Genetic adaptation to captivity is unavoidable
- GADC reduces fitness when reintroduced into wild
- GADC reduced by min gens in captivity, or fragmentation
- Recommend:
  - Captive management to minimize GADC
  - Retain GD