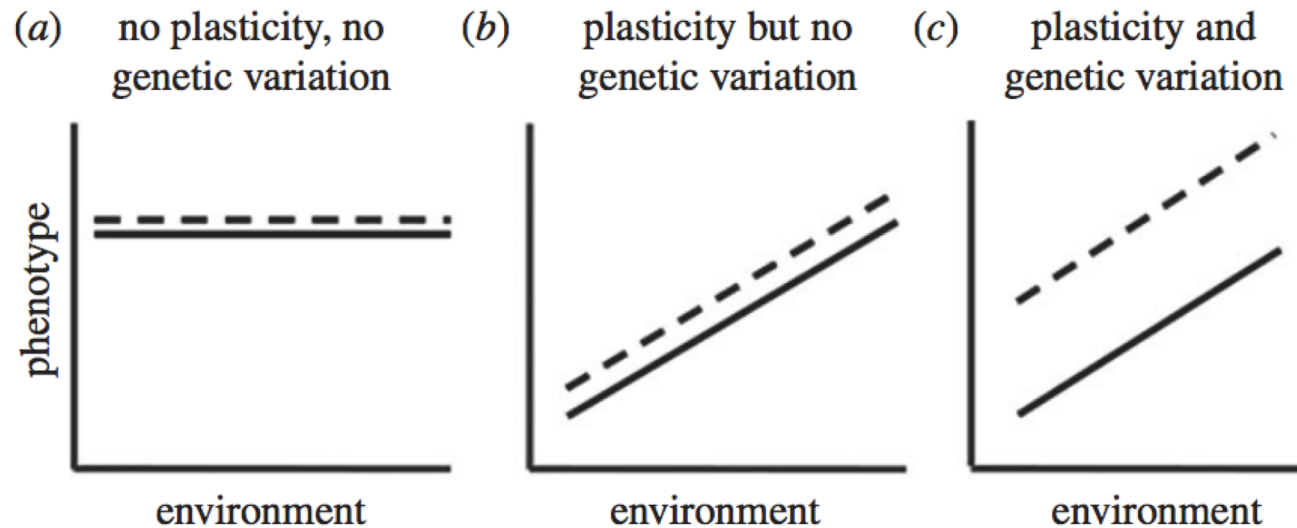


FENOTIPSKA PLASTIČNOST

- fenotipska plastičnost
- razvojna plastičnost
- sezonska plastičnost
- inducirane obrane
- aklimatizacija
- interakcija genotipa i okoliša
- majčinski (roditeljski) učinak
- neizravni genetički učinci

- **Fenotipska plastičnost** definira se kao **sposobnost određenog genotipa da producira različite fenotipove kada je izložen različitim okolišnim uvjetima**
- Određeni način na koji fenotip jedinke/populacije (genotip) varira u odnosu na okoliše naziva se **reakcijska norma**



Na slici su prikazane reakcijske norme dva različita genotipa (puna i isprekidana crta), u odnosu na promjenu u okolišu.

Figure 3. Phenotypic plasticity and reaction norms. In panel (a), phenotype does not vary with the environment and both genotypes have identical reaction norms. In panel (b) both genotypes are plastic and (c) there is also genetic variation. Panel (d) illustrates a genotype-by-environment interaction ($G \times E$), where both genotypes are plastic but their phenotypic reaction norms vary. Genetic variation and $G \times E$ can complicate how much genetic variation is exposed to selection; in panel (e) the genotypes produce the same phenotype in environment (E) 1 but not in environment 2, so selection can only differentiate between the genotypes in environment 2.

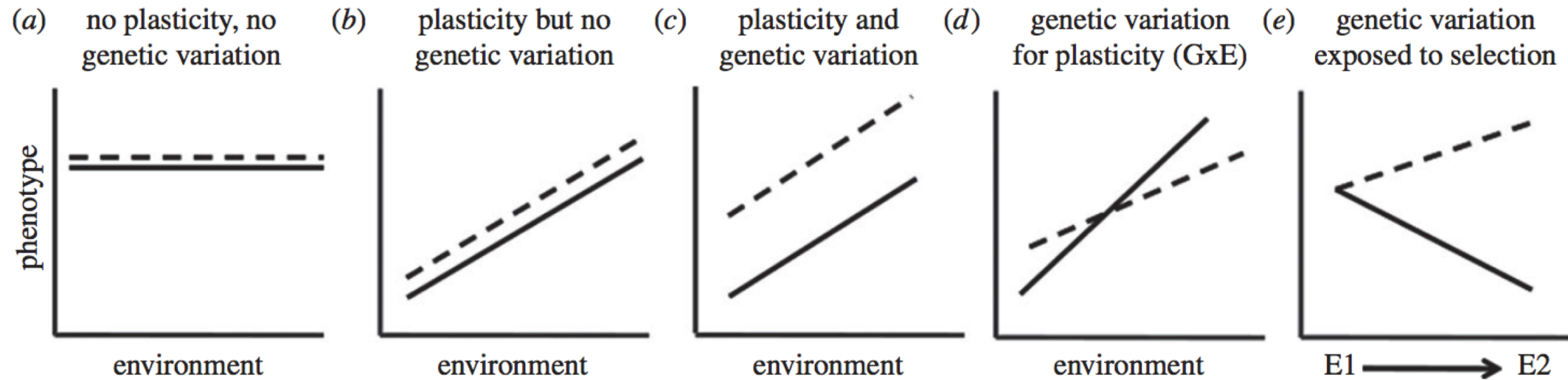
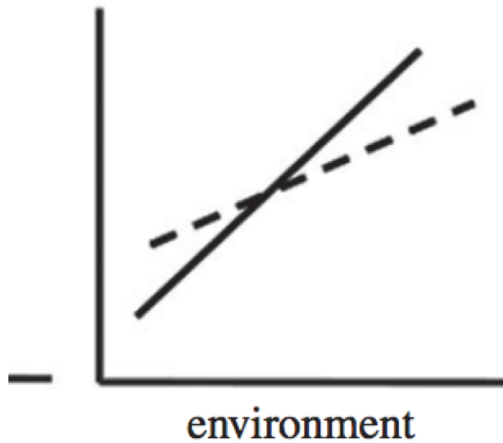
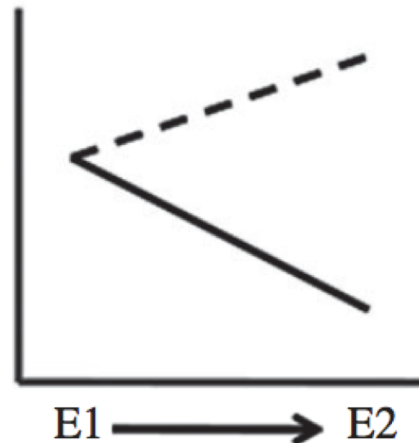


Figure 3. Phenotypic plasticity and reaction norms. In panel (a), phenotype does not vary with the environment and both genotypes have identical reaction norms. In panel (b) both genotypes are plastic and (c) there is also genetic variation. Panel (d) illustrates a genotype-by-environment interaction ($G \times E$), where both genotypes are plastic but their phenotypic reaction norms vary. Genetic variation and $G \times E$ can complicate how much genetic variation is exposed to selection; in panel (e) the genotypes produce the same phenotype in environment (E) 1 but not in environment 2, so selection can only differentiate between the genotypes in environment 2.

(d) genetic variation
for plasticity (GxE)



(e) genetic variation
exposed to selection



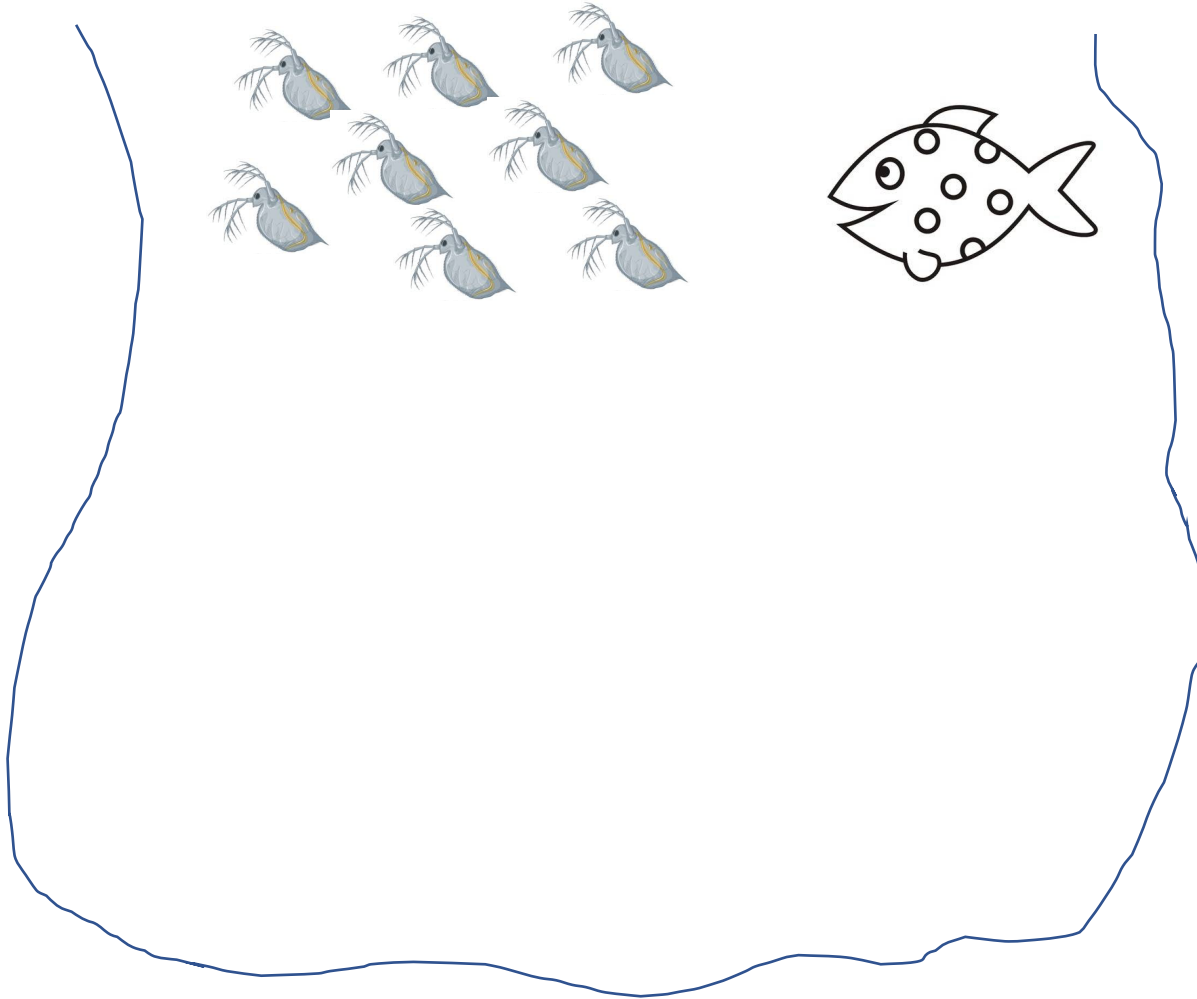
INTERAKCIJA GENOTIPA I OKOLIŠA – GXE

d) genotipi različito reagiraju na promjenu okoliša –
genotipski uvjetovana razlika u plastičnosti

e) samo okoliš dva otkriva razliku u genotipovima

- Fenotipska plastičnost: ponašanje, fiziologija, boja, morfologija, životni ciklus (“life history”), ekspresija gena....

- *Daphnia* eksperiment – De Meester 1996



Fototaksija – najučinkovitije hranjenje dafnia blizu površine tijekom dana

Odgovor na riblje kairomone -
intenzitet predacije varira kroz prostor i vrijeme

Pokus zajedničkog okoliša (“common garden experiment”) s dafnijama iz jezera s drugačijim predatorskim režimom

Dafnije iz tri jezera izložene u vodi s ribljim kairomonima i čistoj vodi: različita reakcijska norma populacija (Blankaart populacija smanjuje fototaksiju, Citadelpark populacija mnogo manje, dok Driehoekvijver populacija ima nižu fototaksiju), i unutar svake populacije različite reakcijske norma za različite klonove – **RAZLIKA UNUTAR I MEĐU POPULACIJAMA**

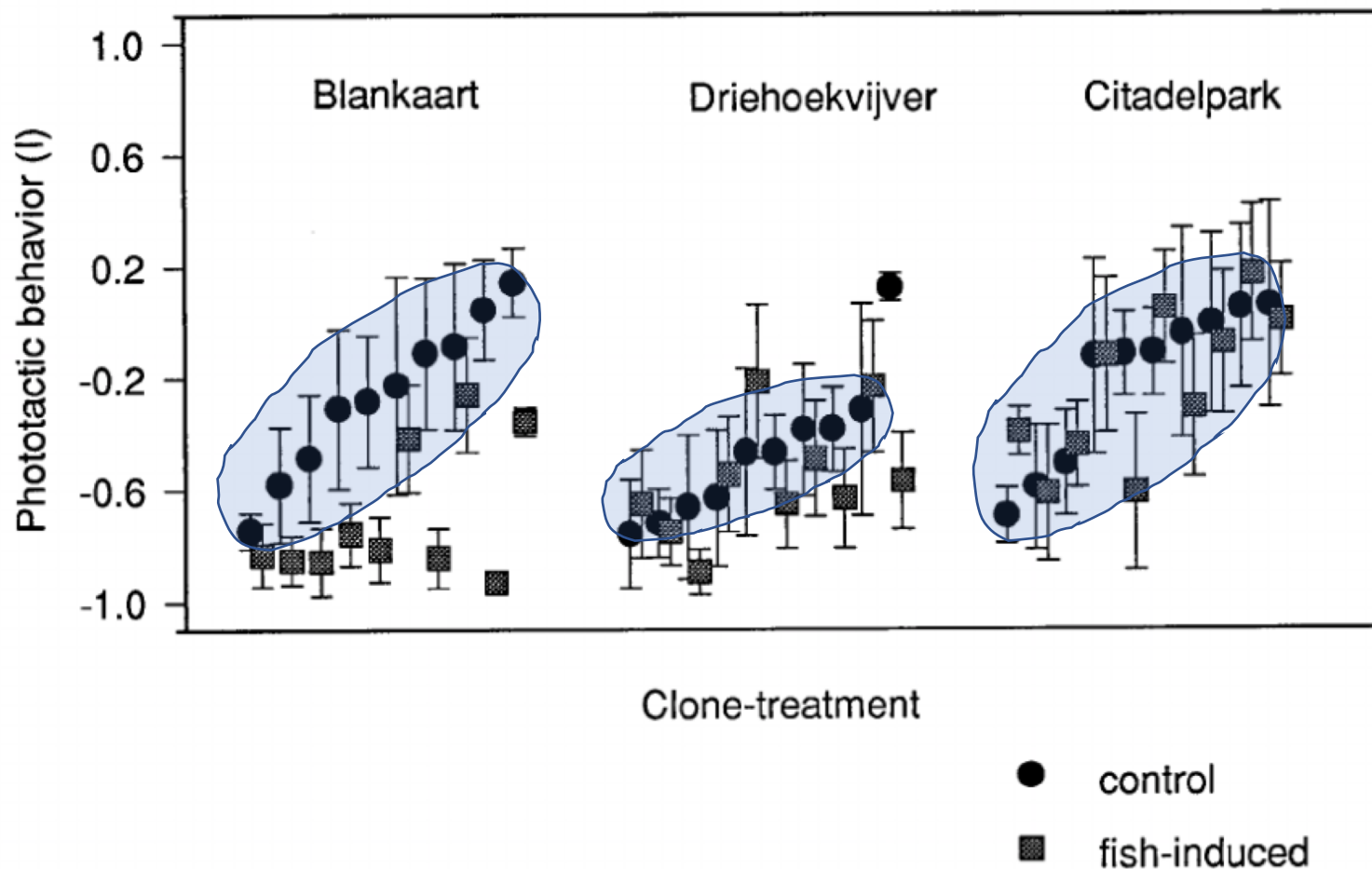
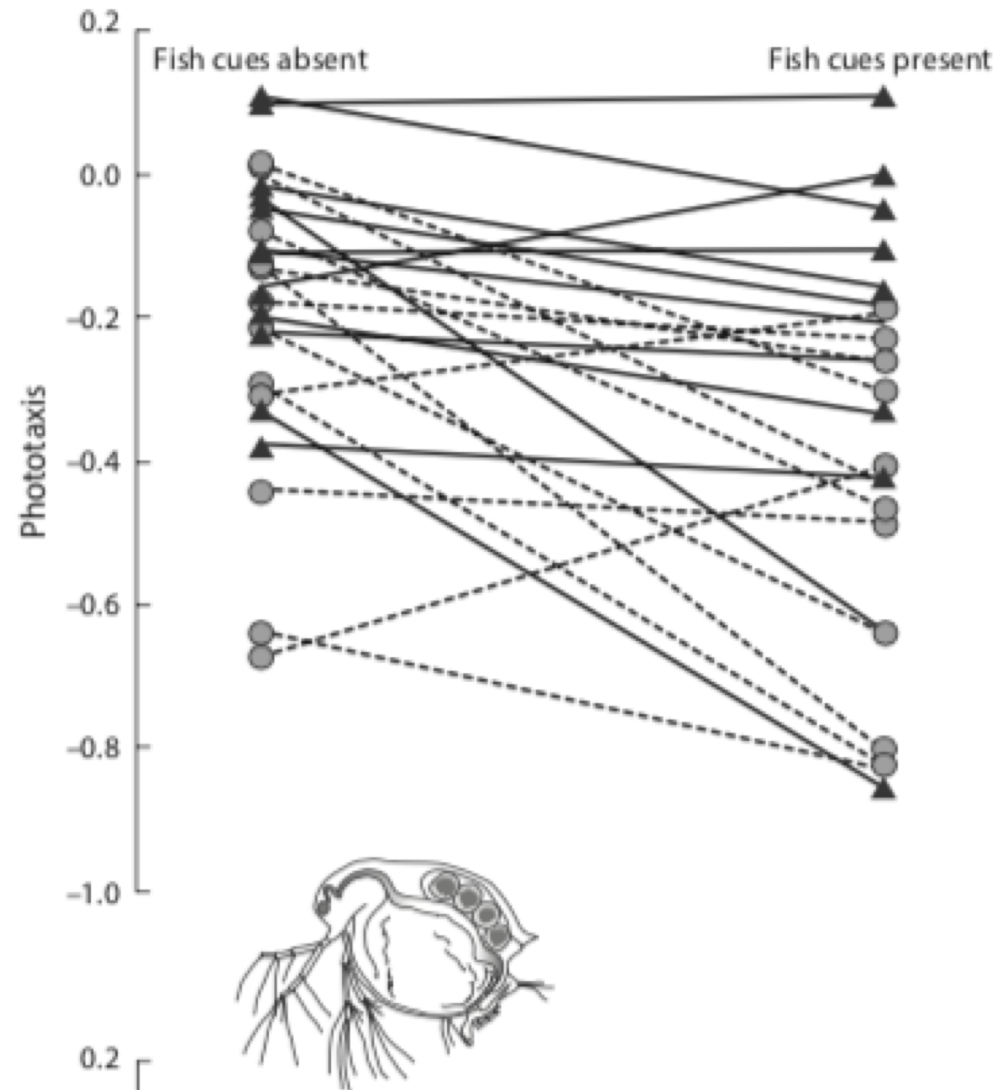
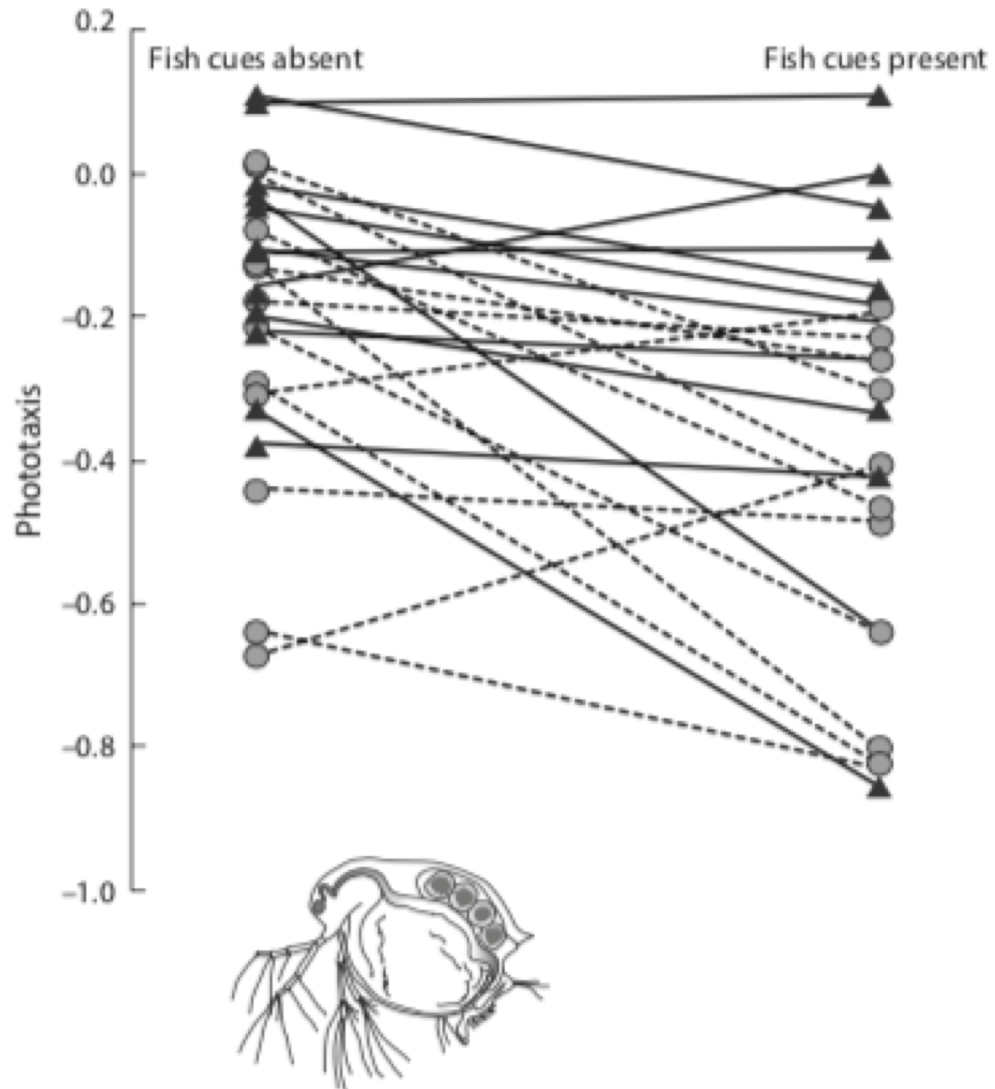


FIG. 1. The phototactic behavior of ex-ephippial clones of three populations (Blankaart, Citadelpark, and Driehoekvijver) in the absence (solid circles) and presence (squares) of fish kairomone. Error bars indicate twice the standard error of the mean. Within each population, clones are ranked from negative to positive phototactic behavior under control conditions. Numbers (B1-B10, C1-C10, and D1-D10) in the text refer to this ordering.

24 klona dafnija iz istog jezera izložena vodi s i bez kairomonima, sakupljane u vrijeme kada je u jezeru prisutna predacija (krugovi, isprekidane crte), i kada nije (trokuti, pune crte)



24 klona dafnija iz istog jezera izložena vodi s i bez kairomonima



- 1) prilagodba na prisutnost kairomona
- 2) **plastičnost** jednog genotipa (jedan genotip više fenotipa)
- 3) različiti genotipovi razlikuju se u **plastičnosti**
- 4) genotipovi se razlikuju bez obzira na plastičnost

Stoks et al. *Ecol. Lett.* (2016)

Hendry A. 2016 *Eco-evolutionary dynamics*

Ukoliko postoji genetska varijabilnost za fenotipsku plastičnost, **selekcija može favorizirati adaptivnu plastičnost:**

- (i) populacije su izložene varijabilnom okolišu
- (ii) okoliš producira pouzdane signale
- (iii) selekcija favorizira različite fenotipe u različitim okolišima
- (iv) ni jedan fenotip nema superiorni fitness u svim okolišnim uvjetima

RAZVOJNA PLASTIČNOST

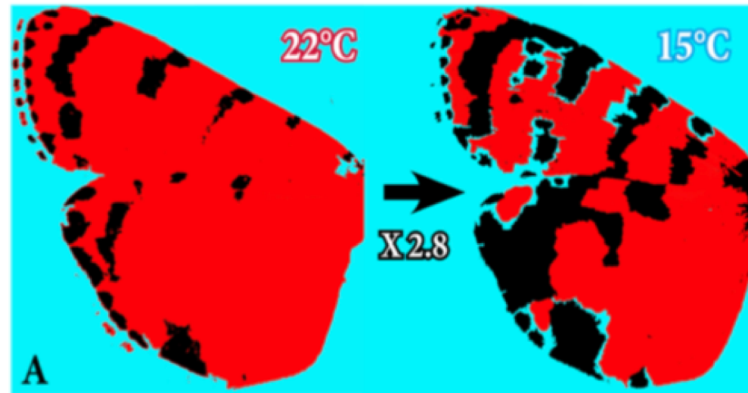
- Vrsta fenotipske plastičnosti
- Razvojni put organizma rezultat je interakcije između genoma, vremenske pojavnosti okolišnih signala i slučajnih događaja na razini interakcije molekula i tkiva.

Sezonski polifenizam u leptira

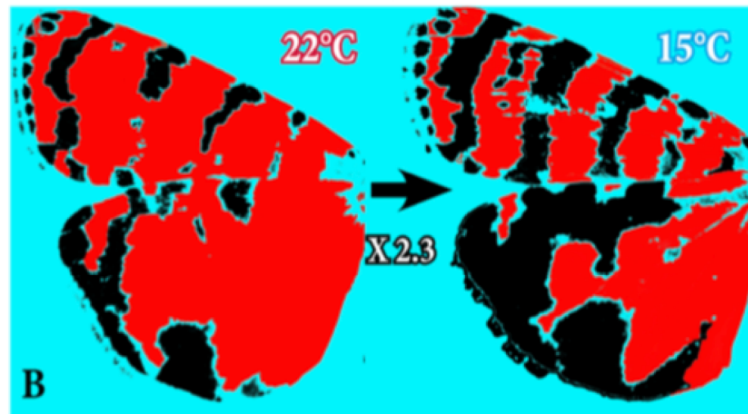


Dva morfa gusjenice
vrste *Nemoria arizonaria*:
sezonski dimorfizam ovisi
o dostupnim dijelovima
biljaka za hranjenje-
cvatovi ili samo lišće i
izdanci

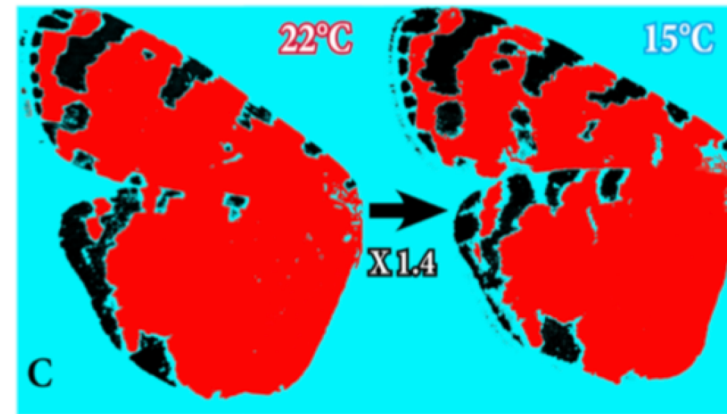
*Polifenizam je fenomen
produkcije dva ili više
značajno različitih
fenotipova od istog
genotipa*



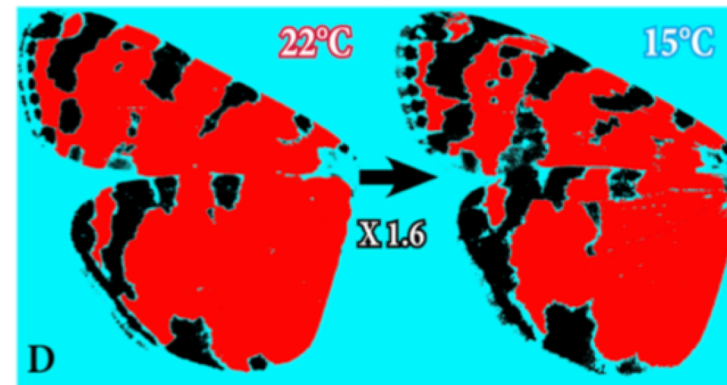
Trial 2, Males



Trial 2-Females



Trial 6, Males



Trial 6. Females

Fig. 2. Schematic illustration of melanic markings on the wing underside of *Utetheisa ornatrix bella* individuals in two temperature reaction norm trials (see text for details). (A) males #1,2 and (B) females #3,4 in Trial 2 (see Supplementary materials), show a 2.3-2.8x increase in black area in cold-induced individuals as compared to controls. (C) males #5,6 and (D) females #7,8 in Trial 6 show a more modest increase of 1.4-1.5x.

Eksperiment izlaganja drugačijim temperaturnim režimima gusjenice *Utetheisa ornatrix*: povećanje crne obojenosti krila u jedinki izloženih nižim temperaturama

INDUCIRANE OBRANE

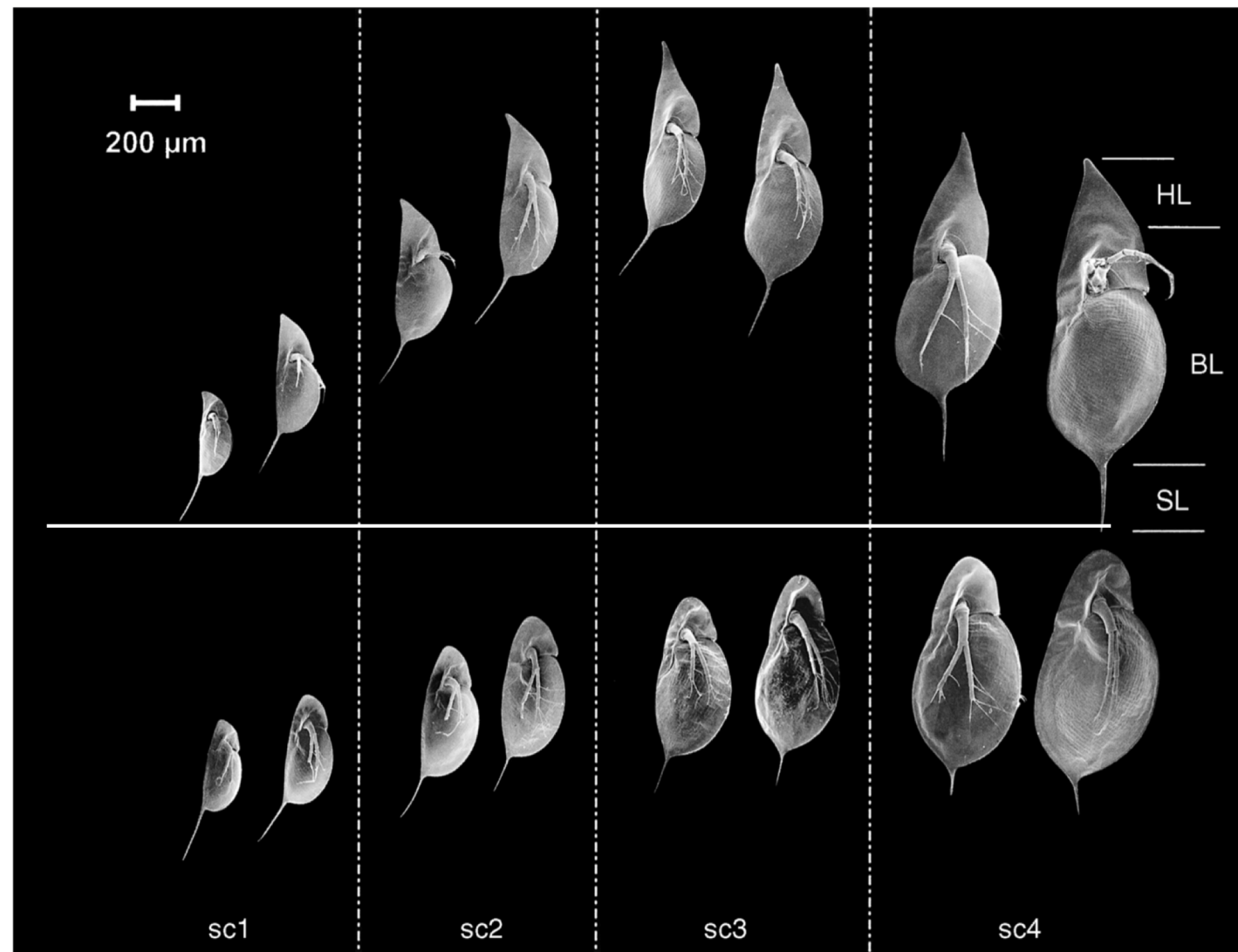
pristupost
predatorskog signala


FIG. 1. Comparative scanning electron micrographs (for method see Laforsch and Tollrian [2000]) of the first eight instars of typical (bottom row) and helmeted (laboratory-induced; top row) *Daphnia cucullata*. The grouping size classes (sc) in our study (sc1–sc4) are separated by vertical lines. The arrangement of *Daphnia* follows the developmental pattern of the relative values of the plastic traits during these life stages. The morphological parameters recorded from *Daphnia cucullata* in our experiments were the helmet length (HL), the body length (BL), and the tail spine length (SL).

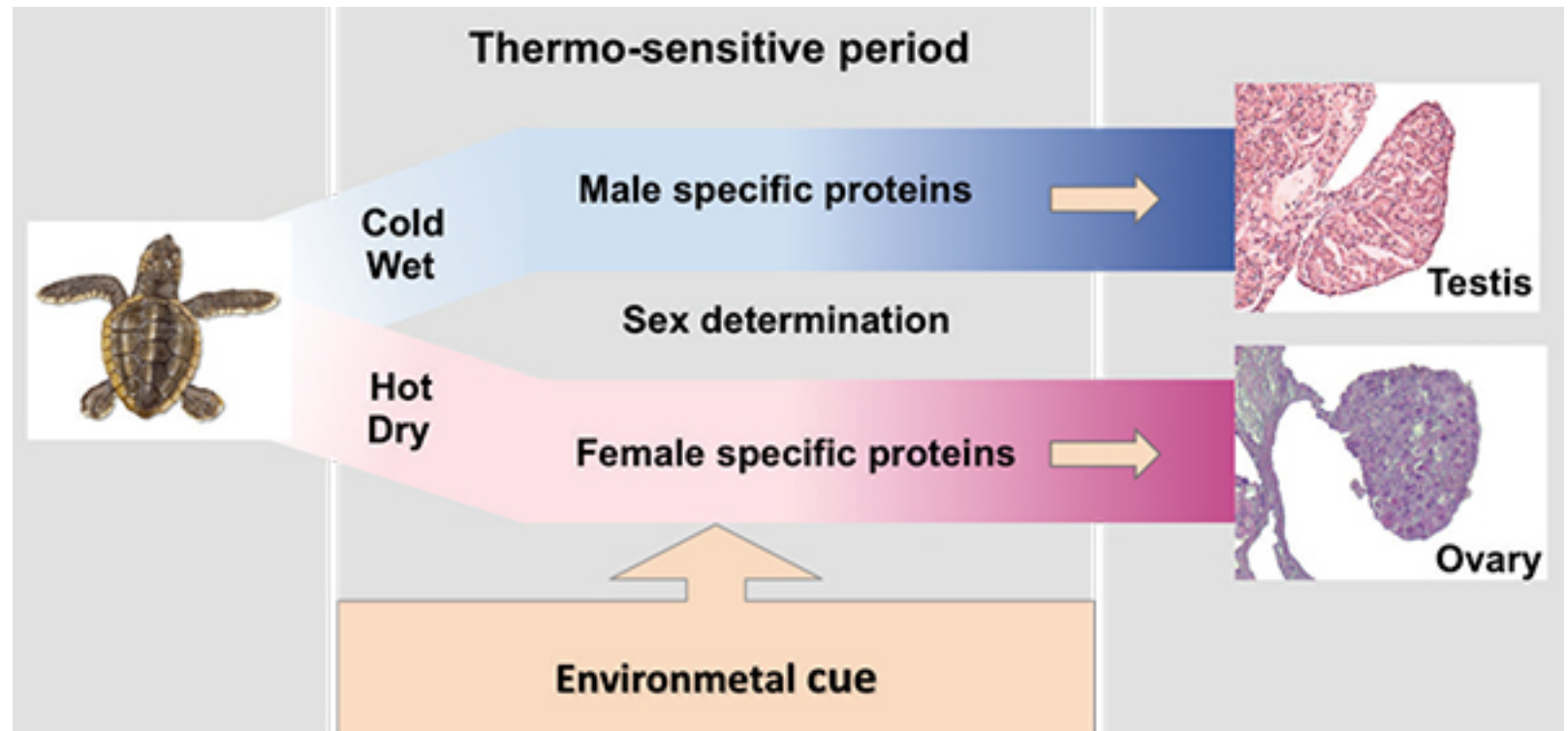
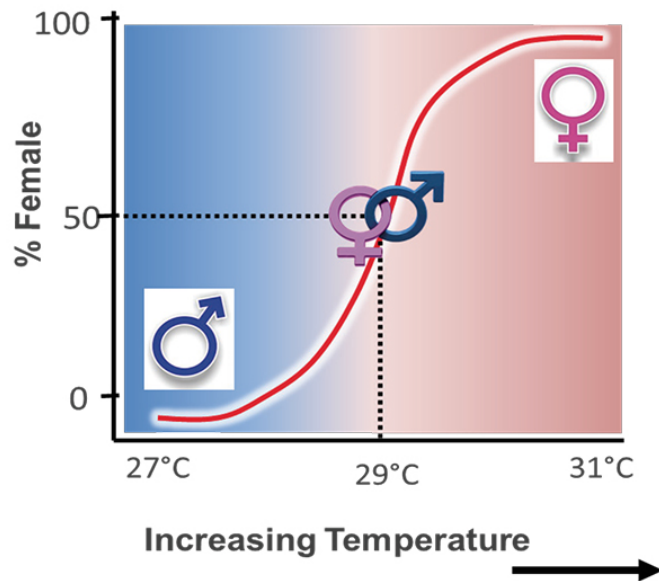
Polifenizam dafnija induciran predatorstvom

- „kacige” vrste *Daphnia cucullata* inducibilne su kemijskim signalima različitih vrsta predatora, a korisne su kao generalna zaštita od predatora različitih strategija lova
- rezultati eksperimenta pokazuju da **izloženost kemijskim signalima više različitih predatora induciraju veće produljenje repnih nastavka i duže „kacige”**

- Polifenizam kasta socijalnih kukaca
- **Okolišno određivanje spola kod gmazova**

Carretta carreta – razlika između laboratorijskih i mjerenja u prirodi – nije samo temperatura!

- nisu reverzibilne plastične promjene



SEZONSKA PLASTIČNOST



SEZONSKA PLASTIČNOST

Trends in Neurosciences

Volume 23, Issue 6, 1 June 2000, Pages 251-258

Review

Seasonal plasticity in the adult brain

Anthony D. Tramontin ^a, Eliot A. Brenowitz ^b



Volumen regija mozga koje kontroliraju pjev ptica drastično se povećava prije sezone parenja, pod utjecajem spolnih hormona povećava se veličina i broj neurona.

AKLIMATIZACIJA

- Aklimatizacija se definira kao fenotipska promjena u fiziologiji koja se javlja kao odgovor na postojeću okolišnu promjenu ili u očekivanju iste
- **Reverzibilna!!!**
- Važna za prilagodbe na klimatske promjene
- **FENOTIPSKA FLEKSIBILNOST** – plastičnost jedinke – reverzibilne i okolišnim kontekstom uvjetovane promjene unutar jedinke fizioloških i morfoloških svojstava, kao i životnog ciklusa („*life history*“)

MAJČINSKI UČINAK

Aquat Toxicol. 2014 Jan;146:61-9. doi: 10.1016/j.aquatox.2013.10.036. Epub 2013 Nov 8.

Improved tolerance of metals in contaminated oyster larvae.

Weng N¹, Wang WX².

Author information

Abstract

Environmental stress experienced by parents may make a significant difference in the response of their offspring. However, relevant studies on marine bivalves are very limited especially for the field populations. In the present study, we examined the relative metal tolerance of offspring produced by four natural populations of oyster *Crassostrea sikamea* that were contaminated by metals to different degrees. We demonstrated that the resistance of oyster offspring to copper and zinc was correlated with the level of metal pollution experienced by the parent oysters. Specifically, the oyster embryo and larvae produced by adult oysters from contaminated sites had a much higher tolerance to metal stress than those from the reference sites. Furthermore, tissue concentration-dependent maternal transfer of Cu and Zn was found in this study, and the metallothionein concentrations in eggs were positively related to the total concentrations of maternally transferred Cu and Zn. Thus, the maternally transferred metals inducing high level of MT synthesis in eggs was one of the possible mechanisms responsible for the enhanced metal tolerance of oyster embryos and larvae from heavily contaminated sites. We concluded that environmental exposure history of adult oysters significantly influenced the ability of their offspring to cope with metal stress. Our findings offered the field evidence of the possible transfer of metal tolerance from adults to offspring in marine bivalves.

- majčinski učinak rezistencije na teške metale kod ličinki kamenica postignut transferom Cu i Zn te indukcijom sinteze metalotioneina

Adaptive maternal and paternal effects: gamete plasticity in response to parental stress

Natasha Jensen¹, Richard M. Allen^{2,3} and Dustin J. Marshall^{*,4}

¹School of Biological Sciences, University of Queensland, Brisbane, Queensland 4072, Australia; ²Department of Oceanography, Dalhousie University, Halifax, Nova Scotia B3H 4R2, Canada; ³Department of Ocean Sciences, Memorial University, St. John's, Newfoundland A1C 5S7, Canada; and ⁴School of Biological Sciences, Monash University, Melbourne, Victoria 3800, Australia

Summary

1. Transgenerational phenotypic plasticity is increasingly recognized as an important buffer of environmental change – many studies show that mothers alter the phenotype of their offspring so as to maximize their performance in their local environment. Fewer studies have examined the capacity of parents to alter the phenotype of their gametes to cope with environmental change. In organisms that shed their gametes externally, gametes are extremely vulnerable to local stresses and transgenerational plasticity in the phenotypes of gametes seems likely in this group.

2. In a marine tubeworm, *Hydroides diramphus*, we manipulated the salinity environment that mothers and fathers experienced before reproduction and then examined the phenotype of their gametes, as well as the performance of those gametes and the resultant larvae in different salinities.

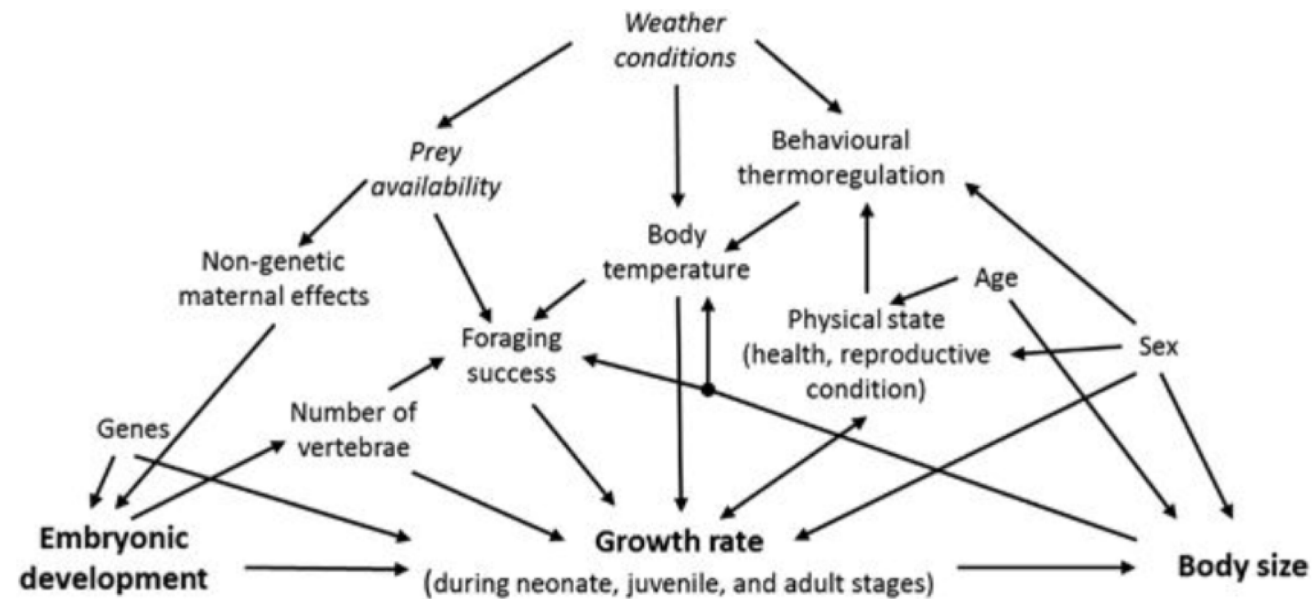
3. We found strong evidence for gamete plasticity – both mothers and fathers adaptively adjust the phenotype of their gametes to maximize the performance of those gametes in the salinity regime experienced by their parents. Parents were quite flexible in the phenotype of gametes that they produced: they could switch the salinity tolerance of their gametes back and forth depending on their most recent experience.

4. Gamete plasticity was not without risks, however. We observed strong trade-offs in performance when gametes experienced an environment that did not match that of their parents. These effects of the parental environment persist for the duration of the larval phase such that larvae may not be able to disperse to environments that do not match their parents. Gamete plasticity may therefore represent an important source of phenotype–environment mismatches.

5. Gamete plasticity may represent an important mechanism for coping with environmental change and an important source of maternal and paternal effects in species with external fertilization. Studies that seek to predict the impacts of stresses that persist across generations (e.g. ocean acidification) should include parental exposures to the stress of interest.

Key-words: epigenetics, non-genetic parental effects, transgenerational phenotypic plasticity

- majčinski i očev učinak-gametna plastičnost kod mnogočetinaša: produkcija gameta otpornih na uvjete saliniteta
- cijena!!! (*trade-off*) – ličinke imaju manju sposobnost preživljavanja u uvjetima drugačijeg saliniteta – smanjenja mogućnost rasprostranjenja



Interdependence among phenotypic dimensions, plasticity, flexibility and environmental influences jointly affect body size in snakes. Schematic representation of the many ways by which different phenotypic dimensions interact and are influenced by internal and external environmental factors and how they may jointly contribute to within- and among-individual variation in growth rate and body size of snakes. This example illustrates that individuals are complex integrated units that cannot be decomposed into a suite of independent 'traits', and that variation in a given phenotypic dimension can be influenced by combinations of both genes, irreversible developmental plasticity and by reversible phenotypic flexibility in response to changes along different environmental factors. See text for details.

Interakcija
mnogobrojnih
čimbenika koji
utječu na veličinu
tijela kod zmija, te
na intra i
interindividualnu
varijabilnost:

- 1) GENOM
- 2) OKOLIŠ:
 - IREVERZIBILNA RAZVOJNA PLASTIČNOST
 - REVERZIBILNA FENOTIPSKA FLEKSIBILNOST

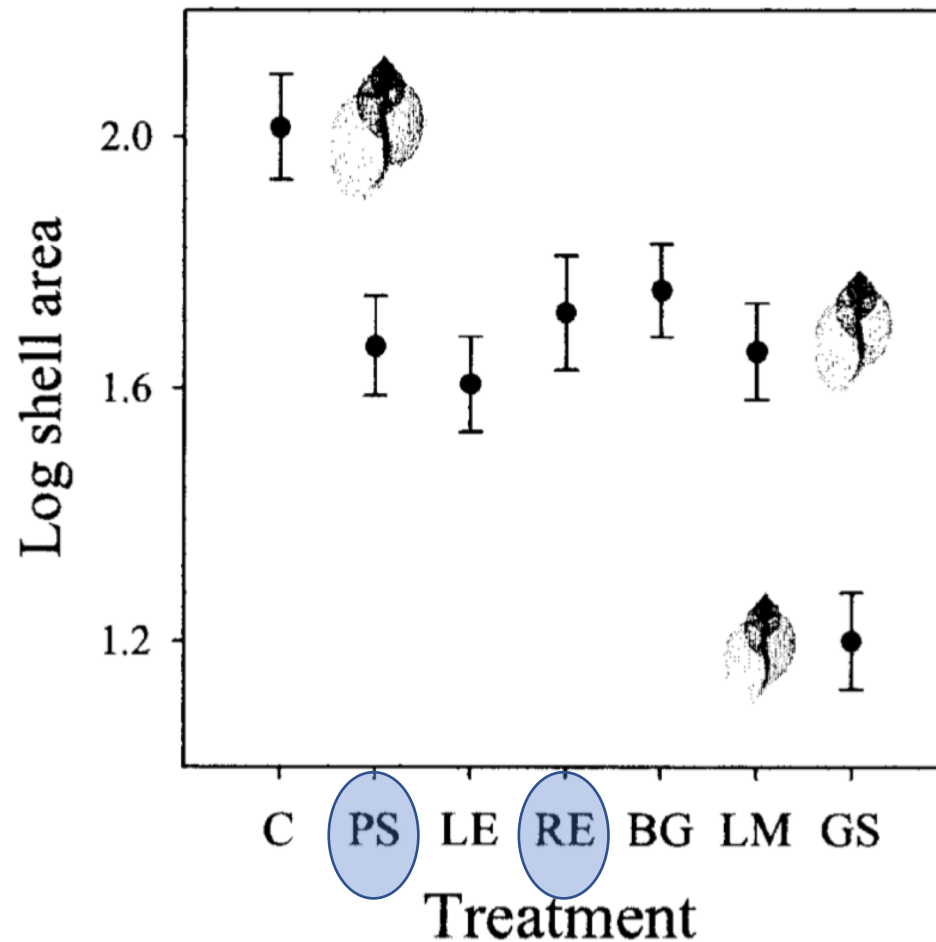


Fig. 1. The shell size of snails raised in the seven environments (mean $\pm$ standard error): control (C), pumpkinseed sunfish (PS), longear sunfish (LE), redear sunfish (RE), bluegill sunfish (BG), large-mouth bass (LM) and green sunfish (GS).

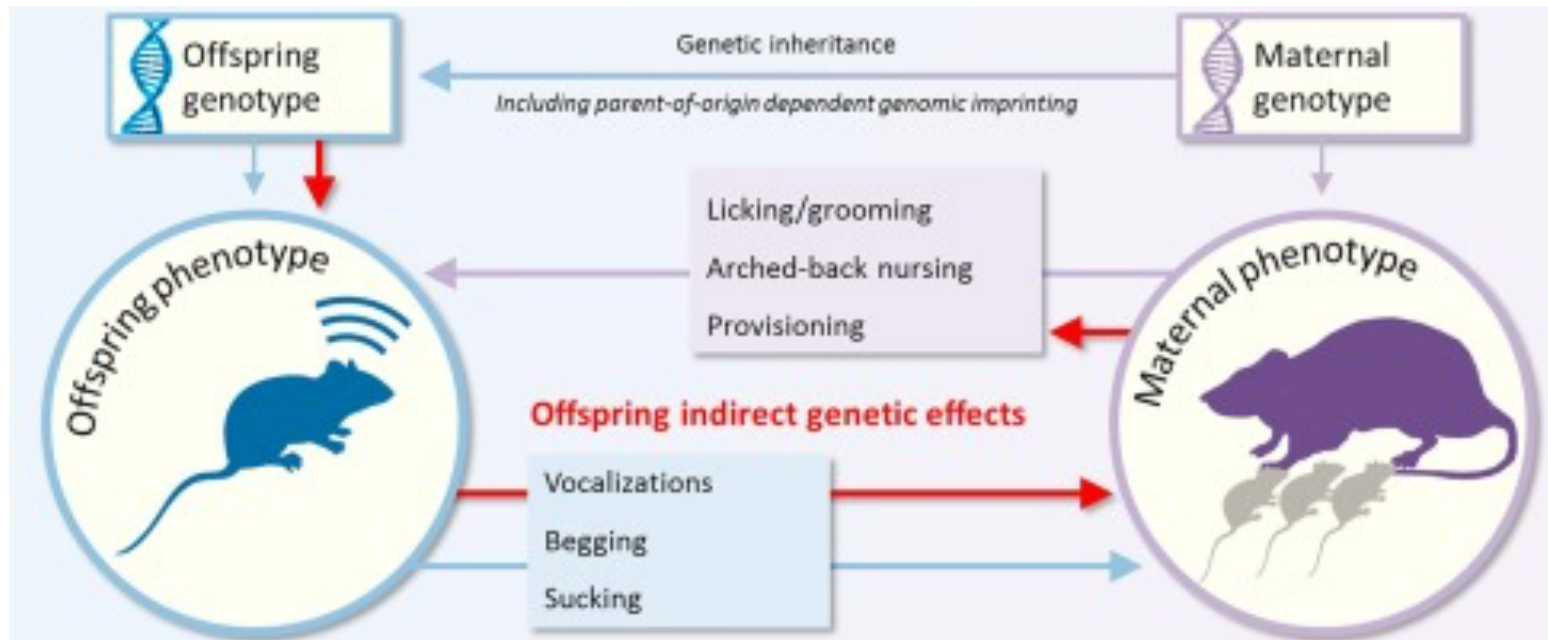
- puž *Physella virgata* stvara **okrugliju kućicu u prisutnosti moluskovornih riba** (plavi krug), ali i u prisutnosti određenih vrsta riba koje se ne hrane mekušcima. Ovaj **maladaptivni odgovor** usporuje rast jedinki i ima posljedice na dinamiku populacije i posljedično biocenoze
- CIJENA!!! (*trade-off*) **Smanjenje rasta smanjuje fekunditet** i omogućuje lakšu predaciju od strane manjih vrsta

- FENOTIPSKA PLASTIČNOST
- ponekad adaptivna, ponekad maladaptivna, ponekad neutralna
- **IMA ENERGETSKU CIJENU** (održavanje, proizvodnja, razvojna nestabilnost...)
- problem određivanja prikladnog fenotipa, vremenski pomak u odgovoru na okolišni signal..

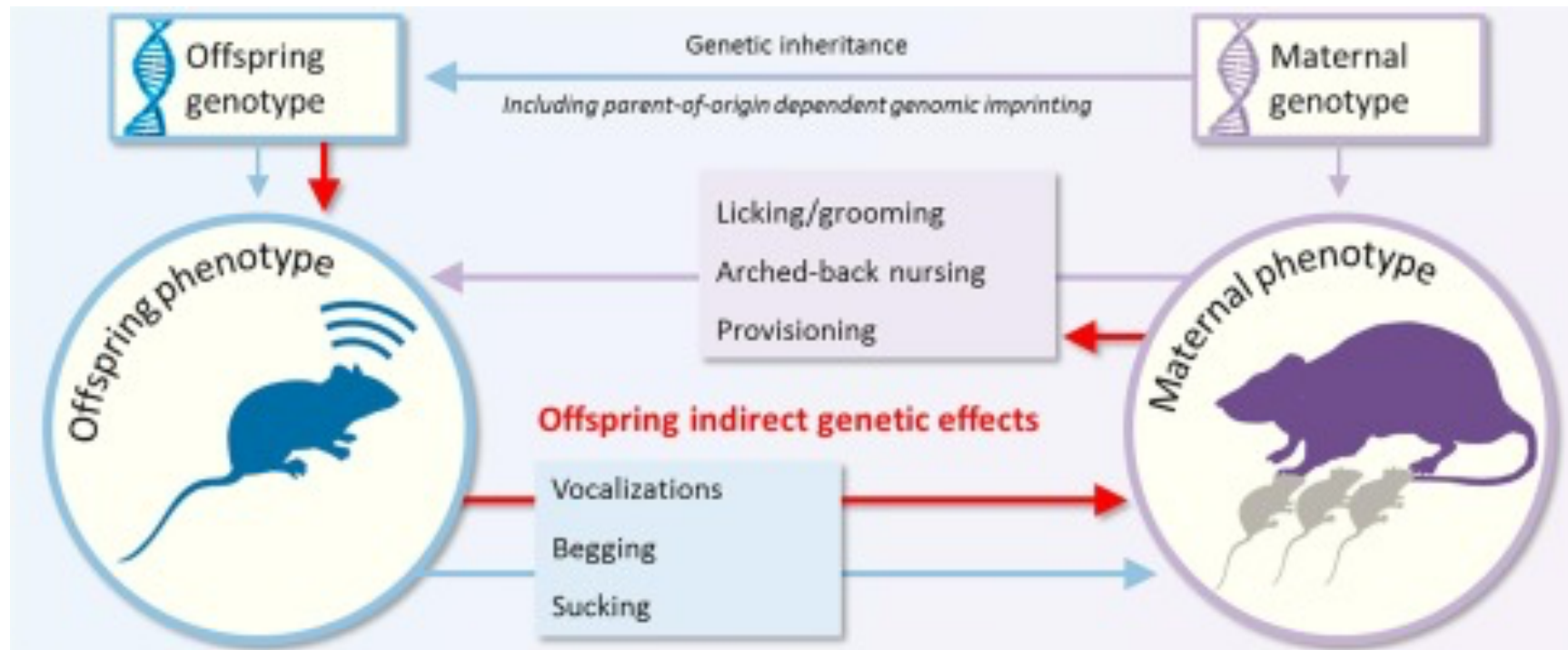
- fenotipska plastičnost
- razvojna plastičnost
- inducirane obrane
- aklimatizacija
- majčinski učinak
- **interakcija genotipa i okoliša**
- **neizravni genetički učinci**
- epigenetika

Neizravni genetički učinci

- fenotipsko svojstvo jedinke je potencijalno pod utjecajem ne samo njenog genotipa, nego i **genotipa drugih jedinki s kojima je u interakciji**
- ponašanje, izbor spolnog partnera
- Kada je dio okoliša koji pružaju roditelji određen genetičkim čimbenicima, tada i okoliš postaje nasljedan i njegov utjecaj na fenotip potomaka naziva se "neizravni genetički učinci"



Neizravni genetički učinci

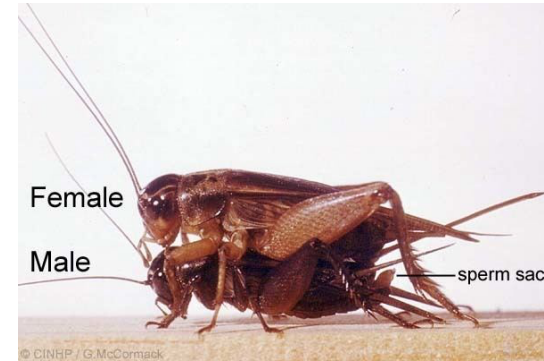
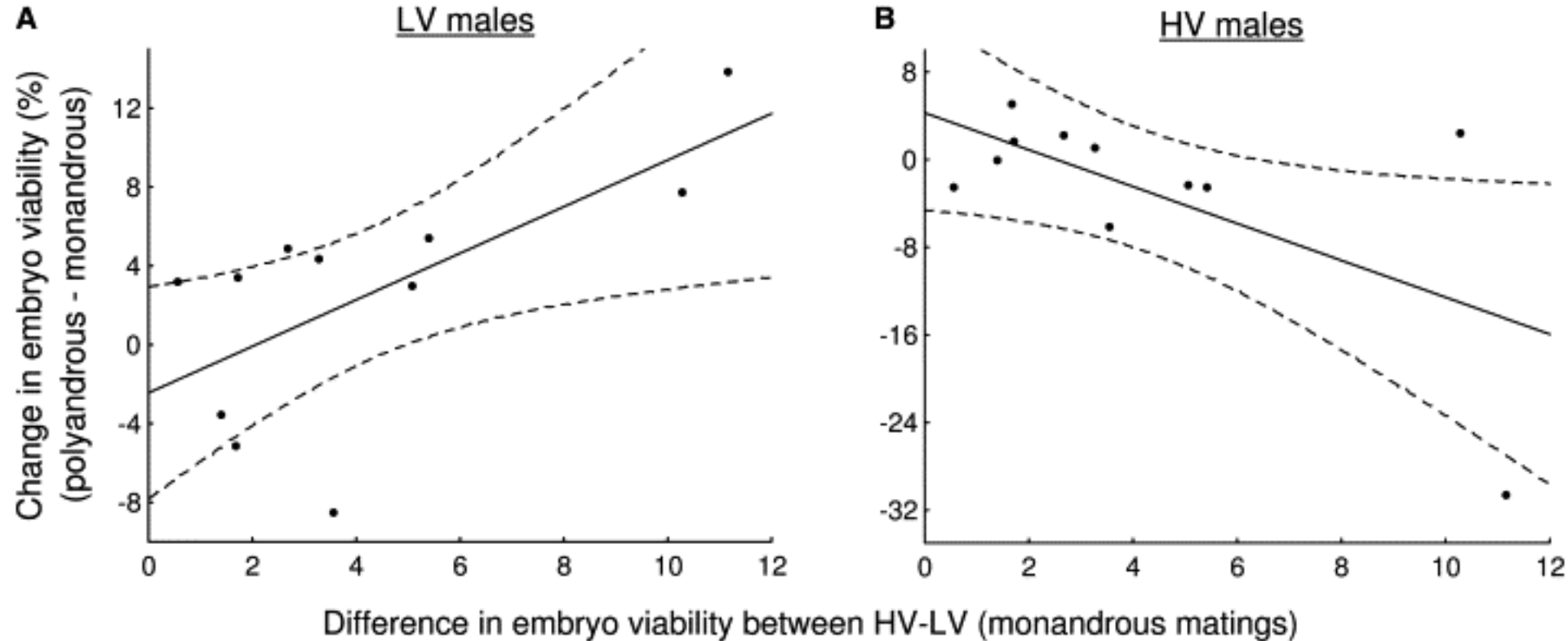


„The evolution of parental care is viewed as the outcome of an evolutionary cost/benefit trade-off between investing in current and future offspring, leading to the selection of traits in offspring that influence parental behaviour.”

Neizravan genetički učinak

Eksperiment razmnožavanja u poliandriji i monoandriji mužjaka zrikavca **visoke i niske embrionalne vijabilnosti (HV i LV)**

- produkti dodatnih spolnih žlijezda uvjetuju žensku reproduktivnost i vijabilnost oplođenih jaja



- A) povećanje vijabilnosti embrija LV mužjaka kada se ženka pari i s HV mužjakom (x-os je odnos kvalitete embrija kod HV i LV), u odnosu na kvalitetu embrija u monoandriji
- B) smanjenje vijabilnosti HV mužjaka ako se ženka parila i s LV mužjakom

- Fenotipska plastičnost definira se kao sposobnost određenog genotipa da producira različite fenotipove kada je izložen različitim okolišnim uvjetima
- Određeni način na koji fenotip jedinke/populacije (genotip) varira u odnosu na okoliše naziva se **reakcijska norma**

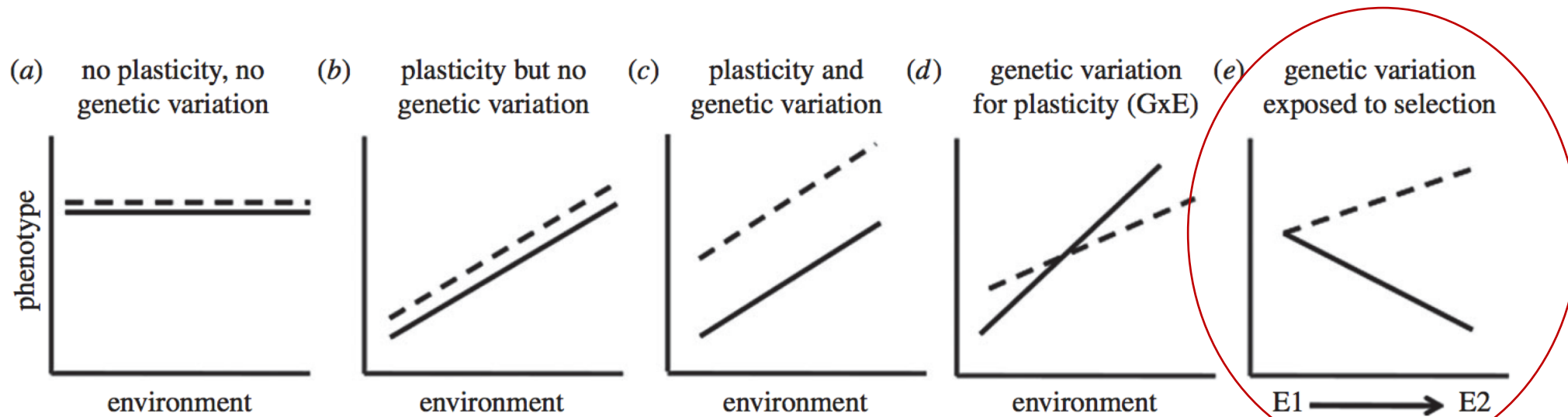


Figure 3. Phenotypic plasticity and reaction norms. In panel (a), phenotype does not vary with the environment and both genotypes have identical reaction norms. In panel (b) both genotypes are plastic and (c) there is also genetic variation. Panel (d) illustrates a genotype-by-environment interaction ($G \times E$), where both genotypes are plastic but their phenotypic reaction norms vary. Genetic variation and $G \times E$ can complicate how much genetic variation is exposed to selection; in panel (e) the genotypes produce the same phenotype in environment (E) 1 but not in environment 2, so selection can only differentiate between the genotypes in environment 2.

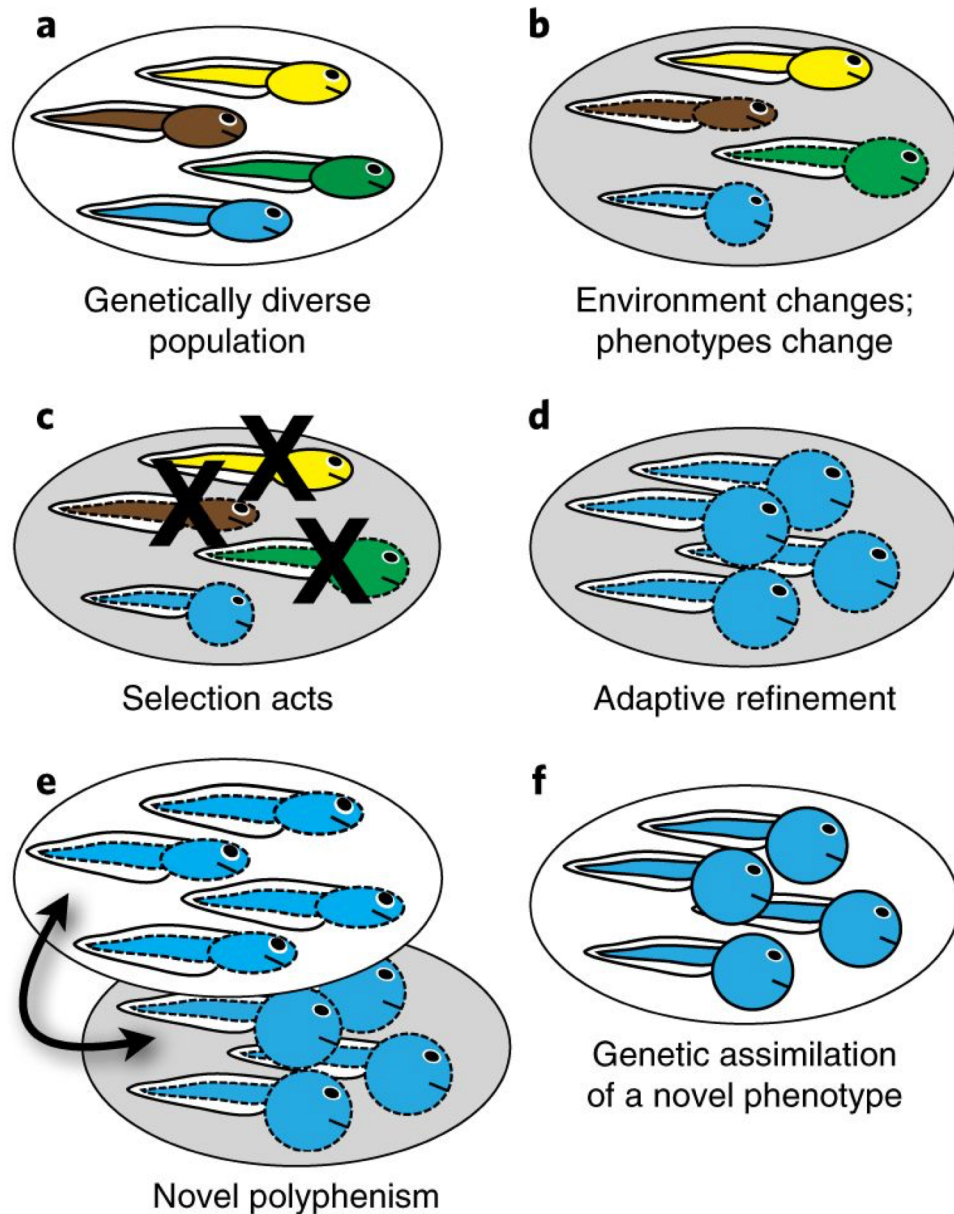
Na slici su prikazane reakcijske norme dva različita genotipa (puna i isprekidana crta), u odnosu na promjenu u okolišu.

Genetska asimilacija

Genetska asimilacija je pojava kada svojstvo koje je **bilo pod izravnim utjecajem okoliša** izgubi „okolišnu osjetljivost” (plastičnost), i postane fiksirano ili konzistentno prisutno u populaciji bez obzira na okolišne uvjete.

Fig. 1: How plasticity can facilitate the evolution of a novel, complex phenotype.

From: Morphological novelty emerges from pre-existing phenotypic plasticity



a,b) Genetski raznolika populacija - različite boje (pokazuju različite genotipe) izložena je novom okolišu (b), koji inducira nove fenotipe

No genotipovi se razlikuju u odgovoru na okolišnu promjenu (oblik)

c) Selekcija djeluje na kritičku genetsku varijaciju koja se pokazuje u novom okolišu i smanjuje fitness onih genotipova koji imaju maladaptivni fenotip

d) To dovodi do adaptivne prednosti određenog genotipa (povećanje plavih punoglavaca na slici)

e) Ako jedinke imaju novi ili ancestralni fenotip ovisno o okolišu, rezultat je novi polifenizam

f) Ukoliko selekcija favorizira gubitak plastičnosti (genetska asimilacija) onda se novi fenotip pojavljuje neovisno o okolišu

Fenotipska plastičnost koju prati **genetska asimilacija** može odrediti **evoluciju novog kanaliziranog svojstva koje će se pojavljivati neovisno o okolišu.**

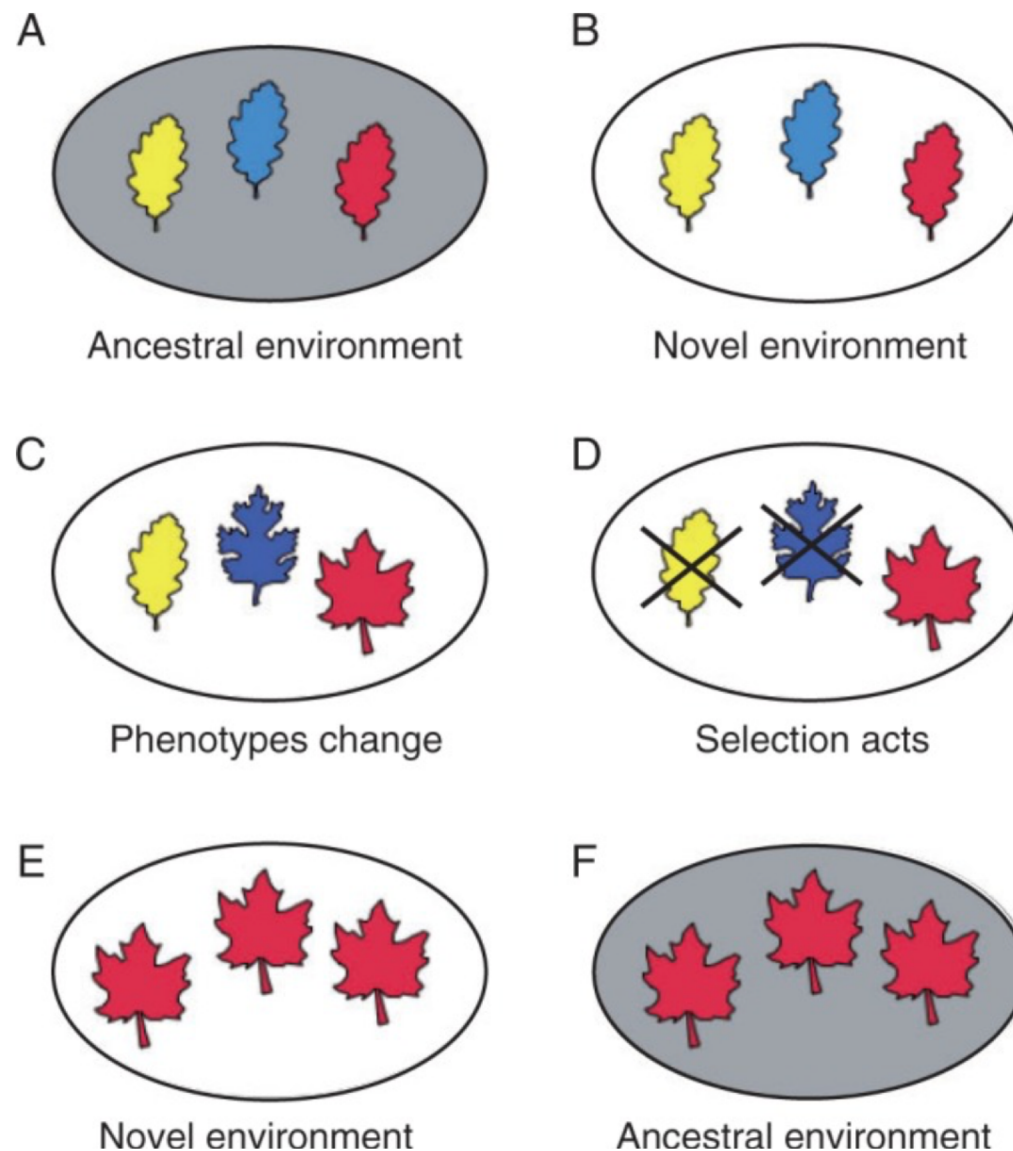
A) Genetski varijabilna populacija

B) Novi okoliš

C) Novi okoliš inducira novi fenotip

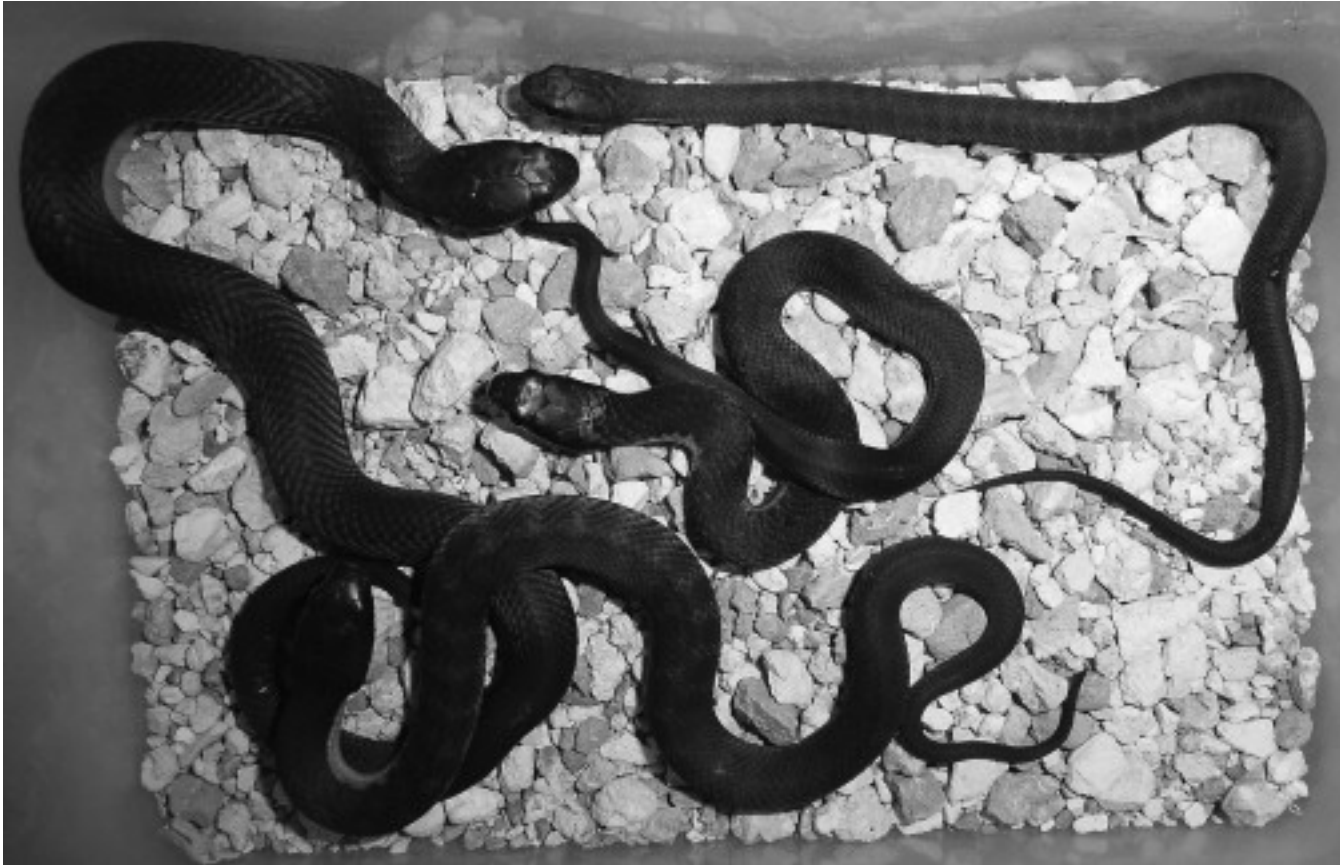
D) Selekcija djeluje protiv genotipova koji stvaraju maladaptivni odgovor u novom okolišu

E) Novo, kanalizirno svojstvo pojavljuje se sada neovisno o okolišu





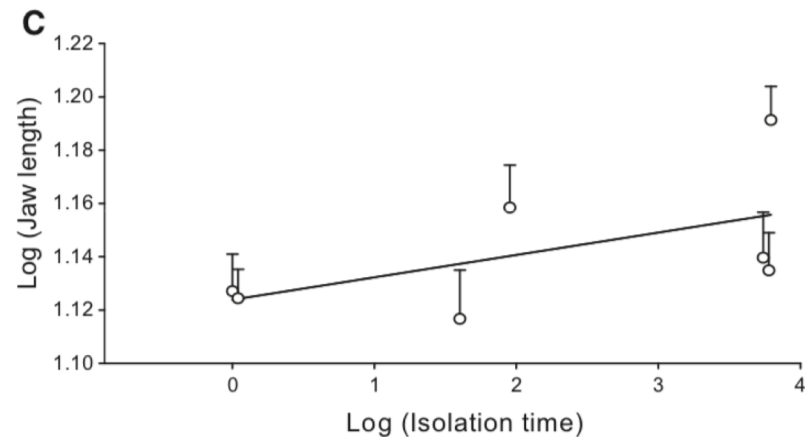
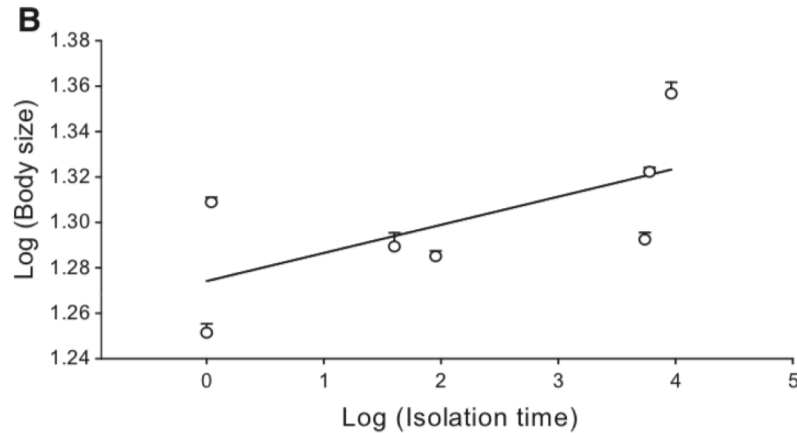
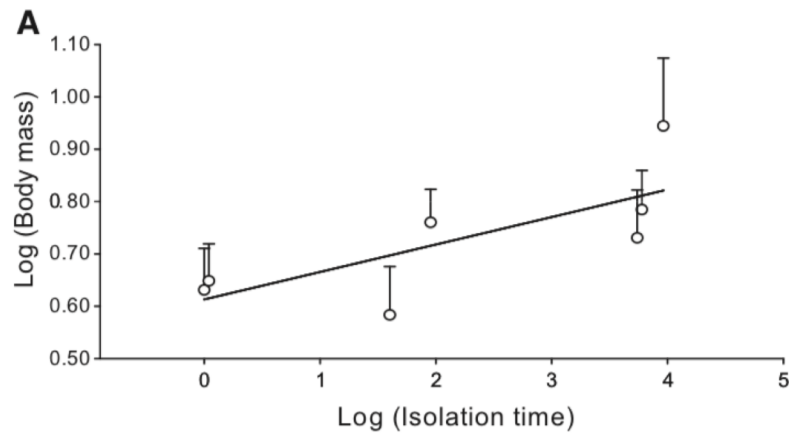
Genetic Assimilation and the Postcolonization Erosion of Phenotypic Plasticity in Island Tiger Snakes



Variation in Body Size and Head Size at Birth among Populations of Australian Tiger Snakes



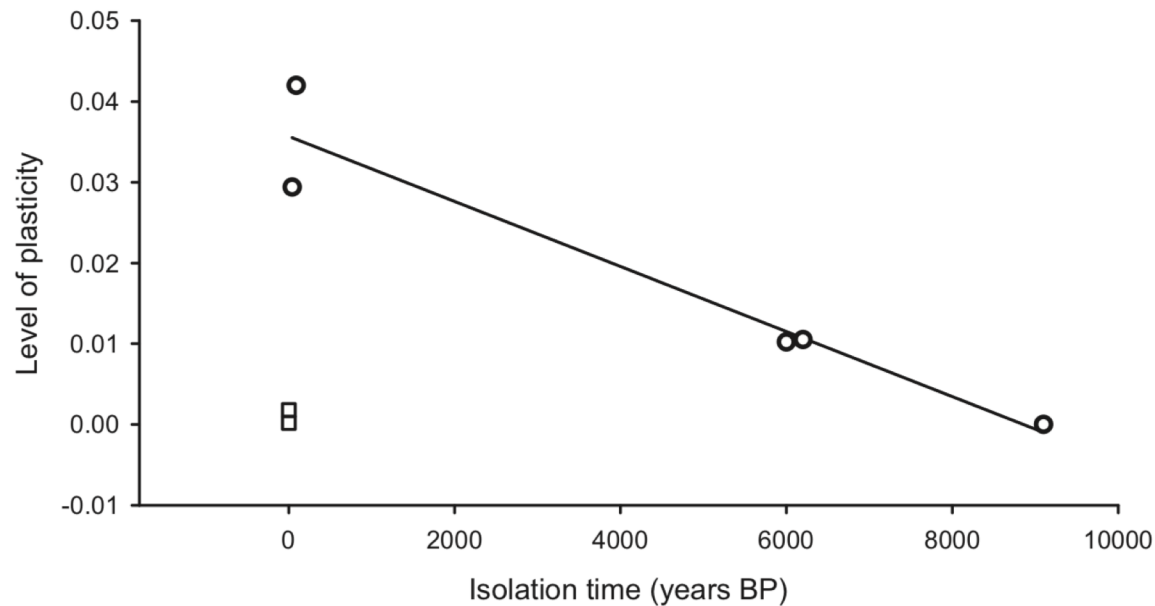
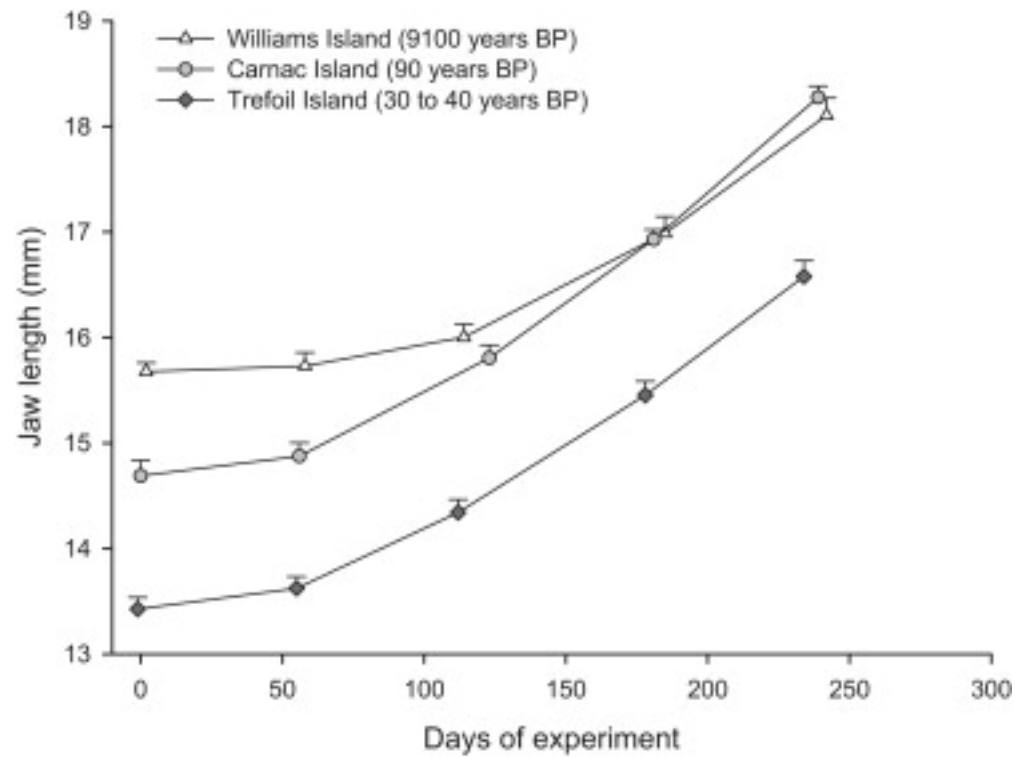
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- Veća glava na otocima omogućuje savladavanje većeg plijena
- Populacije koje su duže na otocima veće glave



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- Pokus zajedničkog okoliša (common garden experiment)
- mlade zmije hranjene velikim i malim plijenom i praćen je rast čeljusti- prikazani rezultati grupe s velikim plijenom- mlađe populacije imaju najveću plastičnost
- Plastična promjena u veličini glave je visoka u nedavno koloniziranih populacija, **populacije koje su dugo na otocima gube plastičnost**