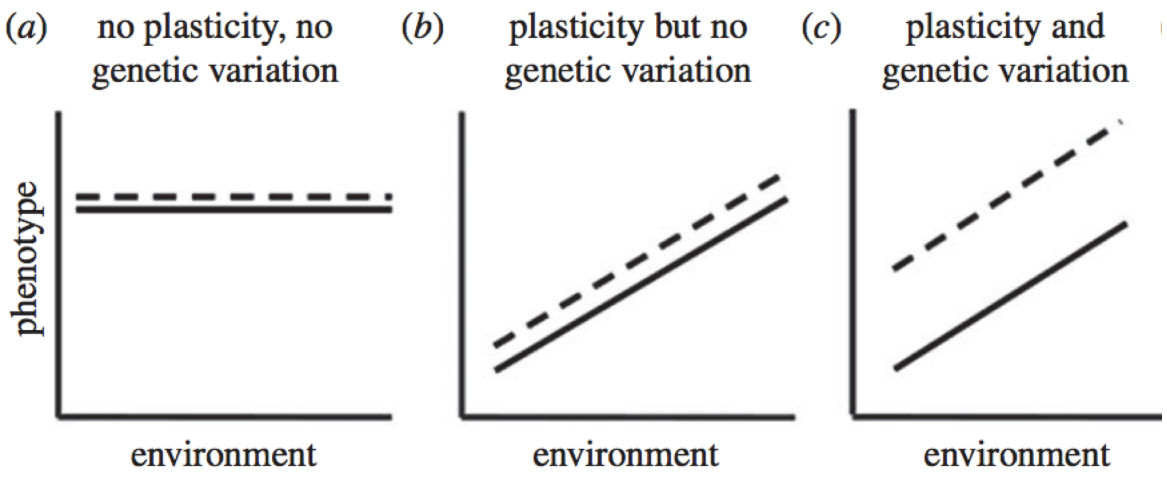
PHENOTYPIC PLASTICTY

- Phenotypic plasticity
- Developmental plasticity
- Seasonal plasticity
- Acclimation
- Induced defences
- Genotype by environment interaction
- Maternal effects
- Indirect genetic effects
- Epigenetic effects

- „ Phenotypic plasticity can be defined as '**the ability of individual genotypes to produce different phenotypes when exposed to different environmental conditions**'
- The particular way an individual's (or genotype's) phenotype varies across environments can be described as a **reaction norm**

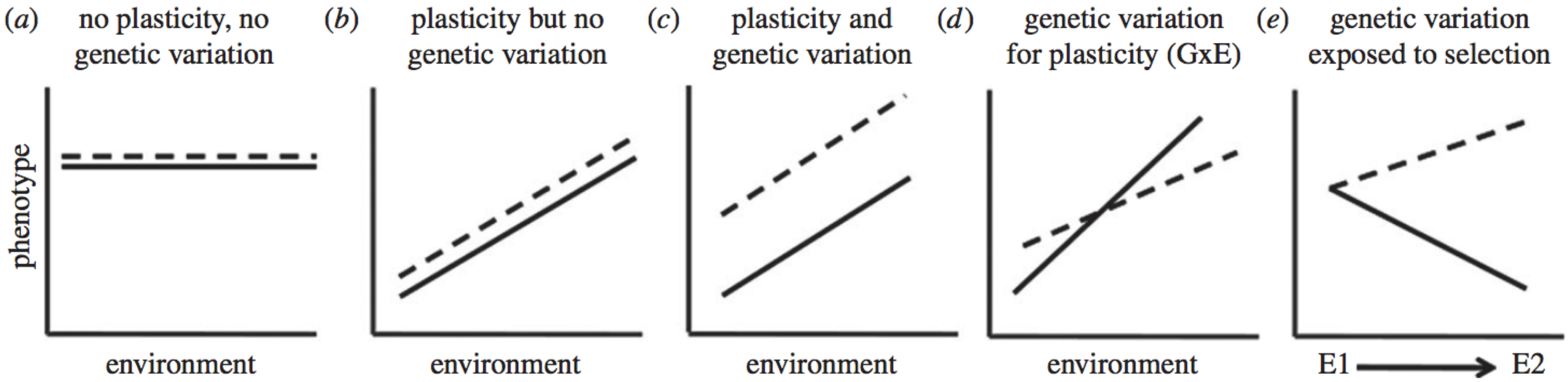


REACTION NORMS OF TWO GENOTYPES

a) **no variation in phenotype, no plasticity**
b) **booth genotypes express the same plastic response**
c) **different genotypes have different phenotypes, similar reaction norms**

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 × E), where both genotypes are plastic but their phenotypic reaction norms vary. Genetic variation and G × 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.

http://dx.doi.org/10.1098/rstb.2013.0365



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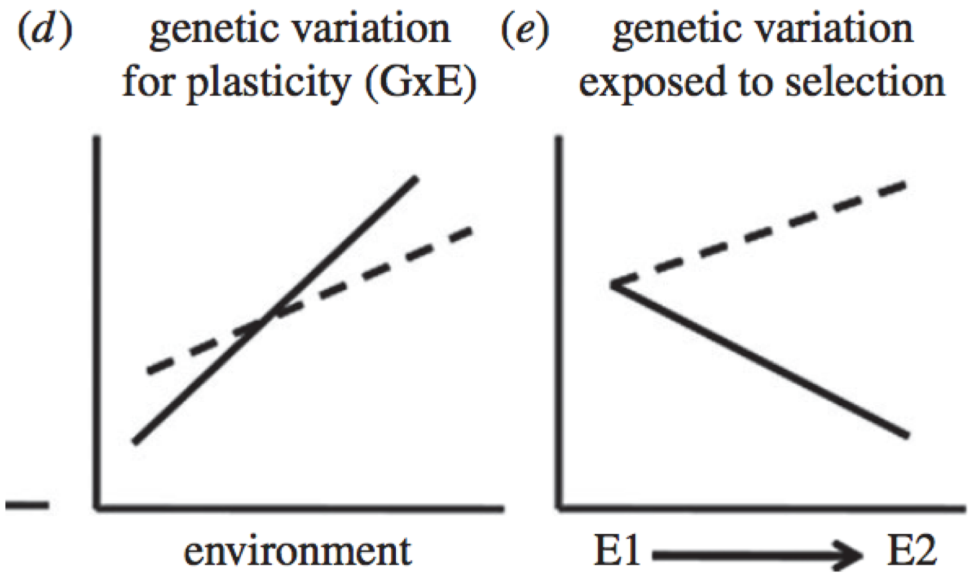


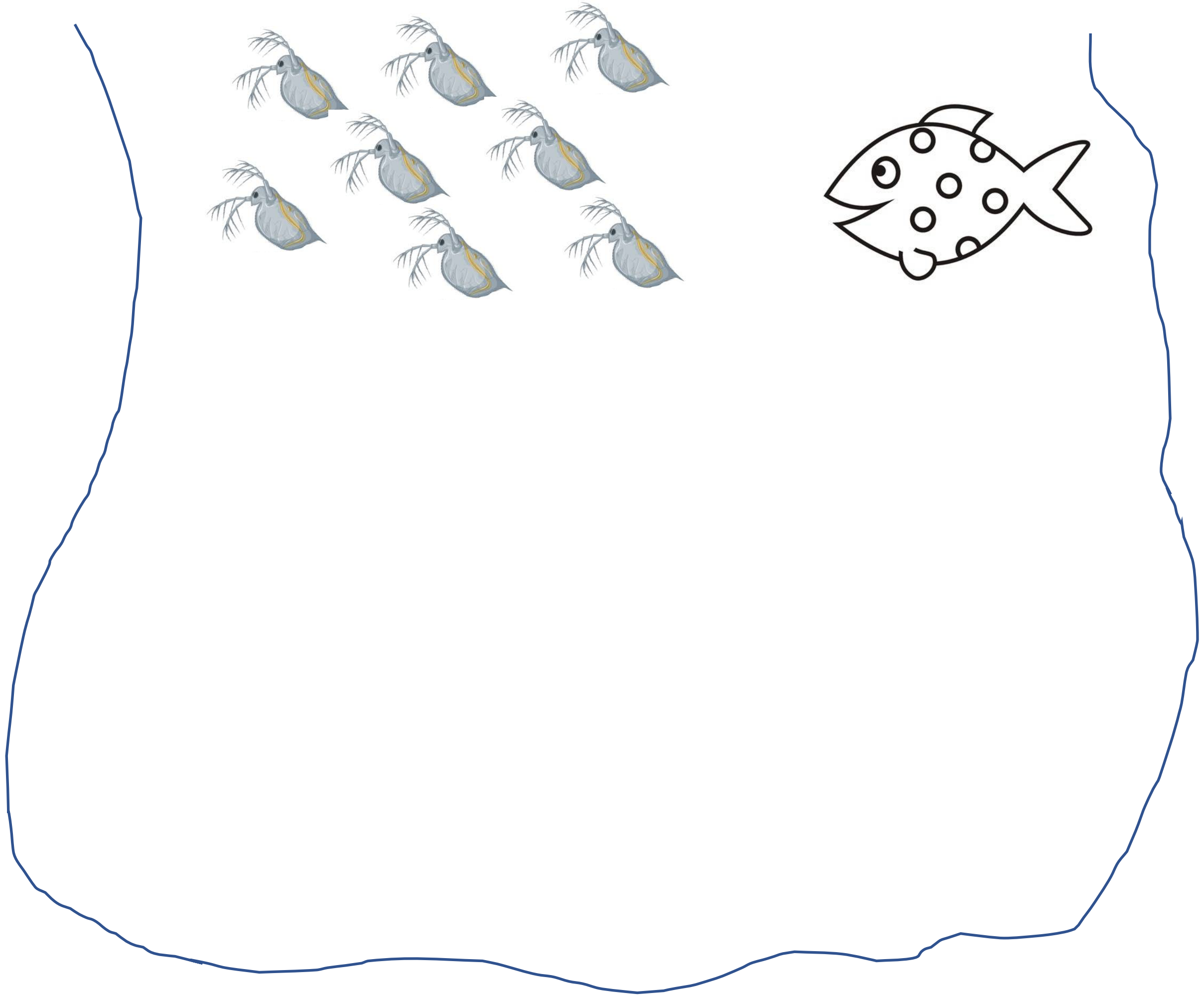
genotype environment interaction – GxE

d) genotypes differ in the response to environmental change- genotypic difference in plasticity

e) change in environment revels difference in genotypes, enabling selection to distinguish between them only in the E2

- Phenotypic plasticity: behaviour, physiology, color, morphology, life history, gene expression…

- Daphnia experiment – De Meester 1996



Phototaxis – most effective feeding near lake surface during a day

Response to fish kairomones

the intensity of predation vary in time and space

Common garden experiment on *Daphnia* from lakes with different predator regime

Daphnias from three lakes exposed to fish kairomones – difference in reaction norms between and within populations

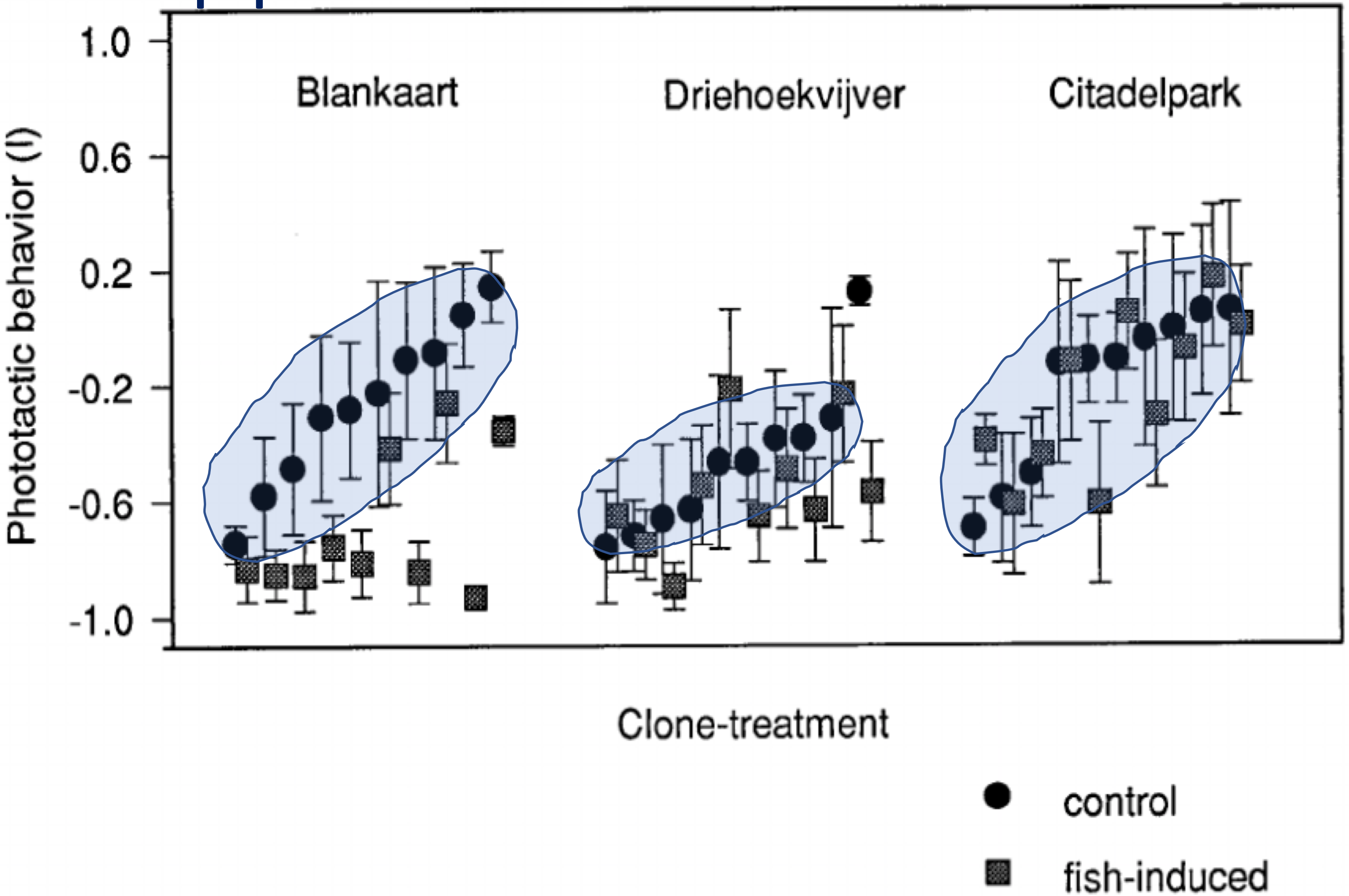
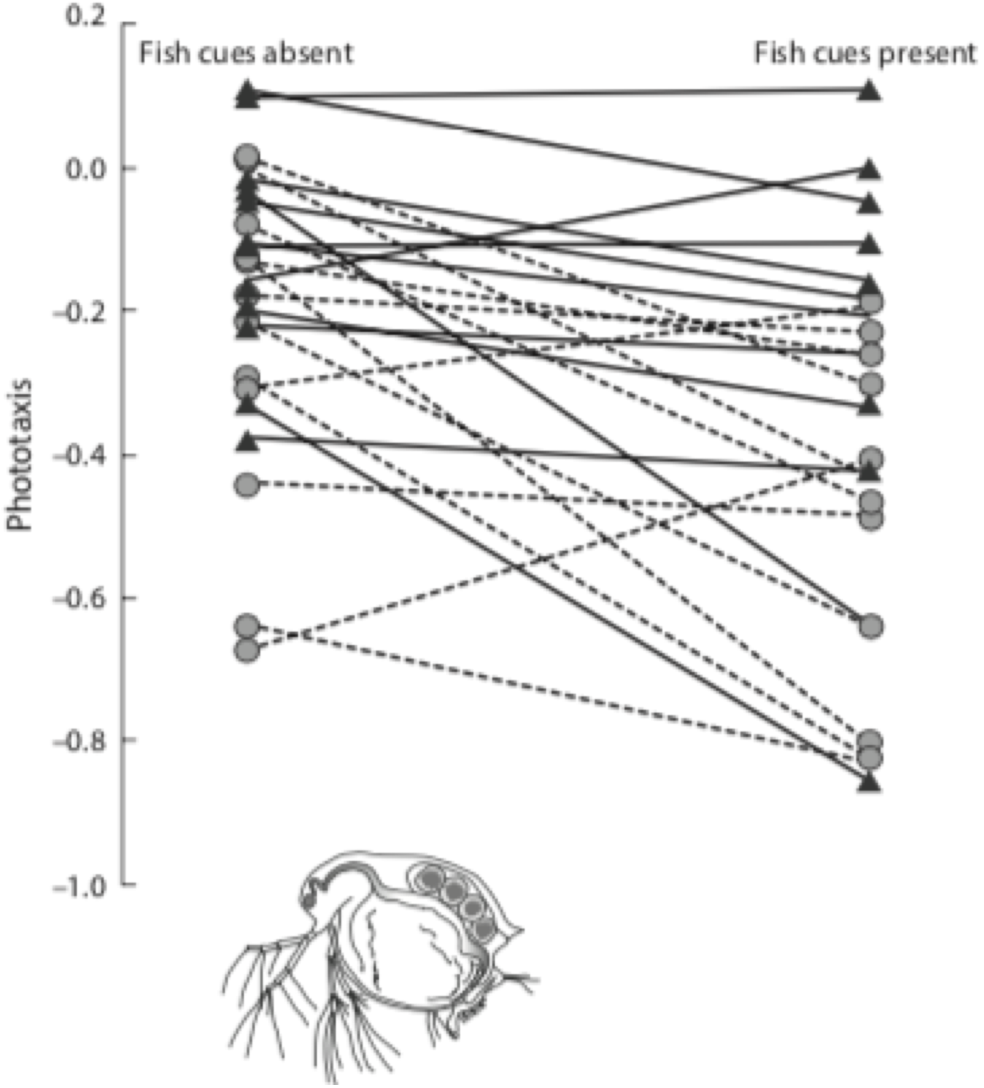


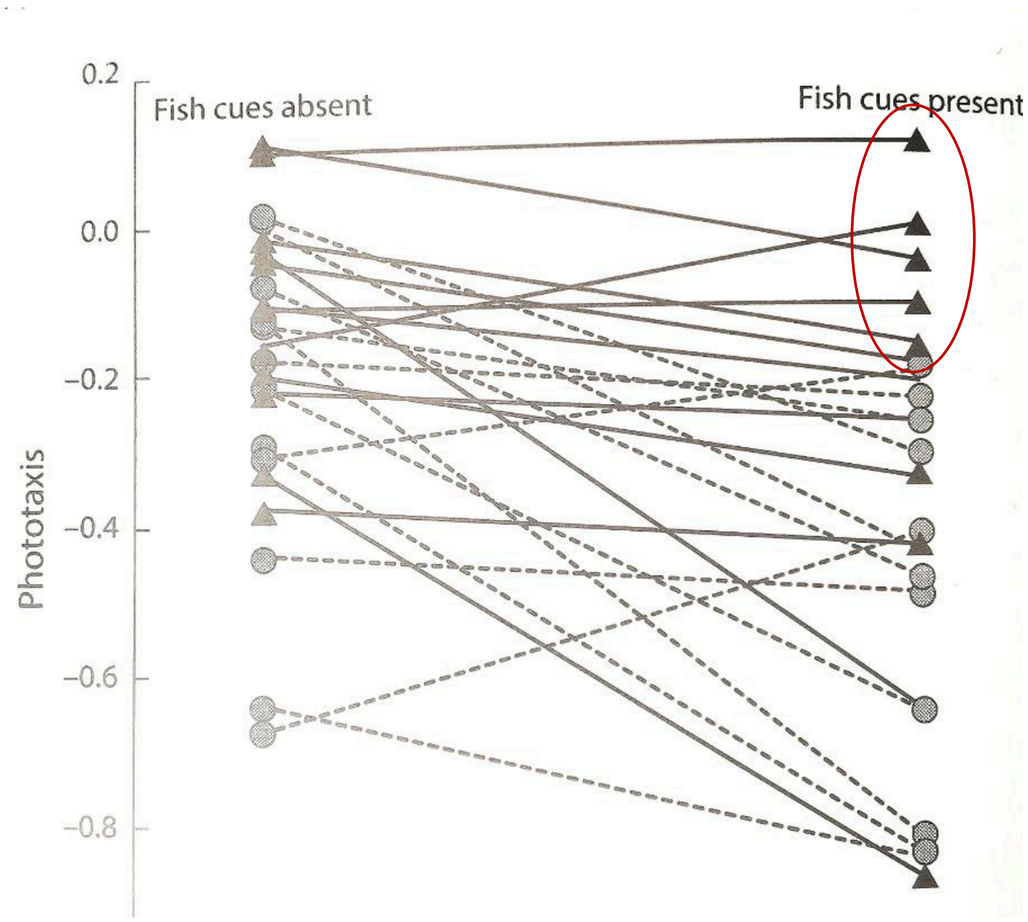
FIG. 1. The phototactic behavior of ex-ephippial clones of three populations (Blankaart, Citadelpark, and Driehoekvijver) in the absence (solid circles) and presence (squares) of fish kairomone. Error bars indicate twice the standard error of the mean. Within each population, clones are ranked from negative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

https://doi.org/10.1111/j.1558-5646.1996.tb02369.x

24 Daphnia clones from the same lake were exposed to water with and without fish kairomones (cues)
Some clones were collected from the lake when predators were present (**circles**), some when predators were absent (**triangles**)



Stoks *et al. Ecol. Lett.* (2016), *A. Hendry 2018*



1) plasticity of single genotype producing multiple phenotypes

2) adaptive responses triggered by env. cue (kairomones)

3)different genotypes differ in plastic responses

4) genotypes differ irrespective of plasticity

Hendry A. 2016 Eco-evolutionary dynamics

Given genetic variation in the plasticity itself, **selection will favour adaptive plasticity** when:

(i) populations are exposed to variable environments

(ii) environments produce reliable cues

(iii) selection favours different phenotypes in each environment

(iv) no single phenotype exhibits superior fitness across all environments

DEVELOPMENTAL PLASTICITY

- Specific type of phenotypic plasticiy

An individual organism's trajectory is the result of a unique interaction between its genome(s), the **temporal sequence of external environments** to which it is exposed during its life and random events at the level of molecular interactions in its tissues

DEVELOPMENTAL PLASTICITY

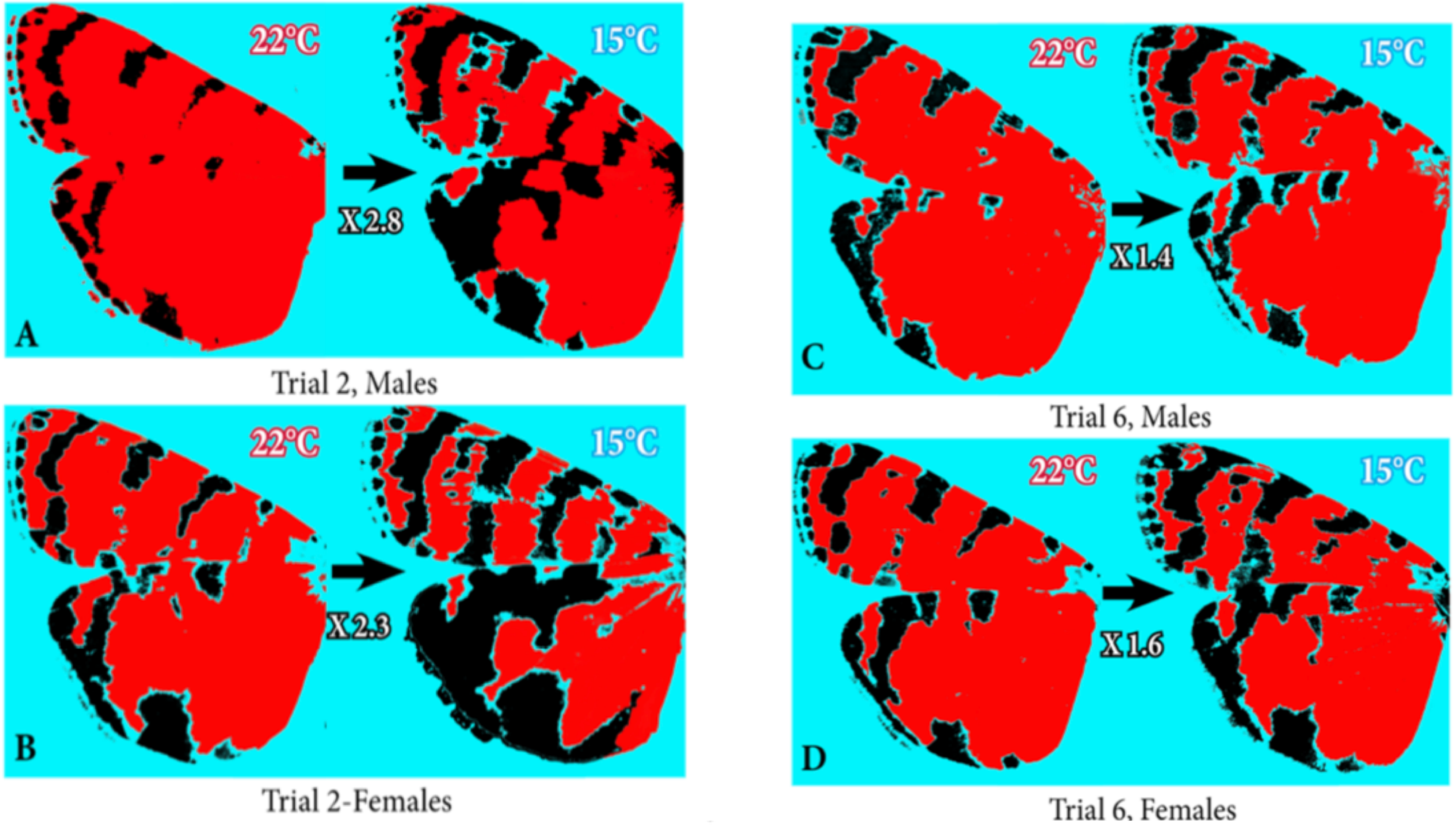
Seasonal polyphenism in butterflies

Catkin (left) and twig (right) - **two morphs** of caterpillars of the moth *Nemoria arizonaria – devepoment conditioned by food available*

Polyphenism is the phenomenon where two or more distinct phenotypes are produced by the same genotype

https://doi.org/10.1016/j.cub.2011.06.006

Seasonal polyphenism in butterflies



Trial 2, Males

Trial 2-Females

Trial 6, Males

Trial 6, Females

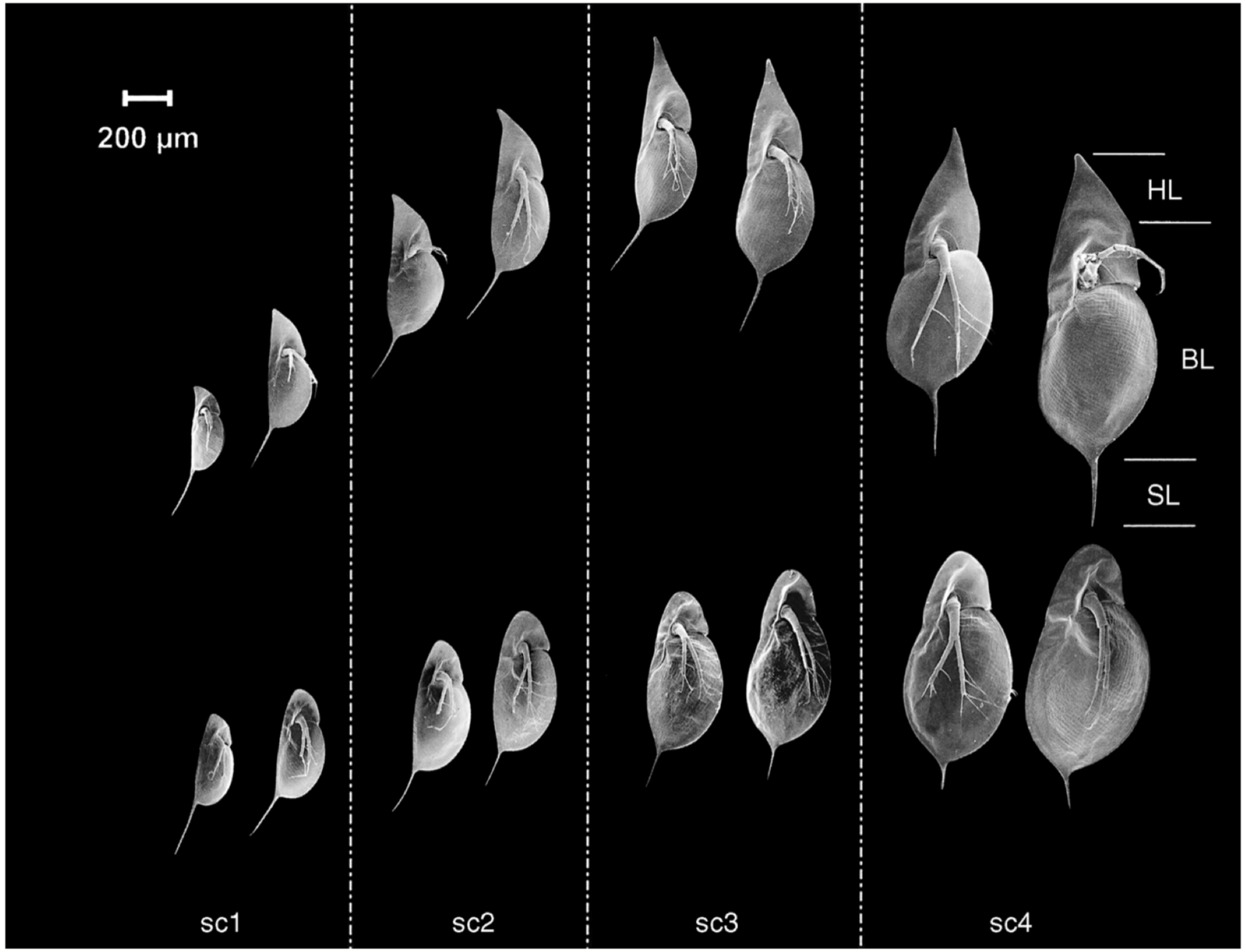
Fig. 2. Schematic illustration of melanic markings on the wing underside of *Utetheisa ornatrix bella* individuals in two temperature reaction norm trials (see text for details). (A) males #1,2 and (B) females #3,4 in Trial 2 (see Supplementary materials), show a 2.3-2.8x increase in black area in cold-induced 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.

Caterpillars of *Utethesia ornatrix*: increasing melanic colouring on wings when raised in lower temperatures

Sourakov (2015)Trop. Lepid. Res., 25(1): 34-45

DEVELOPMENTAL PLASTICITY

Predator-induced polyphenism in cladocerans



predatory cue present

control

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).

- **Helmets of *Daphnia cucullata* are inducible with chemical cues from different kinds of predators and they act as a generalized defense offering protection against several predators, each using a different hunting strategy.**
- **Results from experiment show that chemical cues released from *several predators* induce significantly longer helmets and tail spines**
- **predation experiments revealed that the induced morphological changes offered protection against each of the predators tested.**

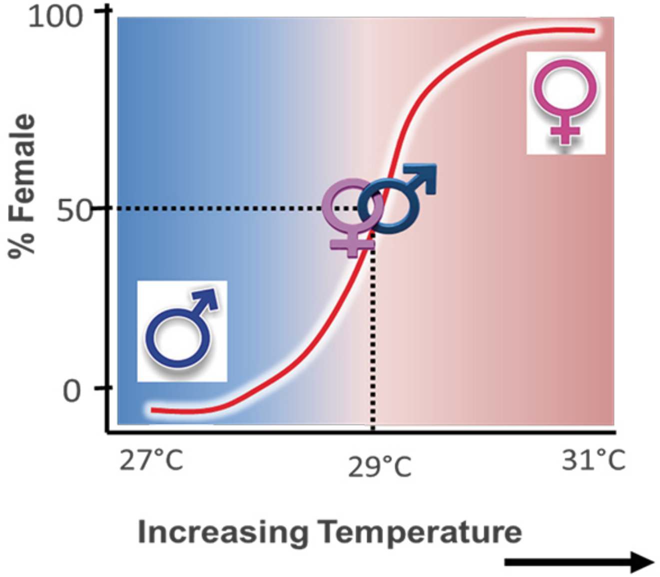
https://doi.org/10.1890/03-0286

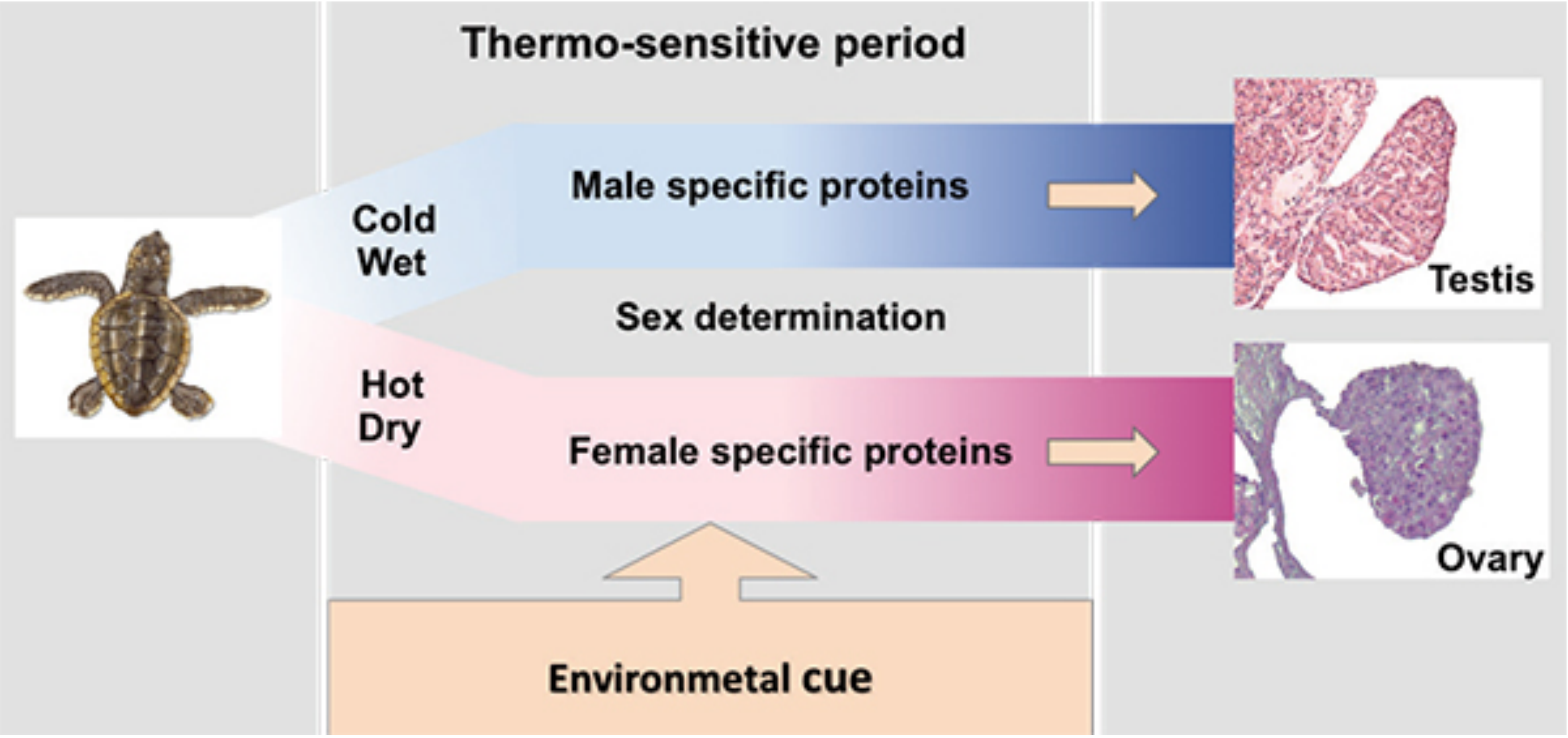
Environmental sex determination in reptiles

Carretta carreta – differences between natural and lab setup

not just temperature, but also humidity

Irreversible plastic changes!





https://doi.org/10.1007/s00360-021-01415-4

Seasonal plasticity

Seasonal plasticity

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]

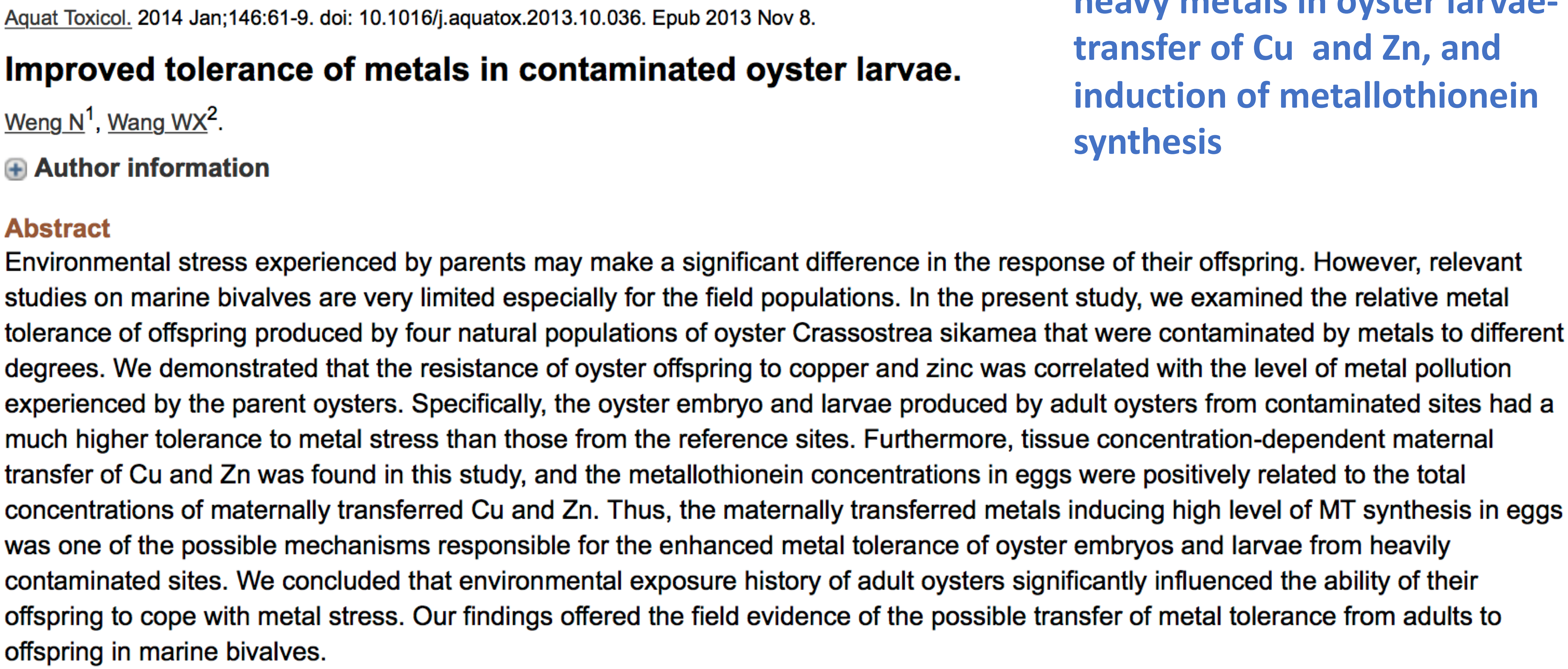
Volume of specific brain regions which control bird singing drastically enlarge before reproductive season, under the influence of sex hormones the number and size of neurons increases

ACCLIMATIZATION

- Acclimatzation is often defined as a phenotypic alteration in physiology that occurs in response to (or in anticipation of) an environmental change
- **Reversible !!!**
- Important for climate change adaptation
- '**PHENOTYPIC FLEXIBILITY**' - intraindividual plasticity - reversible changes within individuals of labile, context-dependent physiological, morphological and life-history traits

MATERNAL EFFECT

Maternal effect of resistance to heavy metals in oyster larvae- transfer of Cu and Zn, and induction of metallothionein synthesis



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

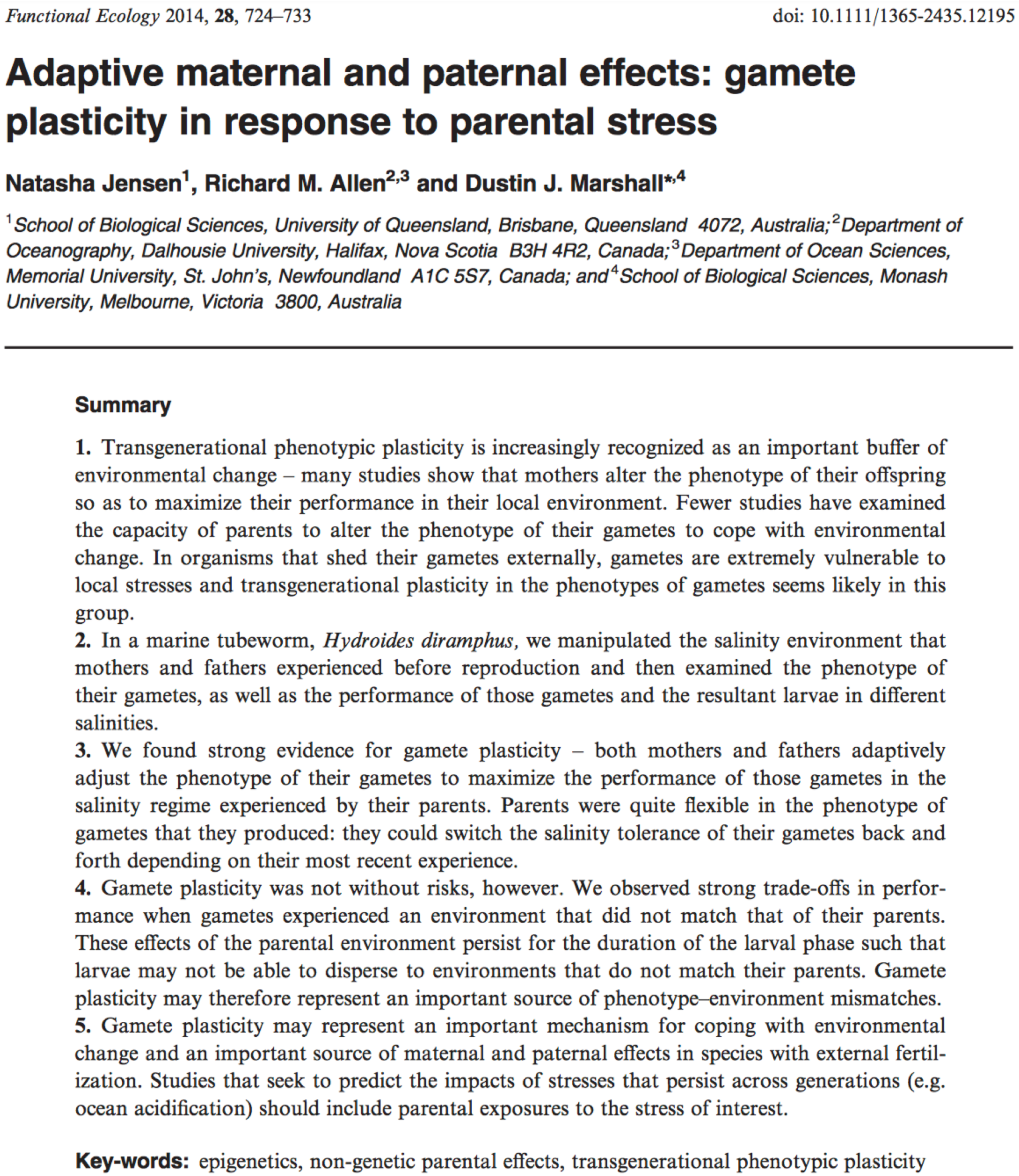
Improved tolerance of metals in contaminated oyster larvae.

Weng N[1], Wang WX[2].

⊕ **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.



Functional Ecology 2014, **28**, 724–733 doi: 10.1111/1365-2435.12195

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

Natasha Jensen[1], Richard M. Allen[2,3] and Dustin J. Marshall*[4]

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

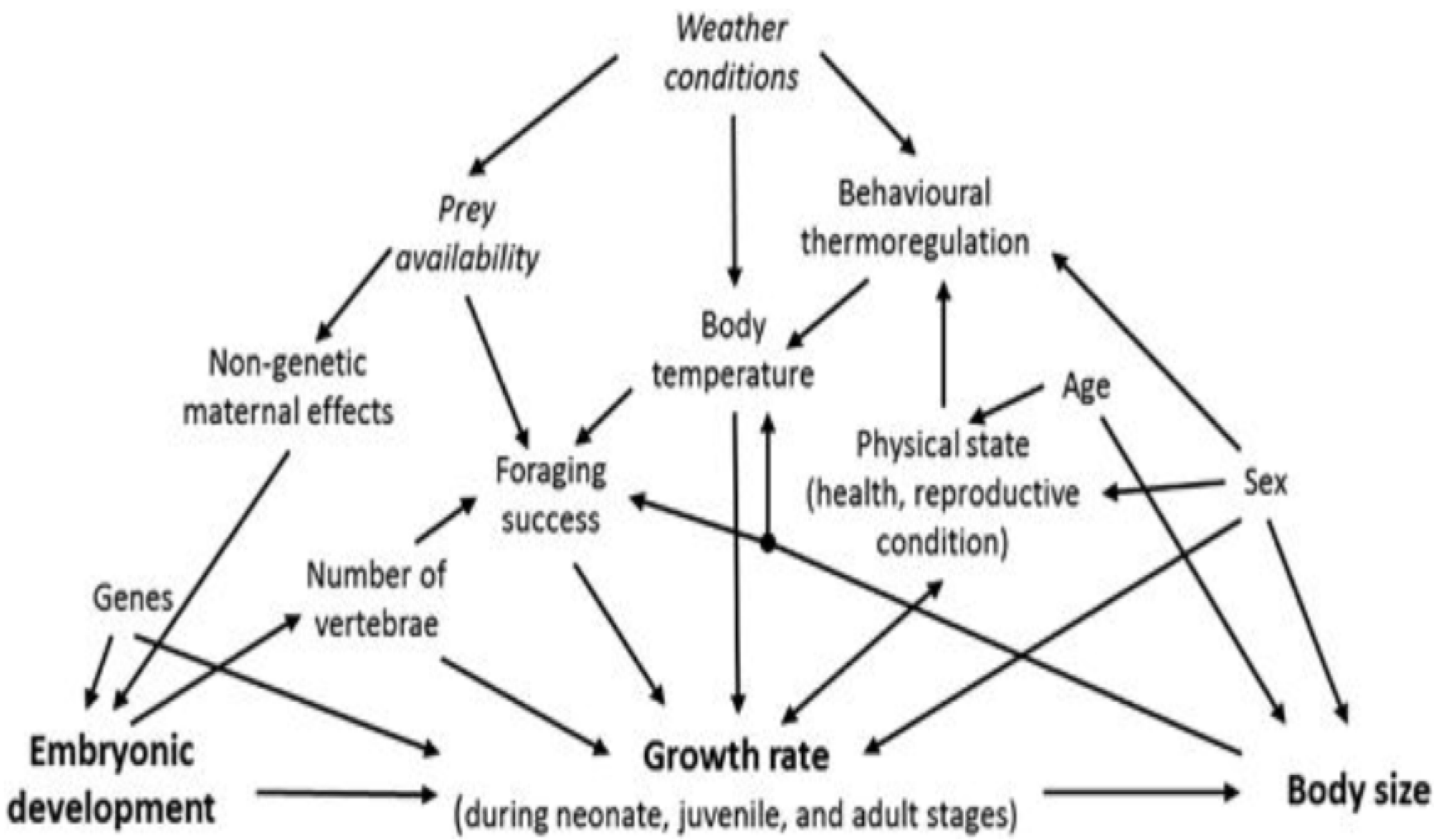
4. Gamete plasticity was not without risks, however. We observed strong trade-offs in performance when gametes experienced an environment that did not match that of their parents. These effects of the parental environment persist for the duration of the larval phase such that larvae may not be able to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

- **Maternal and paternal effect in gametes of polychaetes – production of gametes resistant to particular salinity conditions**
- **COST!! (*trade-off*) – larvae have diminished ability to survive in different salinity conditions, decreased ability to disperse**

From: Rethinking phenotypic plasticity and its consequences for individuals, populations and species



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.

Interaction of multiple factors influencing body size of snakes, and the intra and interindividual variability

1) **GENOM**
2) **ENVIRONMENT:**
   - **IREVERSIBILE PHENOTYPIC PLASTICITY**
   - **REVERSIBILE PHENOTYPIC FLEXIBILITY**

doi: 10.1038/hdy.2014.92.

- Snail *Physella virgata* produces a more rotund shell when in the presence of certain molluscivorous sunfish (blue circle). However, same phenotype is produced in the presence of sunfish that pose no risk. This maladaptive response slows the growth of individuals and is likely to alter population and community dynamics

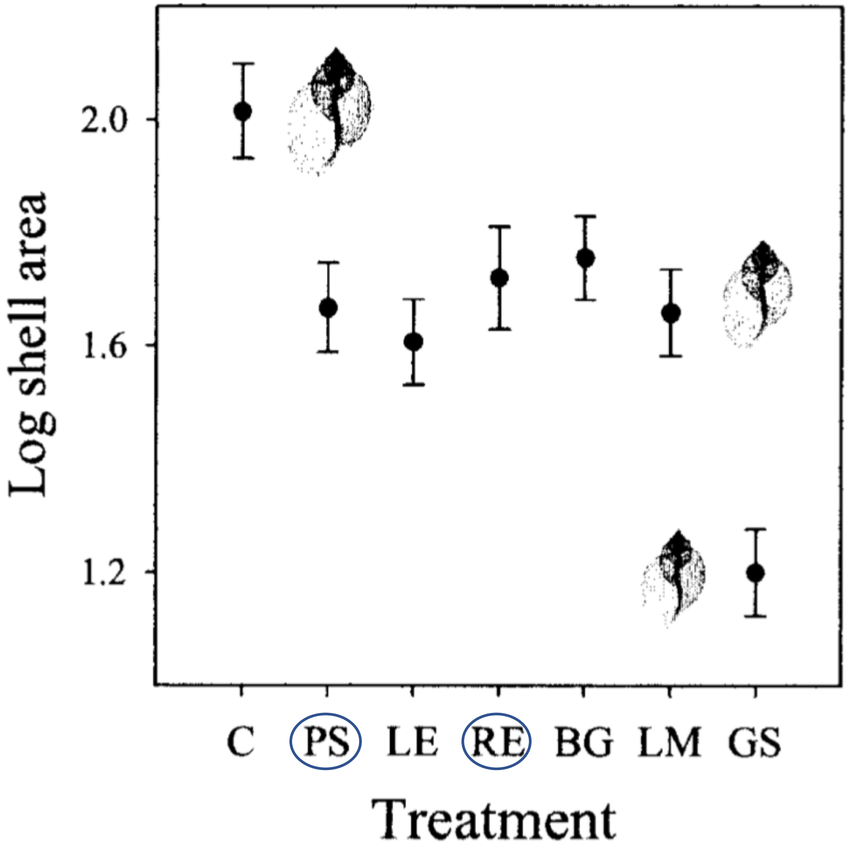


Fig. 1. The shell size of snails raised in the seven environments (mean ± standard error): control (C), pumpkinseed sunfish (PS), longear sunfish (LE), redear sunfish (RE), bluegill sunfish (BG), largemouth bass (LM) and green sunfish (GS).

COST – TRADE- OFF

Growth reduction limits fecundity and prevents snails from attaining size refugia for most predators

Langerhans and DeWitt, 2002, Evol Eco Res

PHENOTYPIC PLASTICITY

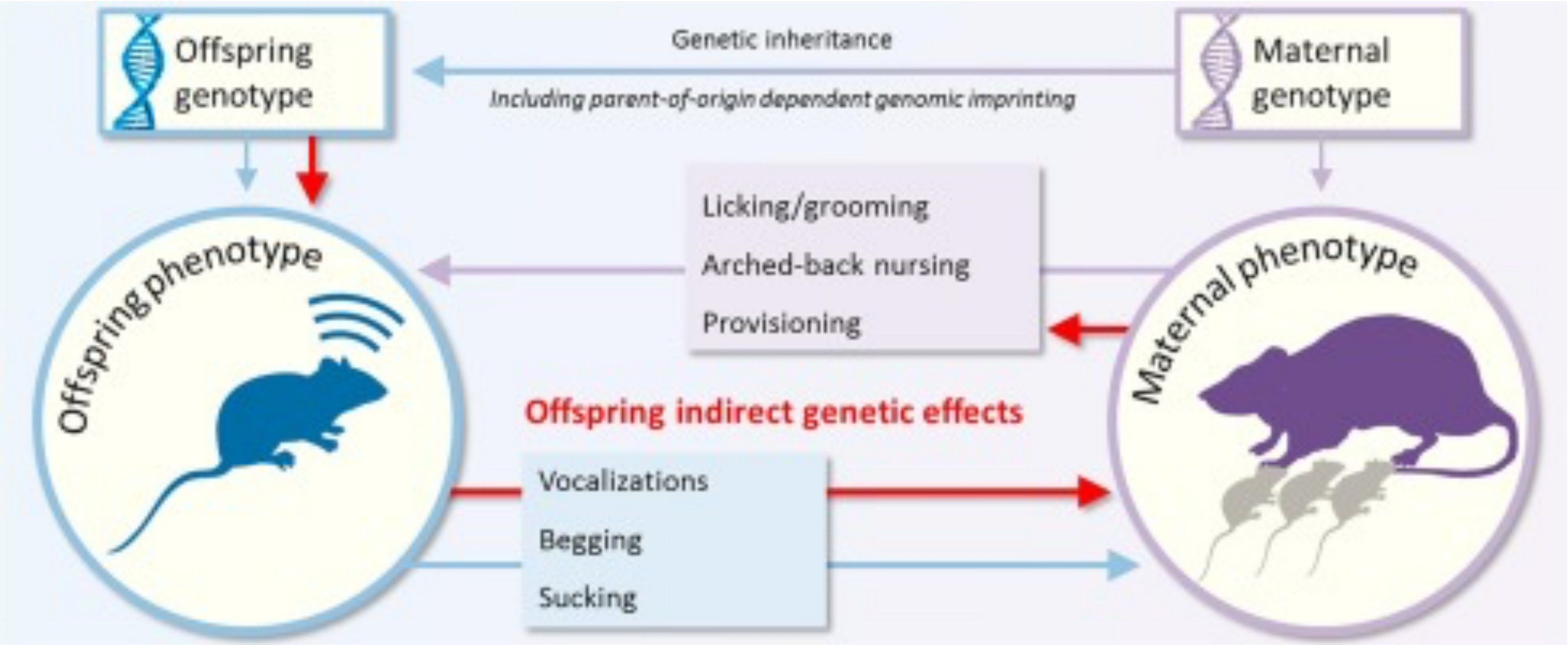
- sometimes adaptive, sometimes maladaptive, sometimes neutral
- **energetically costly**!! (maintenance, production, developmental instability…)
- determination of appropriate phenotype, lag-time limits…

- Phenotypic plasticity
- Developmental plasticity
- Acclimation
- Induced defences
- Maternal effects
- Indirect genetic effects
- Genotype by environment interaction
- Epigenetics

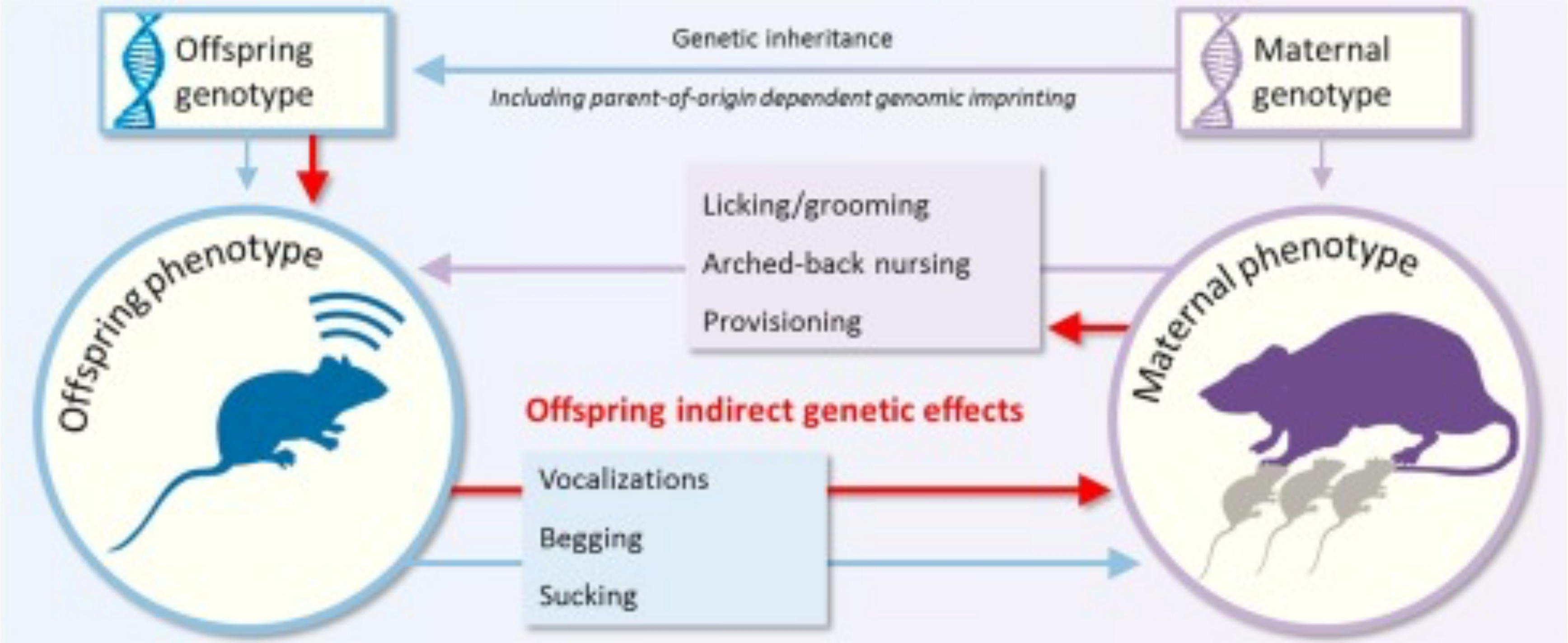
Indirect genetic effects

The trait of a focal individual is potentially influenced not only by its own genotype, but also by that of other individuals with which it interacts.

- behavioural aspects, mate choice
- when the part of environment provided by parents is determined by genetic factors, than this environment becomes heritable and its effect are „**indirect genetic effects”**



Indirect genetic effects



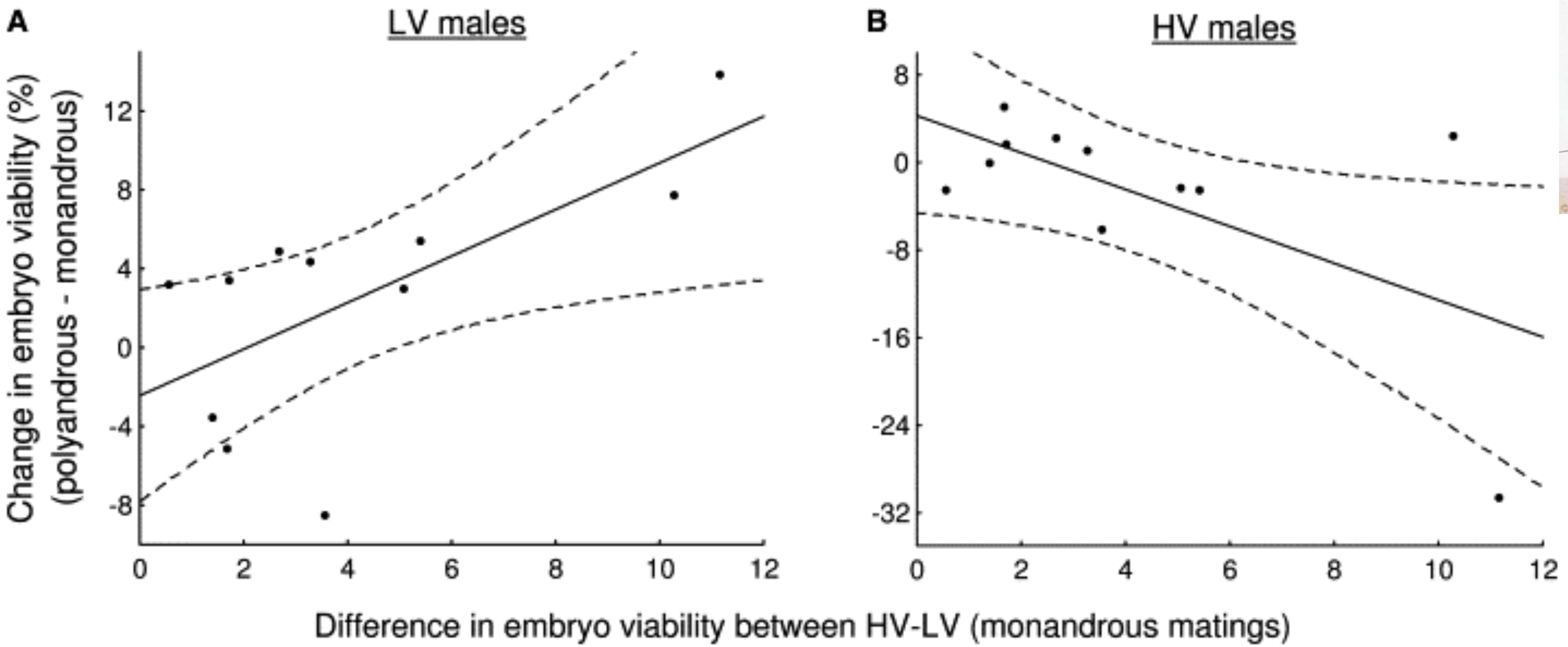
„The evolution of parental care is viewed as the outcome of an evolutionary cost/benefit trade-off between investing in current and future offspring, leading to ***the selection of traits in offspring that influence parental behaviour****."*

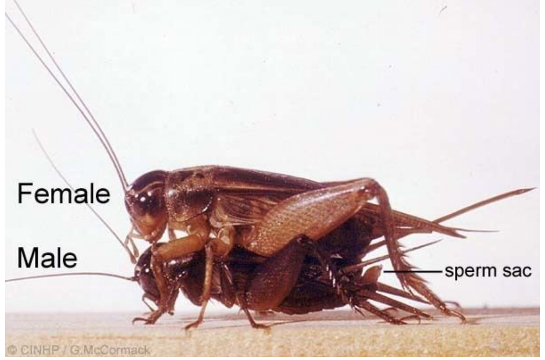
https://doi.org/10.1016/j.yfrne.2018.12.004

Indirect genetic effects

Experiment of reproduction in polyandry and monandry cricket males of high and low embryonic viability (HV and LV)

products of sexual glands affect female reproductivity and viability of embryos





A) increase of viability of embryos sired by LV males when female has also copulated with HV males (x-axis represents ratio of quality of embryos of HV and LV in monandrous copulations)
B) decrease of viability of HV males embryos if female copulated with LV male as well

*https://doi.org/10.1016/j.cub.2006.10.*054

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- The particular way an individual’s (or genotype’s) phenotype varies across environments can be described as a **reaction norm**

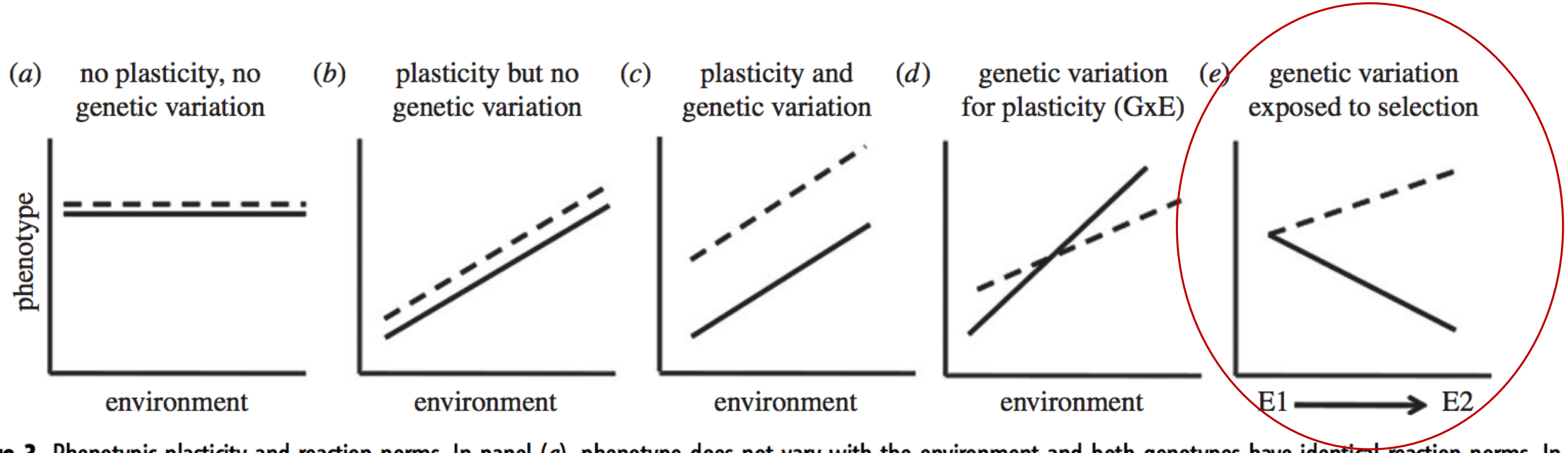


Figure 3. Phenotypic plasticity and reaction norms. In panel (*a*), phenotype does not vary with the environment and both genotypes have identical reaction norms. In panel (*b*) both genotypes are plastic and (*c*) there is also genetic variation. Panel (*d*) illustrates a genotype-by-environment interaction (G × E), where both genotypes are plastic but their phenotypic reaction norms vary. Genetic variation and G × 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.

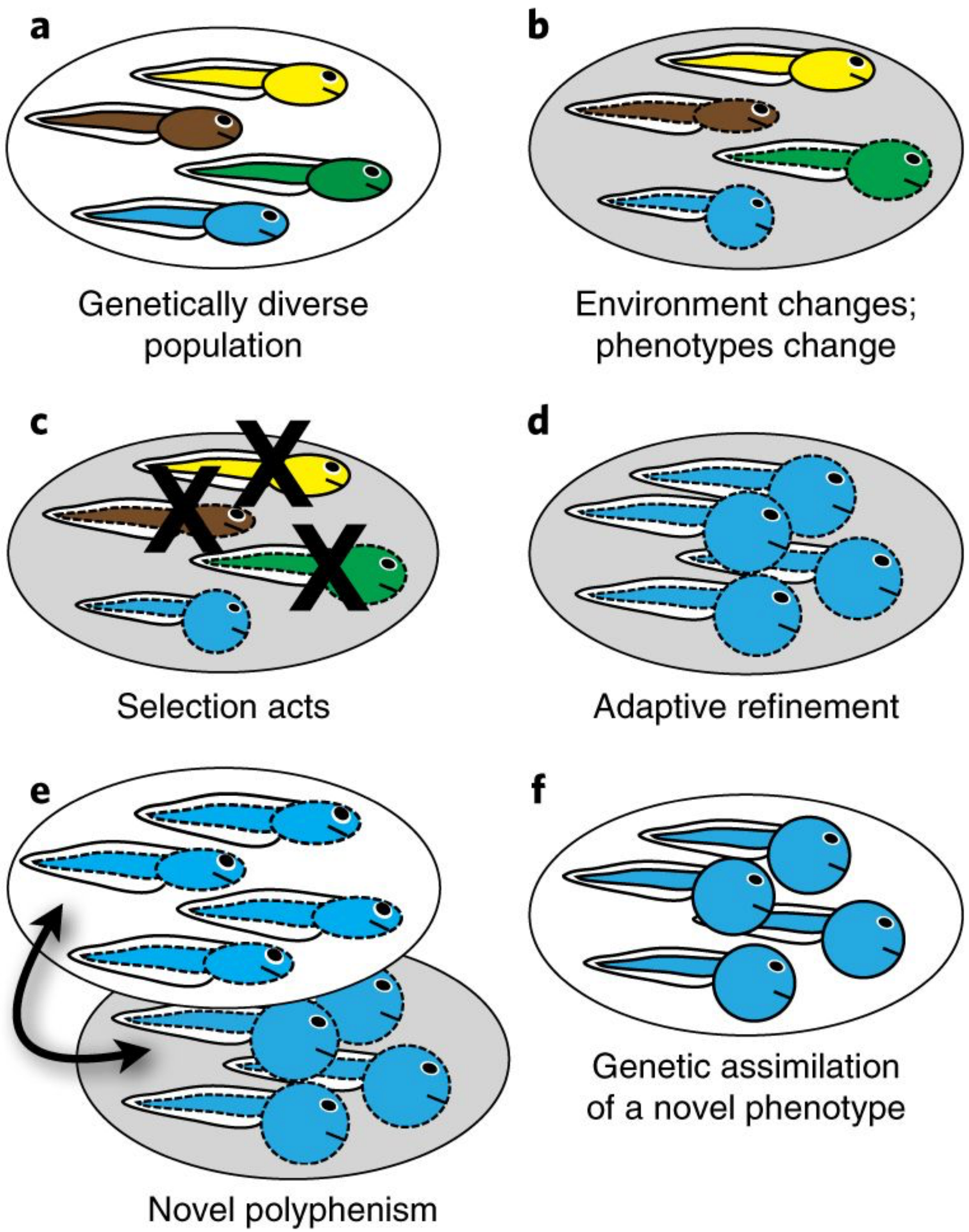
http://dx.doi.org/10.1098/rstb.2013.0365

Genetic assimilation

Genetic assimilation occurs when a trait that was **originally triggered by the environment** loses this environmental sensitivity (i.e. plasticity) and ultimately becomes ‘**fixed**’ or expressed constitutively in a population.

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

From: Morphological novelty emerges from pre-existing phenotypic plasticity



Genetically diverse population

Environment changes; phenotypes change

Selection acts

Adaptive refinement

Novel polyphenism

Genetic assimilation of a novel phenotype

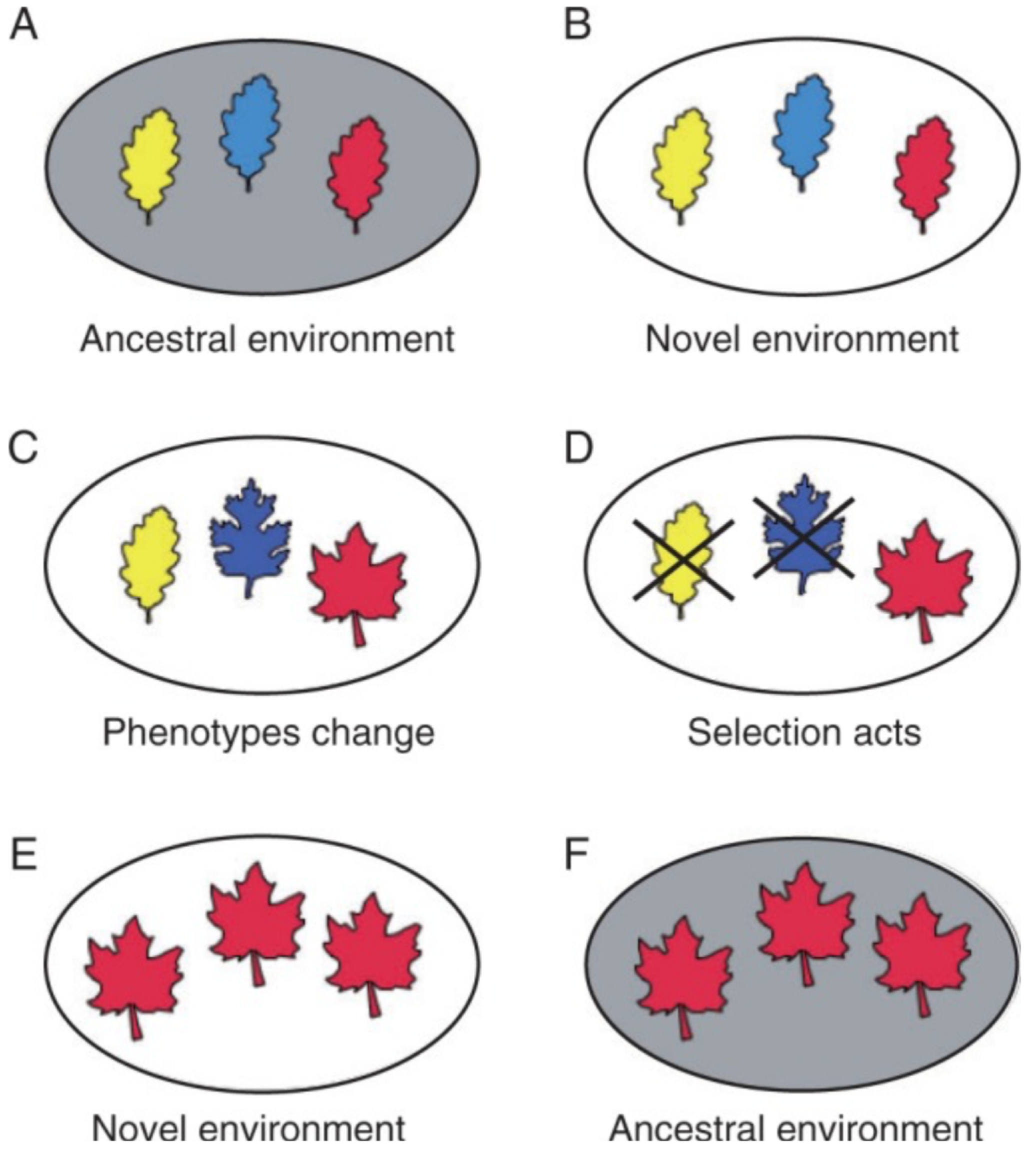
a) *A genetically diverse population (**a**, different colours indicate different genotypes) experiences a novel environment (**b**, shading), which induces novel phenotypes (dashed lines), but genotypes differ in whether and how they respond to the novel environment (differences in shape).*

c) *Selection acts on this formerly cryptic genetic variation (revealed by a change in environment) and disfavours genotypes that produce maladaptive or poorly adapted phenotypes.*

d) *This leads to the adaptive refinement of the favoured phenotype (enlargement of the blue tadpole).*

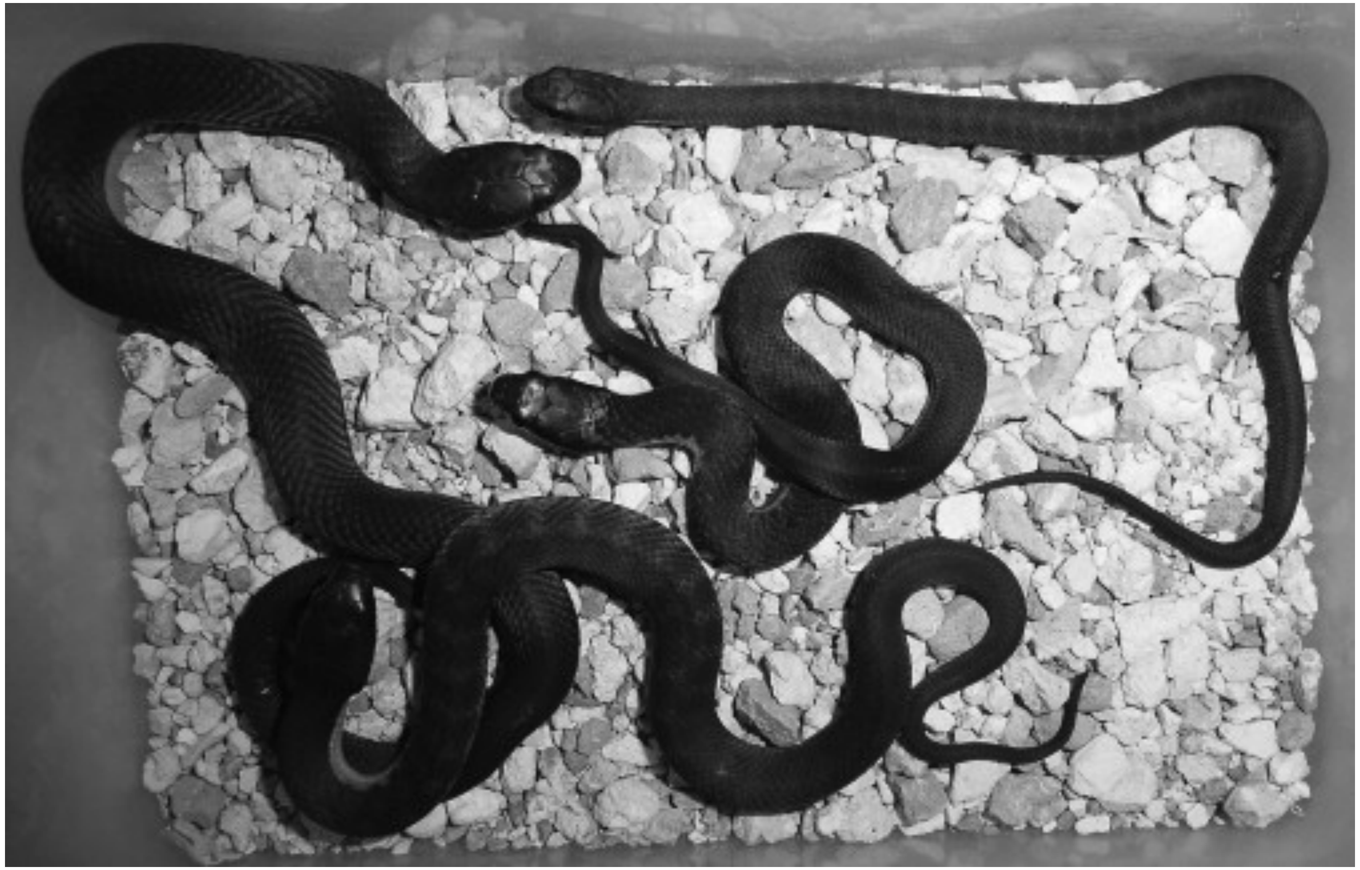
e) *If individuals produce either this novel phenotype or the ancestral phenotype depending on their environment, then the result is a novel polyphenism.*

f) *Alternatively, selection might favour the loss of plasticity (that is, genetic assimilation), resulting in a novel phenotype that is produced regardless of the environment (indicated by the loss of dashed lines).*



Phenotypic plasticity, followed by genetic assimilation, may facilitate the evolution of a new, canalized trait regardless of the environment through the following steps (here, the trait is a new leaf shape; different colours represent different genotypes). (A) A genetically variable population (B) experiences a novel environment (indicated here as a change from a shaded to an unshaded background). (C) Consequently, the environment induces novel phenotypes (different leaf shapes), but different genotypes respond differently (by producing different-shaped leaves). (D) Selection disfavours those genotypes that produce maladaptive phenotypes (leaf shapes) in the novel environment (indicated here by an X). (E) Such selection may result in the evolution of a novel, canalized trait (a novel leaf shape) that is expressed regardless of the environment. (F) That is, the novel trait is produced even when the environment changes back to the original, ancestral state.

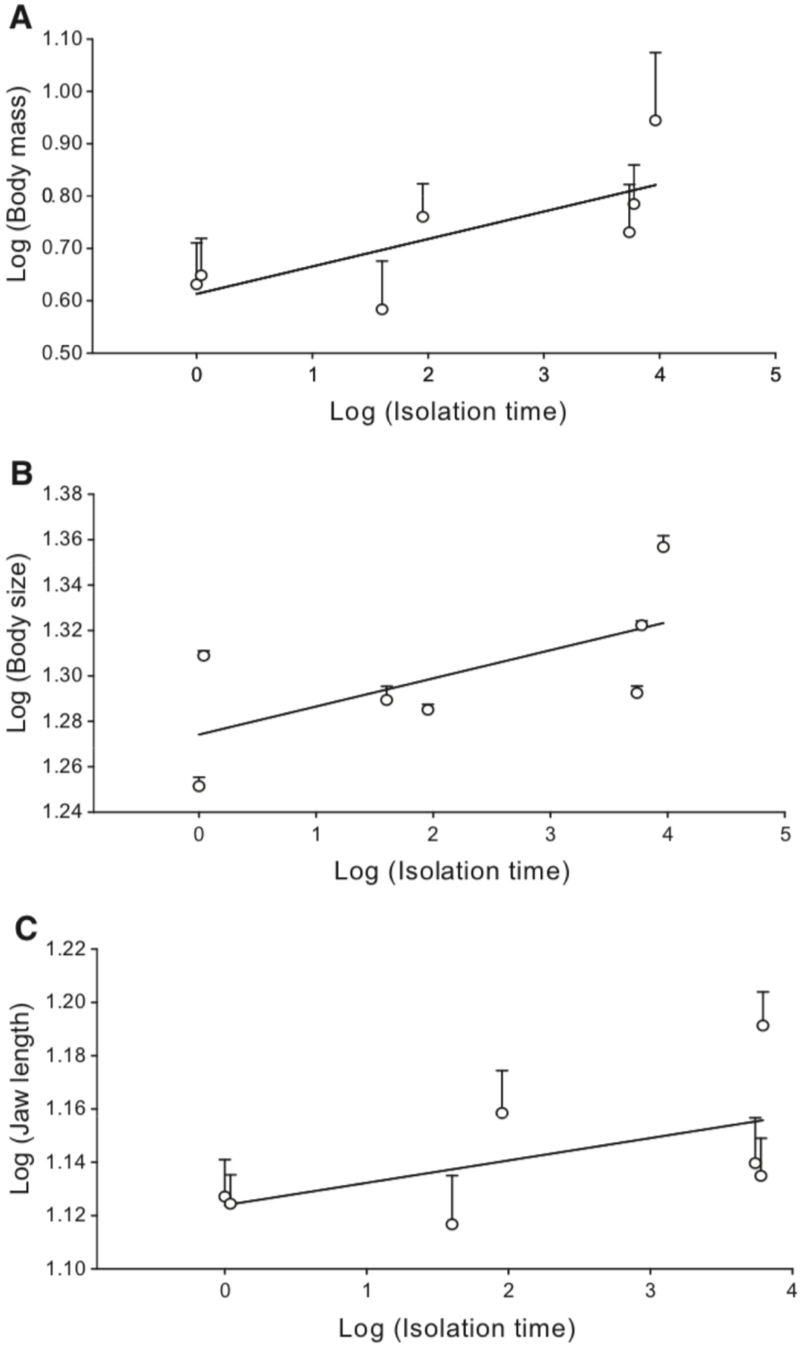
Genetic Assimilation and the Postcolonization Erosion of Phenotypic Plasticity in Island Tiger Snakes



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

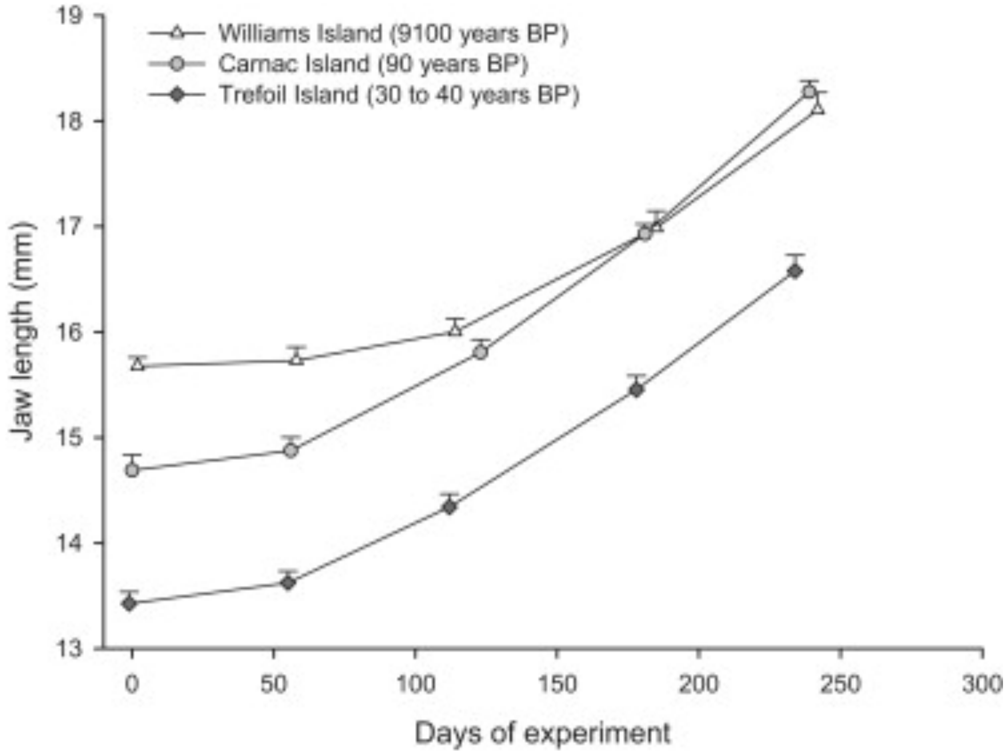
https://doi.org/10.1016/j.cub.2009.09.061

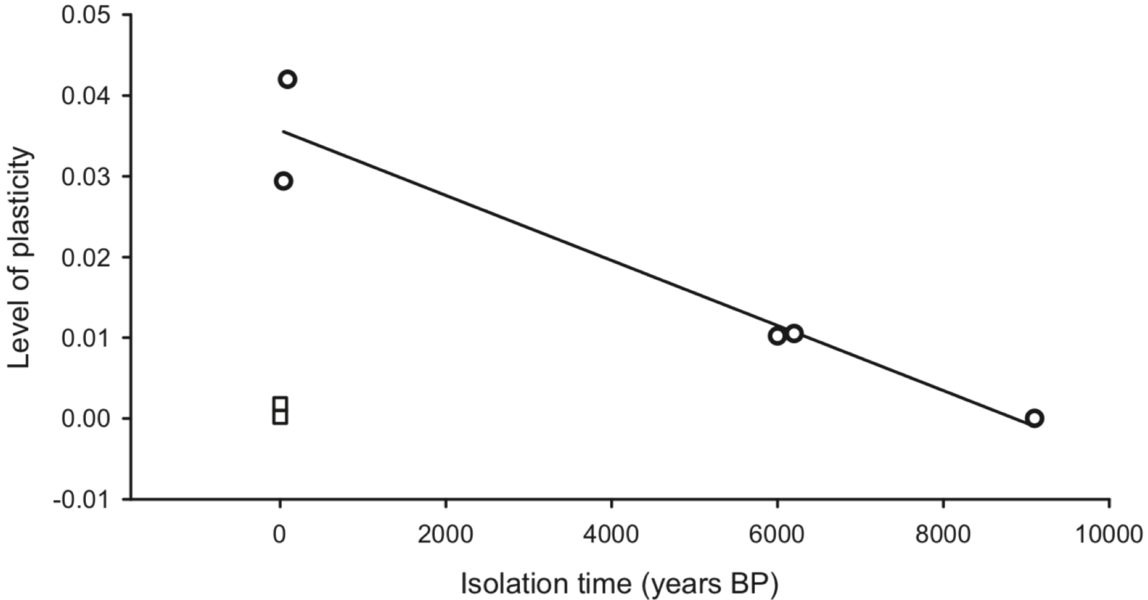
Genetic Assimilation and the Postcolonization Erosion of Phenotypic Plasticity in Island Tiger Snakes



- Bigger head on islands – bigger prey
- Long established insular populations have bigger heads

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





- Common garden experiment
- young snakes fed by large and small pray- the growth of the jaw length is tracked – the results show the group feed by large pray
- **Plasticity of head dimensions is high in recently colonised islands**, long established populations have decresed plasticity