

The Question that Stumped Darwin

ANTS & EVOLUTION



Prof. Ehab Abouheif

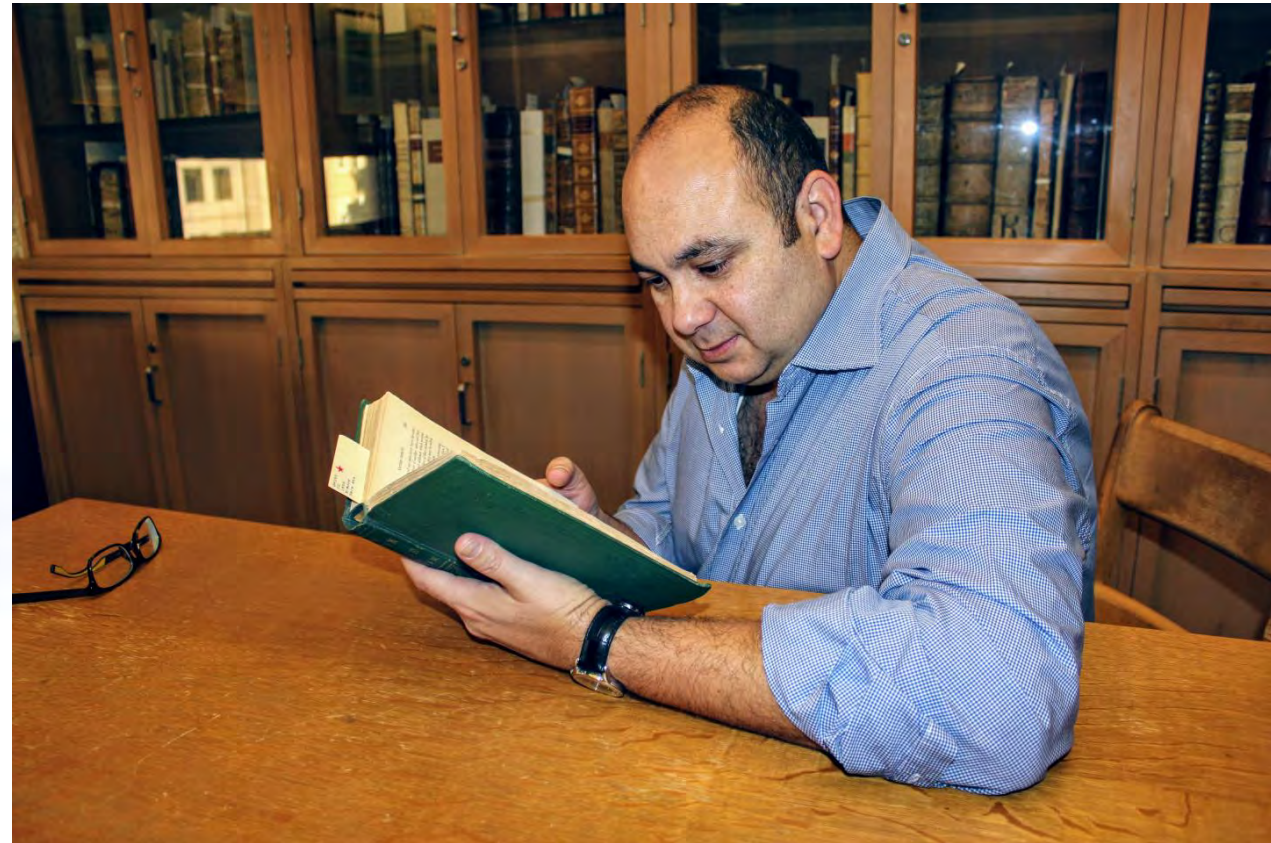
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Rare Books and Special Collections

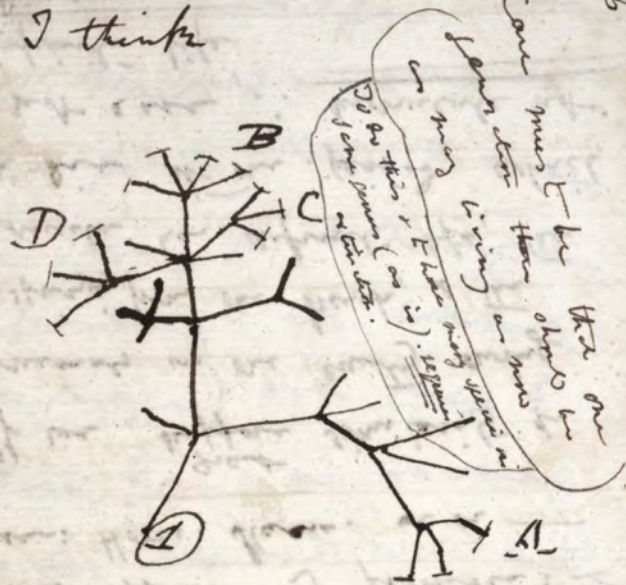
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36



Then between A & B. various
sort of relation. C & B. The
first gradation, B & D
rather greater distinction
Then genus would be
formed. - bearing relation

W. WHEWELL: *Bridgewater Treatise*.

BACON : *Advancement of Learning.*

Down, Bromley, Kent,
October 1st, 1859.

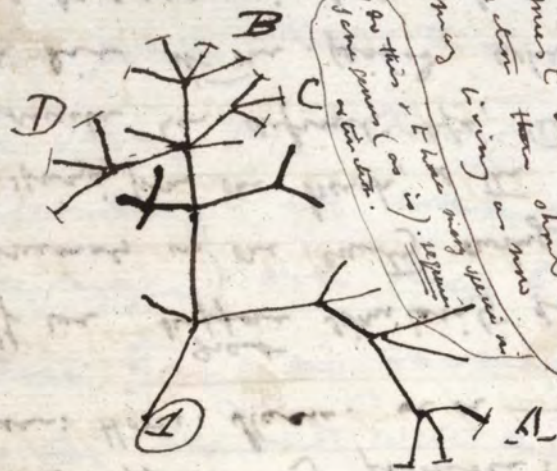
ON

OR THE

FELLOW OF THE ROYAL, GEOLOGICAL, LINNEAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. SEAGLE'S VOYAGE
ROUND THE WORLD.'

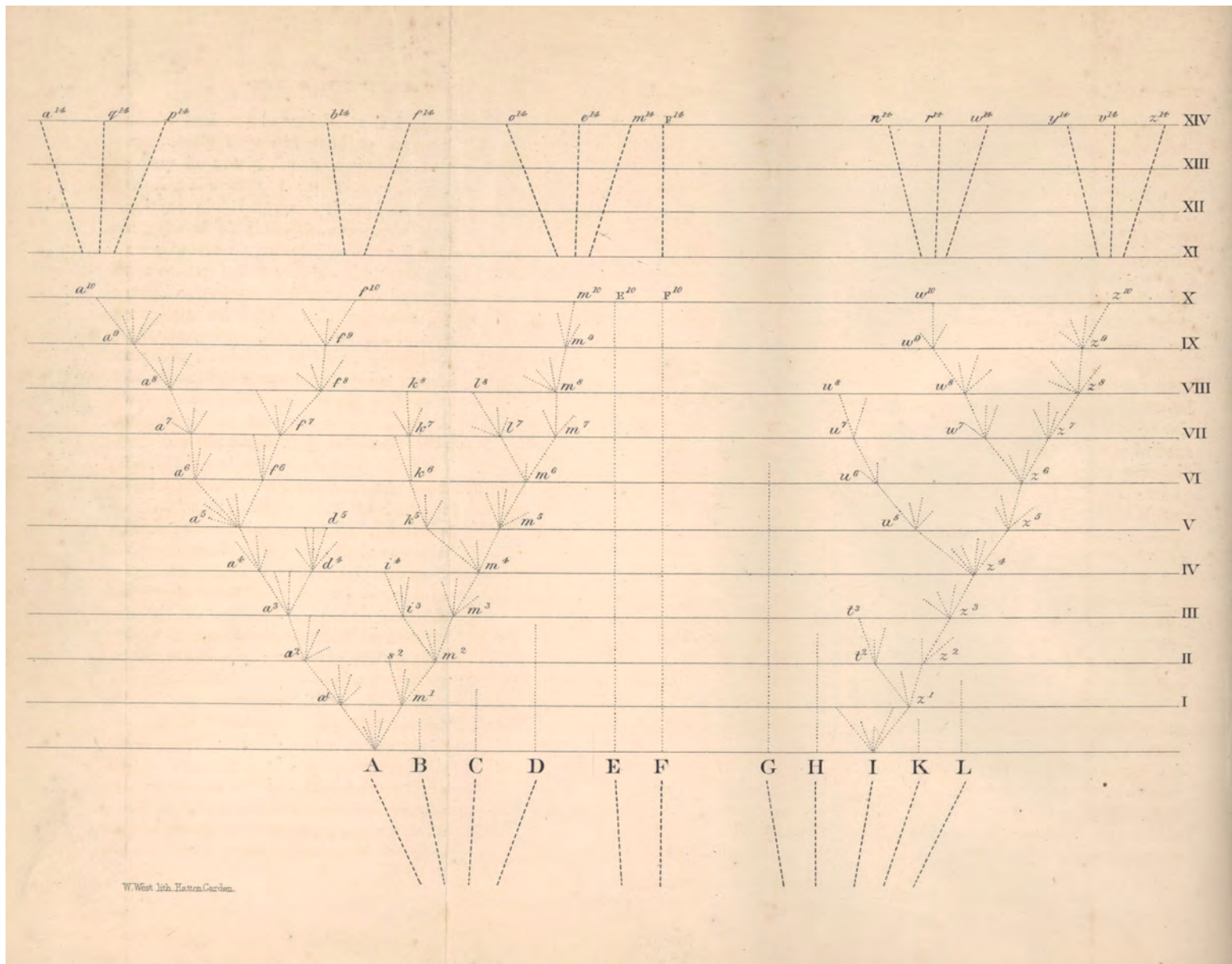
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I think



Can you be
seen from there
as you
are living in
the air
Do you think it is
a good idea
to see them
as they are?

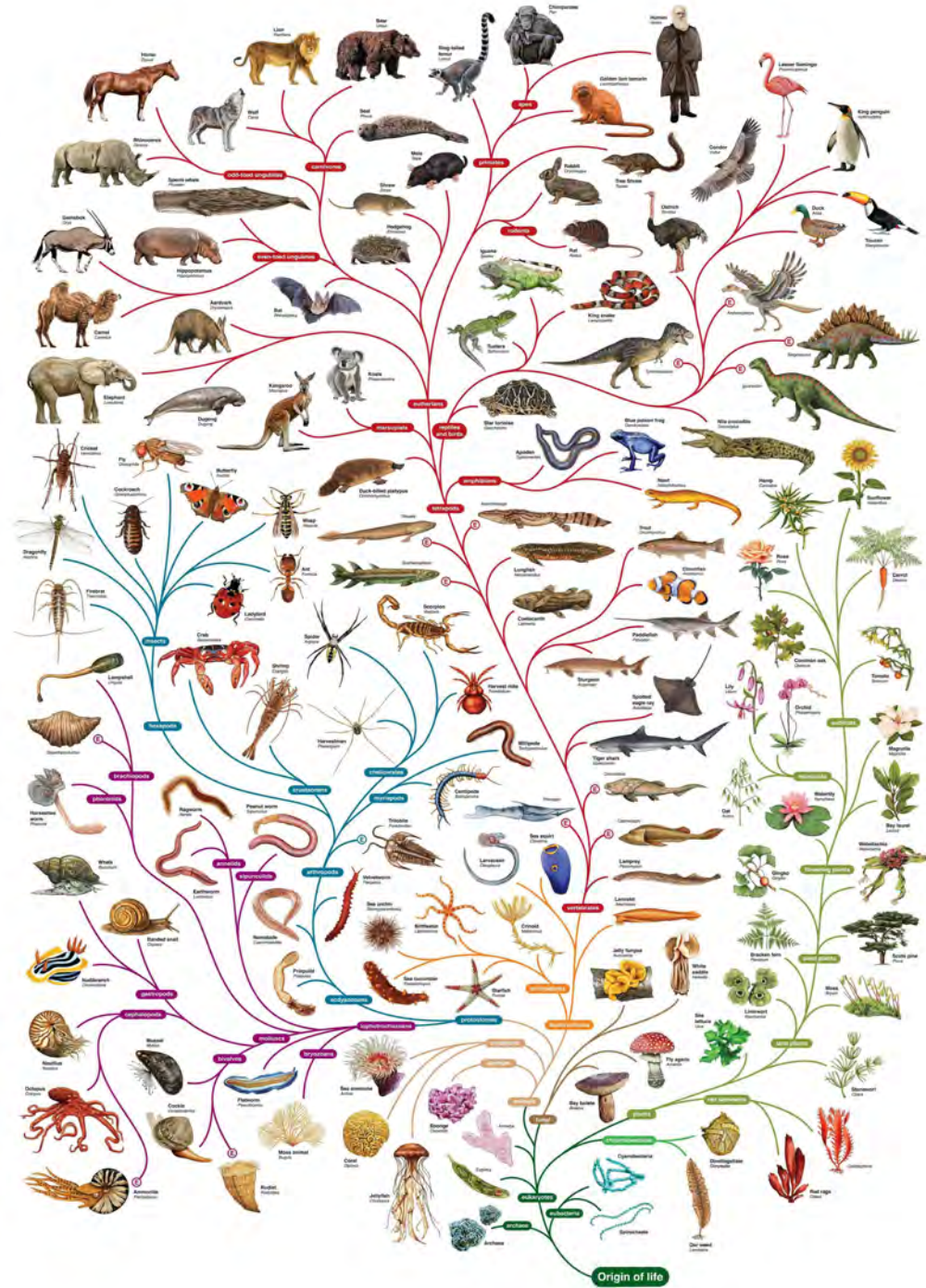
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How many described species on earth?

- A. ~500 000
- B. ~1 million
- C. ~2 million
- D. ~10 million
- E. ~ 20 million

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- E. ~ 20 million

Which of the following group of organisms have the greatest number of species?

A. Bacteria / Archea

B. Protists

C. Fungi

D. Plants

E. Animals

Which of the following group of animals have the greatest number of species?

A. Bacteria / Archea

B. Protists

C. Fungi

D. Plants

E. **Animals**

Which of the following group of animals have the greatest number of species?

A. Mammals

B. Insects

C. Flatworms (platyhelminthes)

D. Mollusks (clams, snails)

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A. Mammals

B. **Insects**

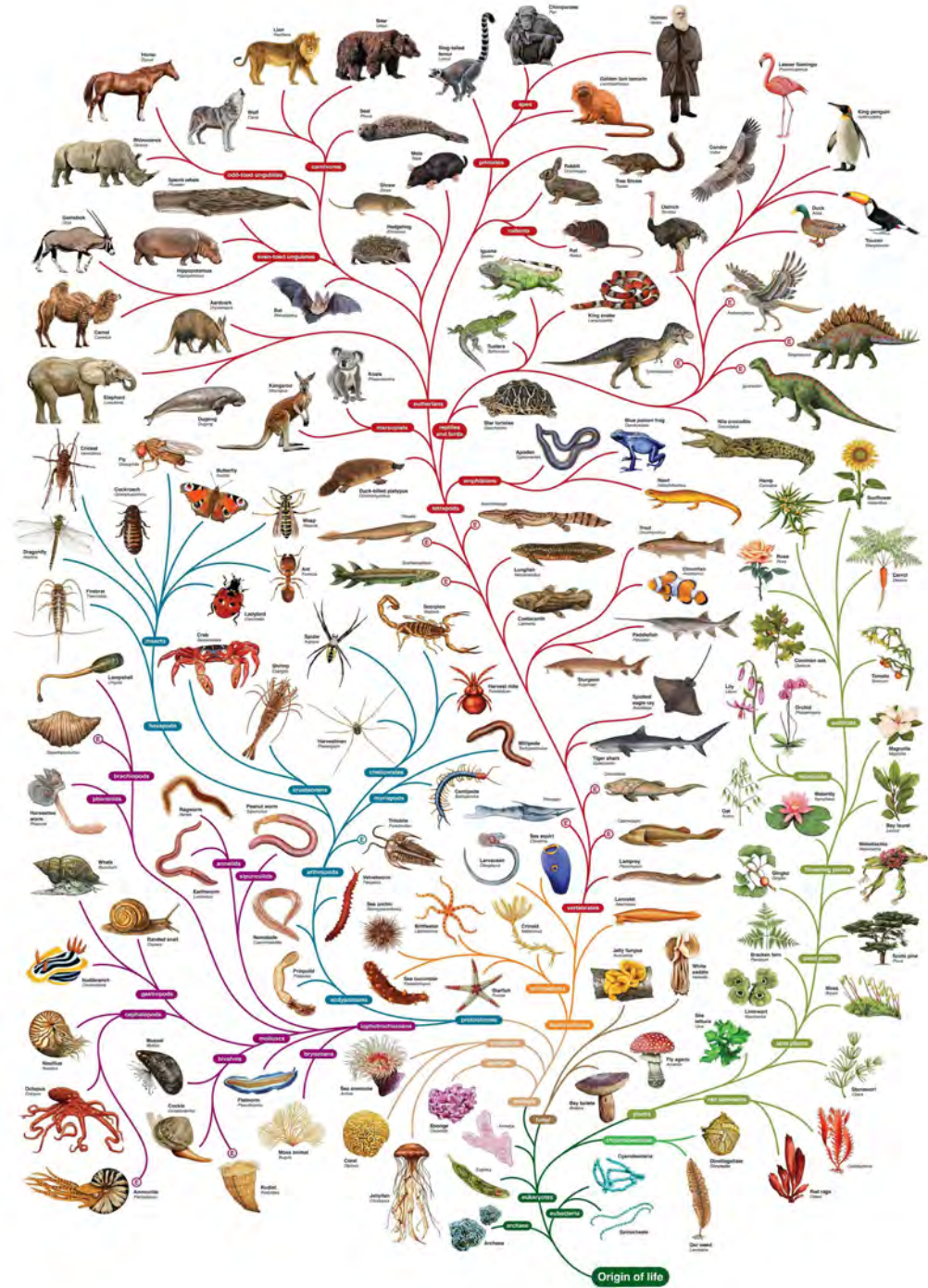
C. Flatworms (platyhelminthes)

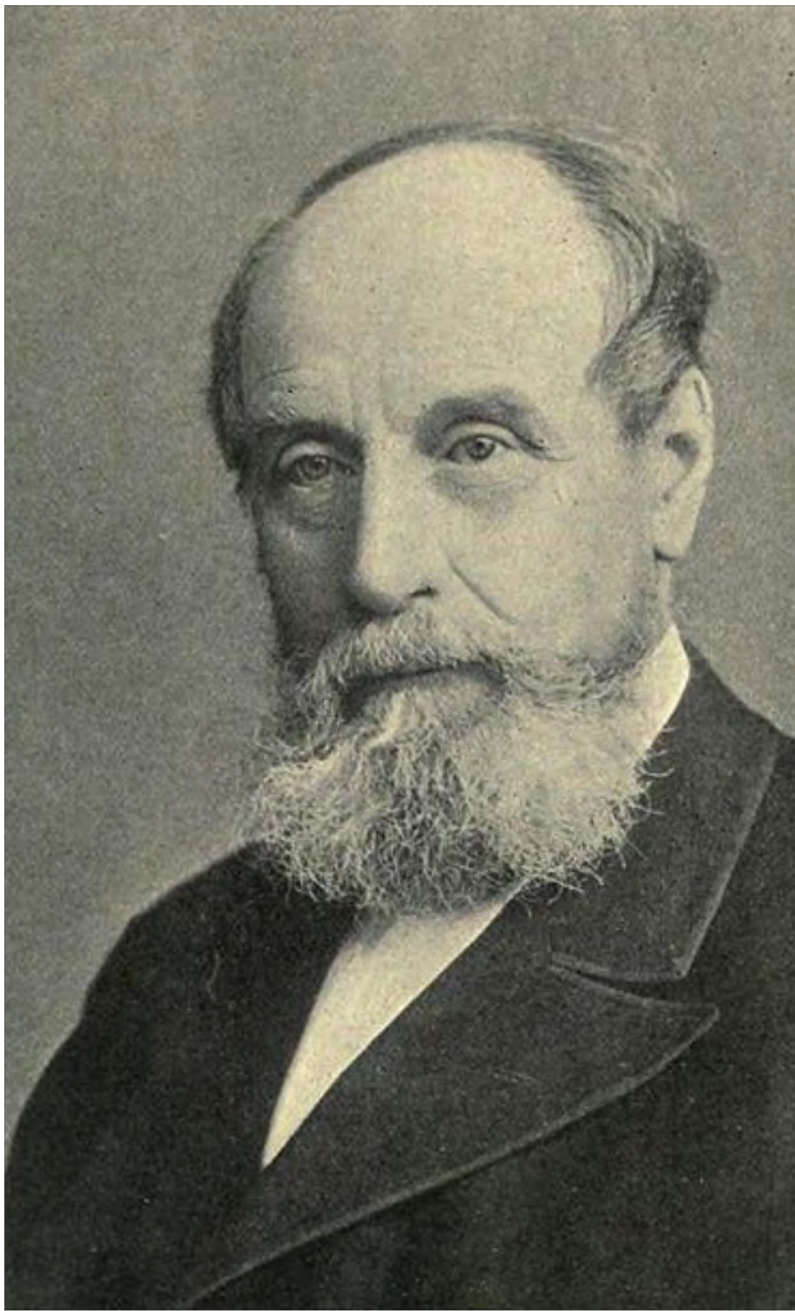
D. Mollusks (clams, snails)

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Sir John William Dawson

Down,
Beckenham, Kent.

Jan 19. 1872

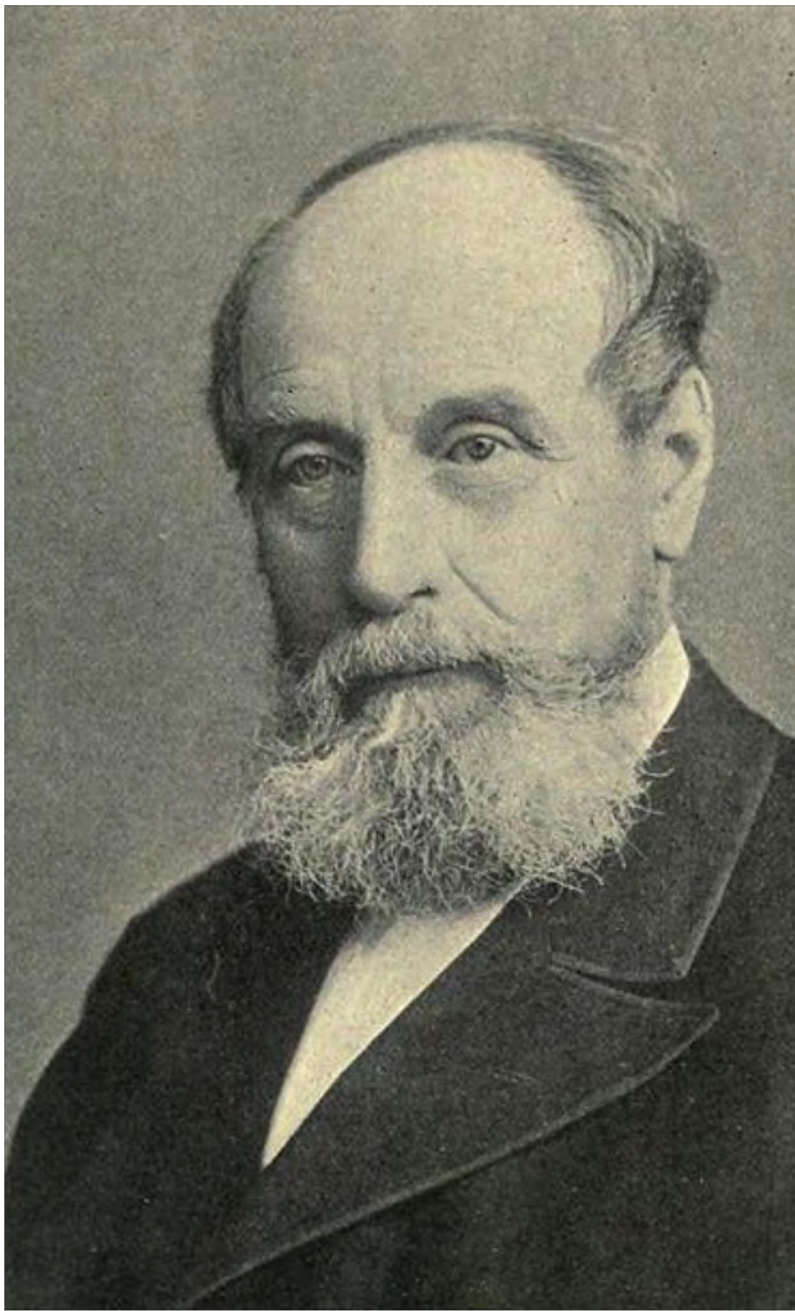
My dear Sir

I am greatly indebted
to your kindness for having
sent me yr valuable memoir
on the fossil plants of the
Devonian & Upper-Silurian
formations. When we
remember our state of
knowledge only a few years
ago, it is wonderful that

a monograph shd have
been published on the
plants of these ancient
formations.

With much respect
I remain dear Sir
yours faithfully
& M^{rs} D

Charles Darwin



One of the founders of the science of palaeobotany

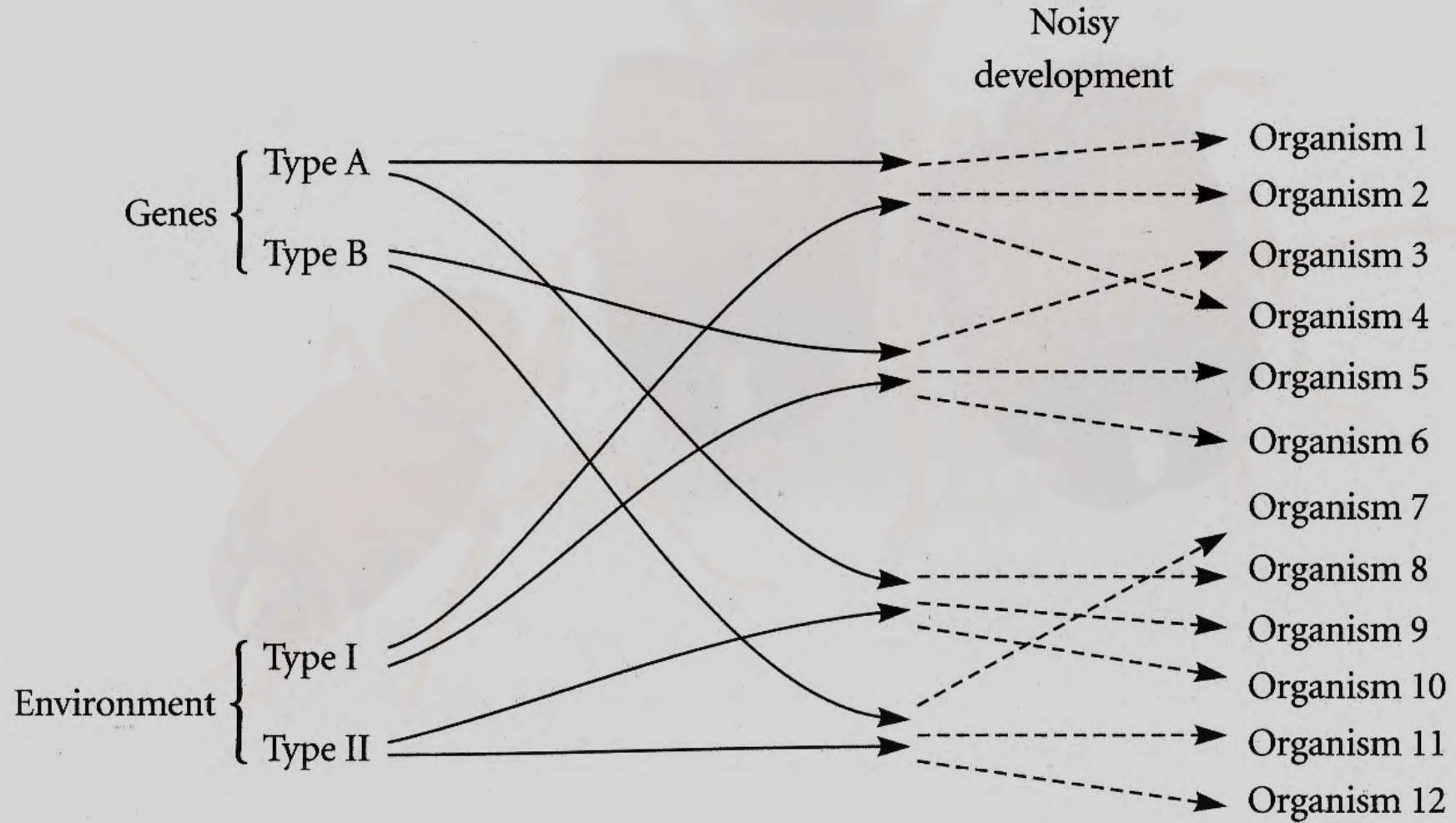
The Origin of the World, According to Revelation and Science (1877)

Facts and Fancies in Modern Science: Studies of the Relations of Science to Prevalent Speculations and Religious Belief (1882)

The Story of the Earth and Man

Sir John William Dawson

eco-evo-devo



*what are the main tenets
of eco-evo-devo?*

Discovery of genes that regulate development

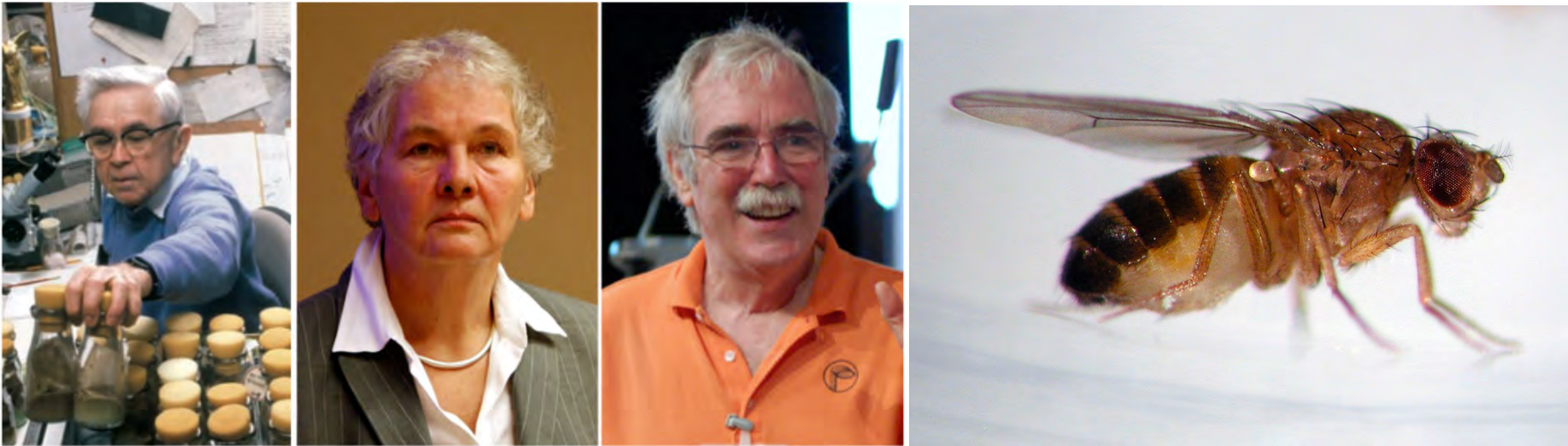


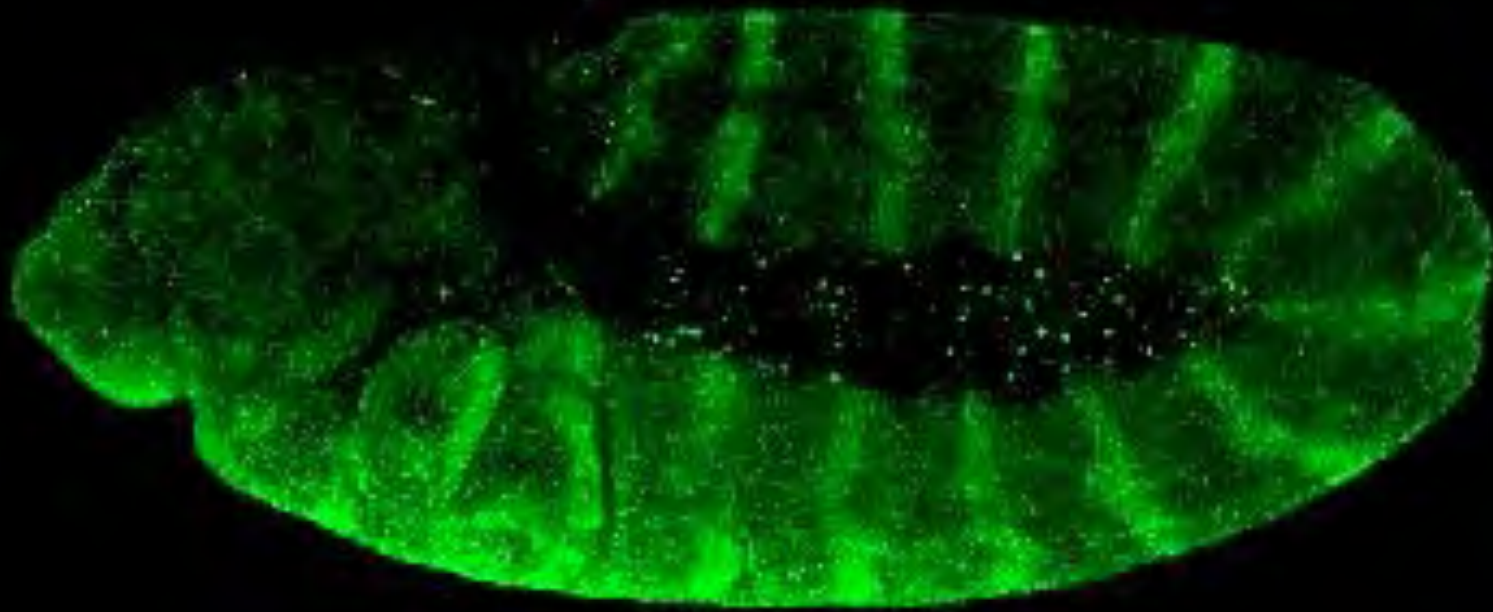
Figure 1. Edward B. Lewis (left), Christiane Nüsslein-Volhard (middle) and Eric F. Wieschaus (right).

Left: Reprinted by permission from Genetics Society of America: *Genetics*, Crow, J.F. and Bender, W., Edward B. Lewis, 1918-2004. *Genetics* 168, 1773-1783. Copyright 2004

Middle: photograph by Rama, Wikimedia Commons, Cc-by-sa-2.0-fr;
http://commons.wikimedia.org/wiki/Christiane_N%C3%BCsslein-Volhard

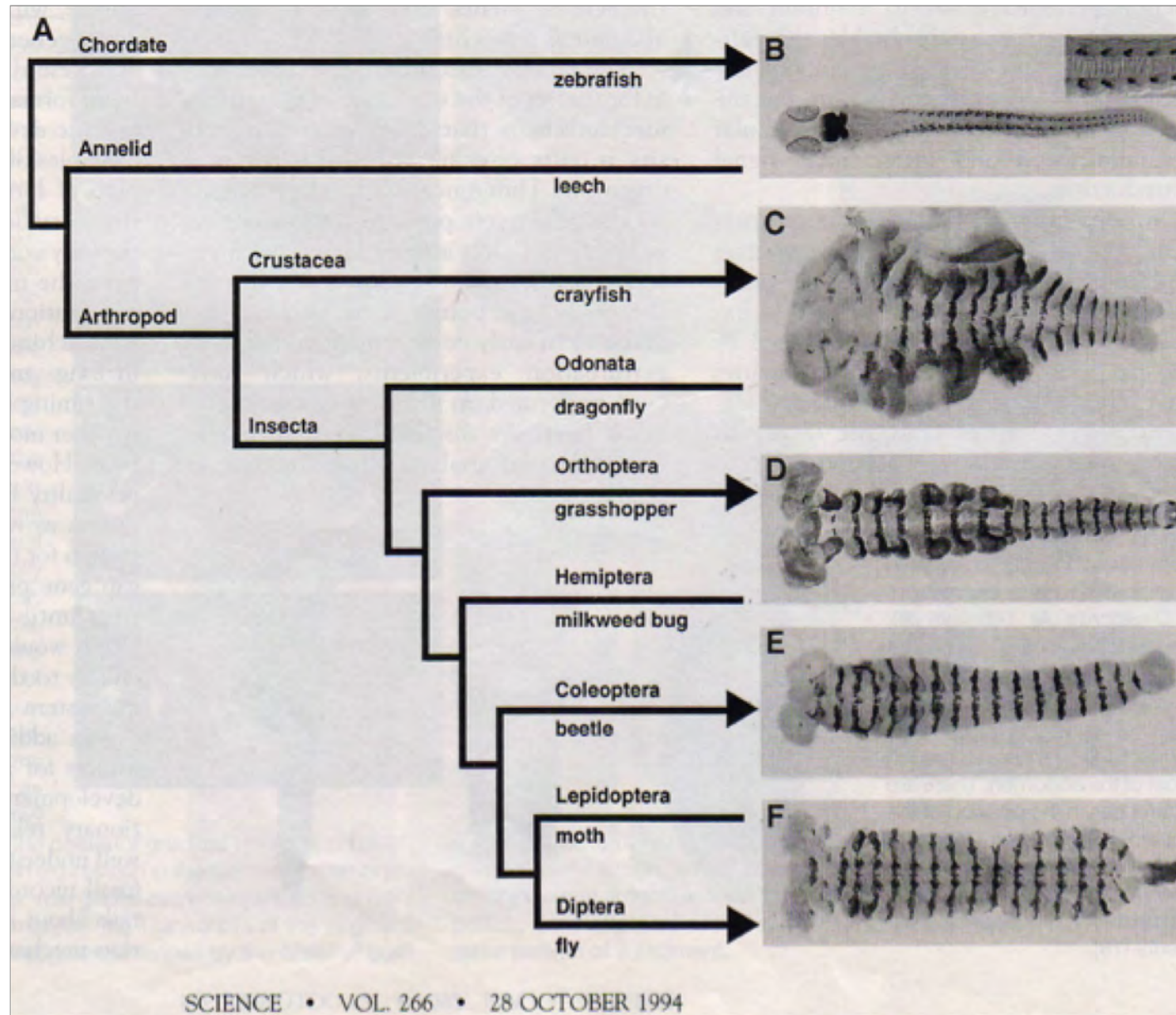
Right: photograph by Matthias Kubisch, Wikimedia Commons.
http://commons.wikimedia.org/wiki/Category:Eric_F._Wieschaus

engrailed
a segment polarity gene



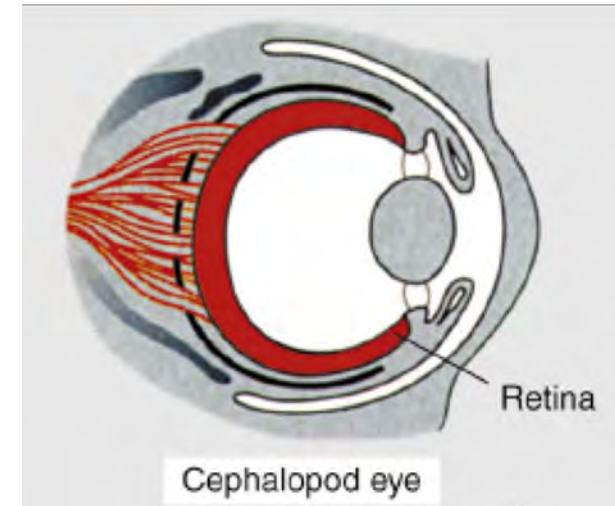
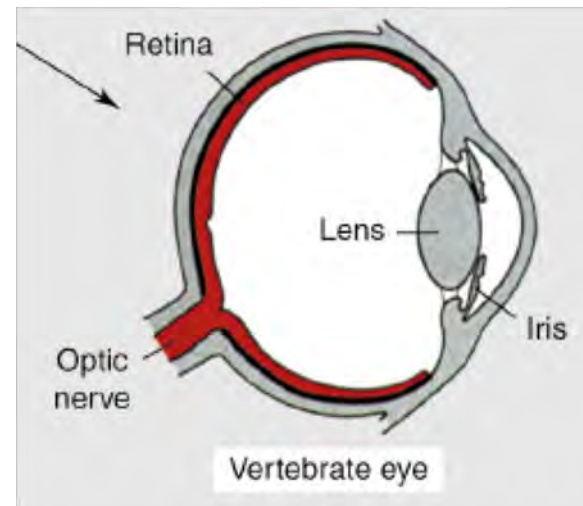
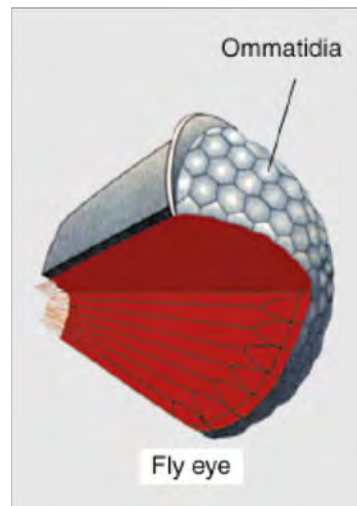
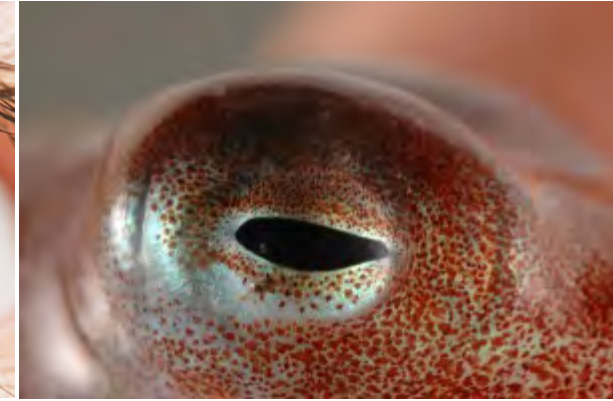
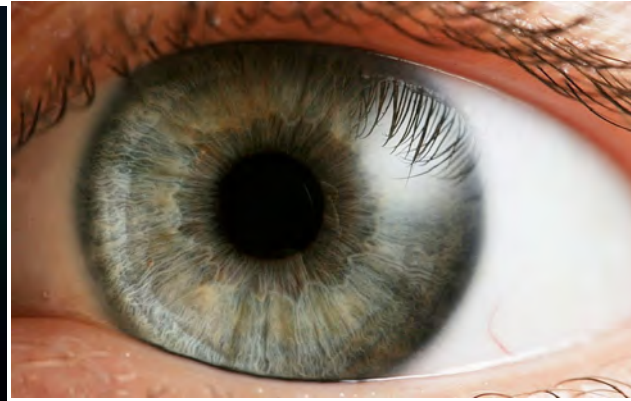
expression and function is highly
conserved across all animals

engrailed is highly conserved



Pax6/eyeless gene

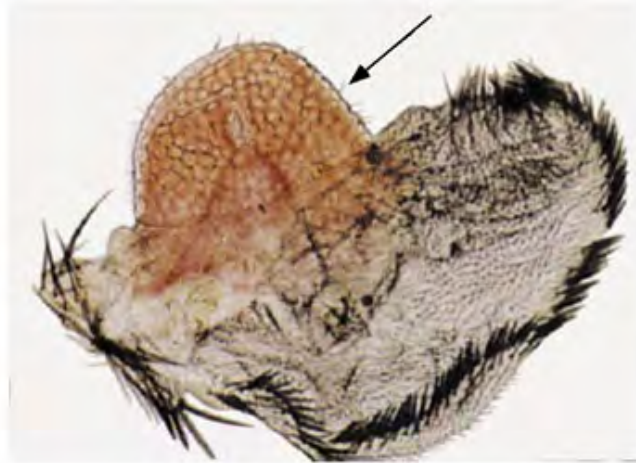
an eye development gene



Pax6/eyeless gene is highly conserved



Normal Wing



**Wing Mis-expressing
Mouse *pax6* Gene**

changes in sequence, expression,
function, and number lead to
evolution of form and function

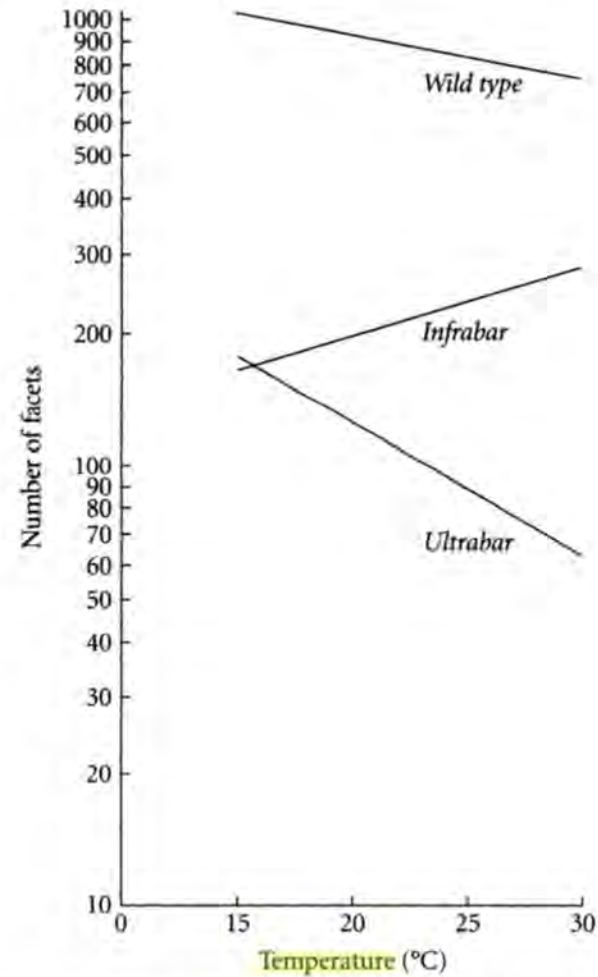
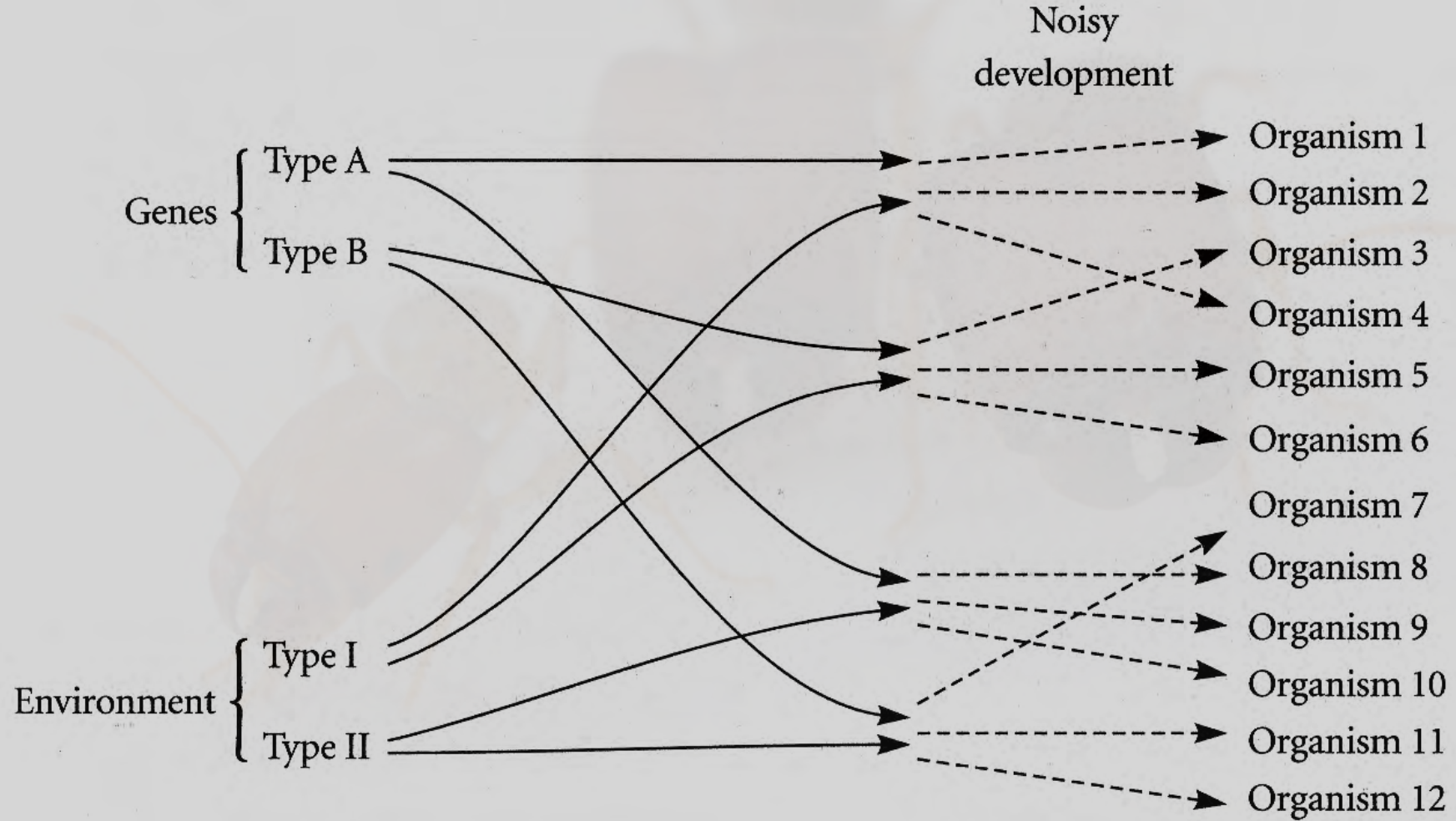


Figure 1.9. The size of the eye, measured by the number of cells (facets), as a function of temperature, for normal wild-type *Drosophila* and two mutant forms, Infrabar and Ultrabar.

From *An Introduction to Genetic Analysis* by Suzuki et al., © 1996, 1993, 1989, 1985, 1981, 1976 by W. H. Freeman and Company. Used with permission.

eco-evo-devo







Ants are Eusocial

cooperation



photos © Alex Wild

Ants are Polyphenic



photo © Alex Wild

Environment

nutrition
temperature
social interactions

Genome

The Question that Stumped Darwin

ANTS & EVOLUTION



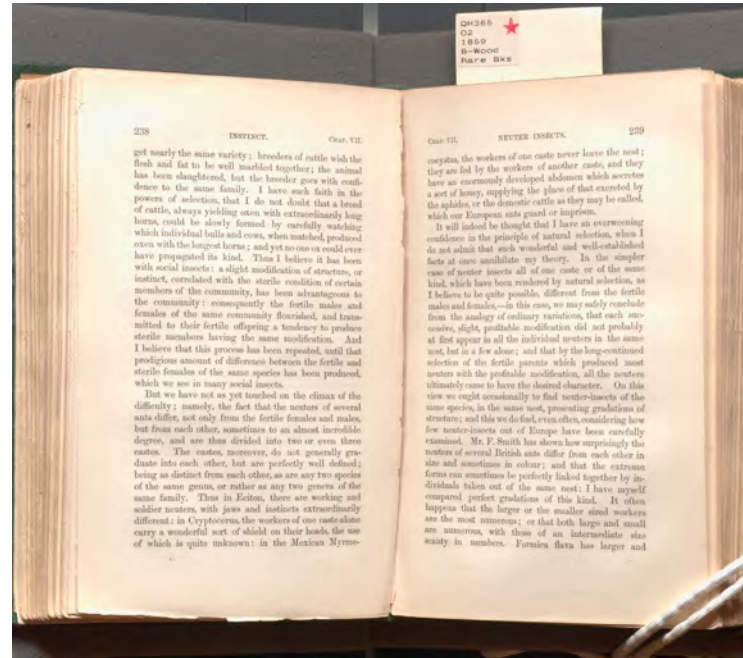
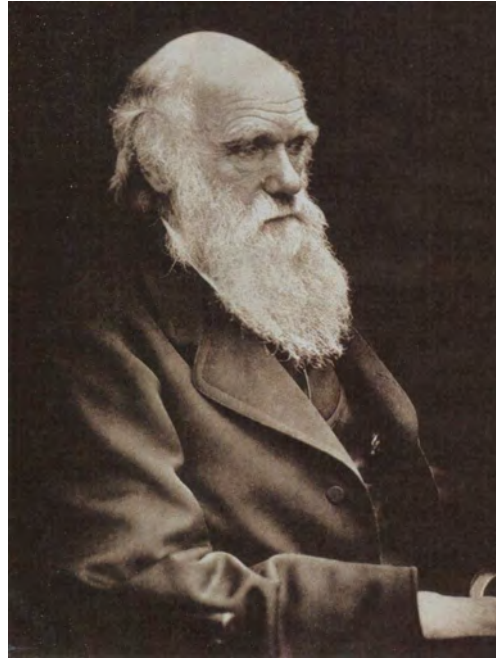
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Darwin 1859 (pages: 257-263):



... But we have not as yet touched on the climax of the difficulty; namely, the fact that the neuters of several ants differ, not only from the fertile males and females, but from each other, sometimes almost to an incredible degree, and thus are divided into two or even three castes.”

A Major Transition in Ant Evolution



A Major Transition in Ant Evolution



A Major Transition in Ant Evolution



My Collaborators



Professor Diana Wheeler
University of Arizona



Christian Metz
OldGermanPapers.com

Pheidole



Ancestral Developmental Potential Facilitates Parallel Evolution in Ants

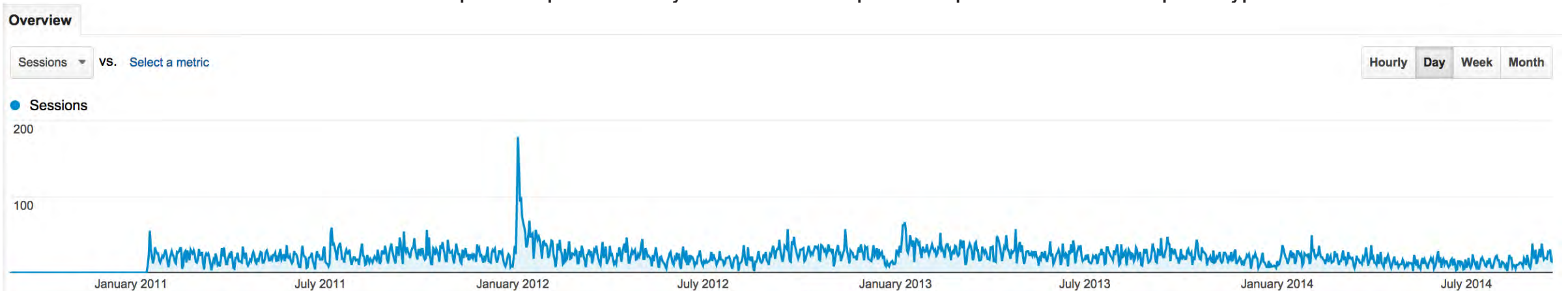
Rajendhran Rajakumar,¹ Diego San Mauro,^{1*} Michiel B. Dijkstra,^{1†} Ming H. Huang,²
Diana E. Wheeler,² Francois Hiou-Tim,¹ Abderrahman Khila,^{1‡}
Michael Cournoyea,^{1§} Ehab Abouheif^{1||}

Complex worker caste systems have contributed to the evolutionary success of advanced ant societies; however, little is known about the developmental processes underlying their origin and evolution. We combined hormonal manipulation, gene expression, and phylogenetic analyses with field observations to understand how novel worker subcastes evolve. We uncovered an ancestral developmental potential to produce a “supersoldier” subcaste that has been actualized at least two times independently in the hyperdiverse ant genus *Pheidole*. This potential has been retained and can be environmentally induced throughout the genus. Therefore, the retention and induction of this potential have facilitated the parallel evolution of supersoldiers through a process known as genetic accommodation. The recurrent induction of ancestral developmental potential may facilitate the adaptive and parallel evolution of phenotypes.

Ancestral Developmental Potential Facilitates Parallel Evolution in Ants

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McGill Scientists Create Monster Ants

**NationalPost: Super soldier'
ants created at McGill**

BBC: Ants turned into 'supersoldiers'

Nature: Return of the super ants

PBS: Honey, I Blew Up the Ants

Scientific American: Scientists Make Supersoldier Ants

McGill Scientists Create Monster Ants

The Telegraph: Frankenstein ants created by scientists

**WebProNews: Giant-Headed Supersoldier Ants
Protect The Colony, Haunt My Nightmares**

The Week: New York's 'horrific' supersoldier ants

Pheonixnewtimes: We're Doomed: Scientists Create "Supersoldier" Ants with Jaws

**DailyMail: Welcome to a brave new world: Genetic scientists
create freakish man-made monster ants with huge heads and
jaws**

Read more: <http://www.dailymail.co.uk/sciencetech/article-2082799/Supersoldier-ants-gigantic-jaws.html#ixzz2AQSUbo2l>

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Pheidole



Pheidole in the New World

A DOMINANT, HYPERDIVERSE ANT GENUS

Edward O. Wilson



supersoldiers naturally produced in
at least 8 *Pheidole* species!



Pheidole in the New World

A DOMINANT, HYPERDIVERSE ANT GENUS

Edward O. Wilson



Pheidole in the New World

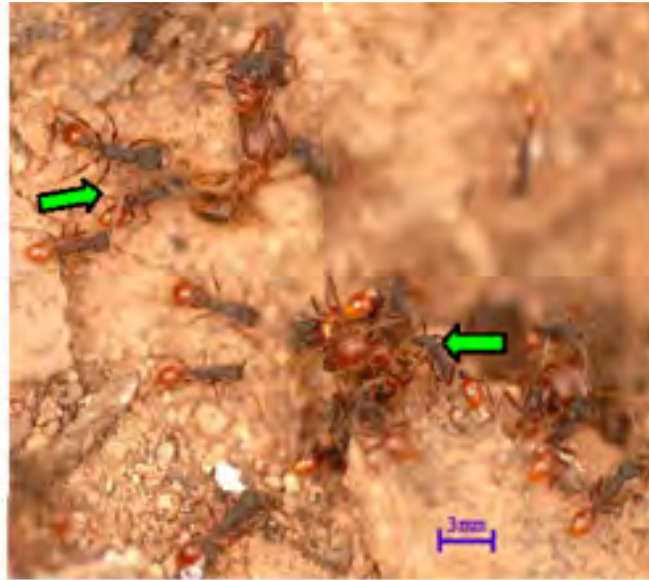
A DOMINANT, HYPERDIVERSE ANT GENUS

Edward O. Wilson



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Defend against Army Ant Raids!



Huang 2009



3mm

Huang 2009

B



Huang 2009



3mm
Huang 2009



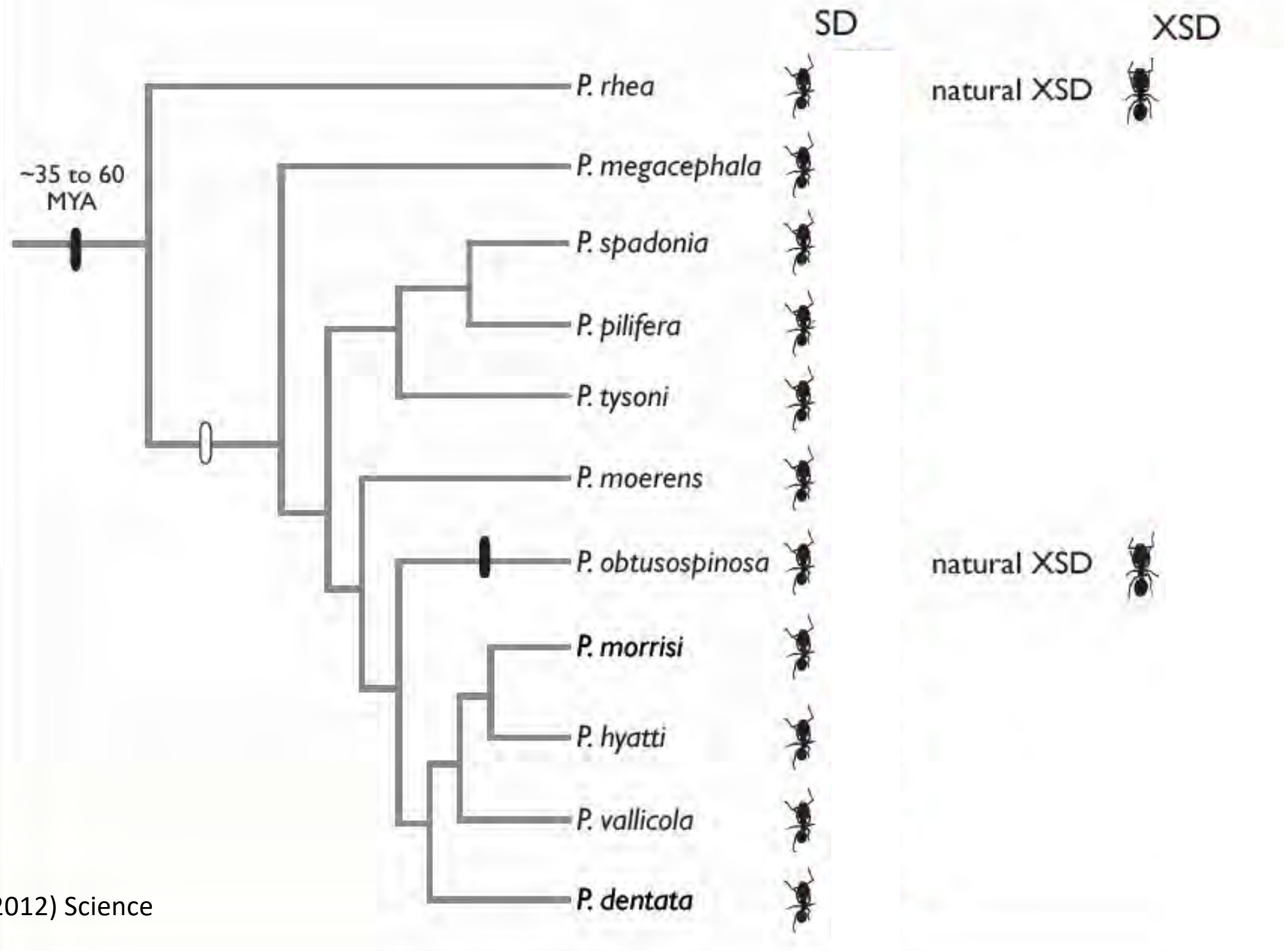
Pheidole morrisi

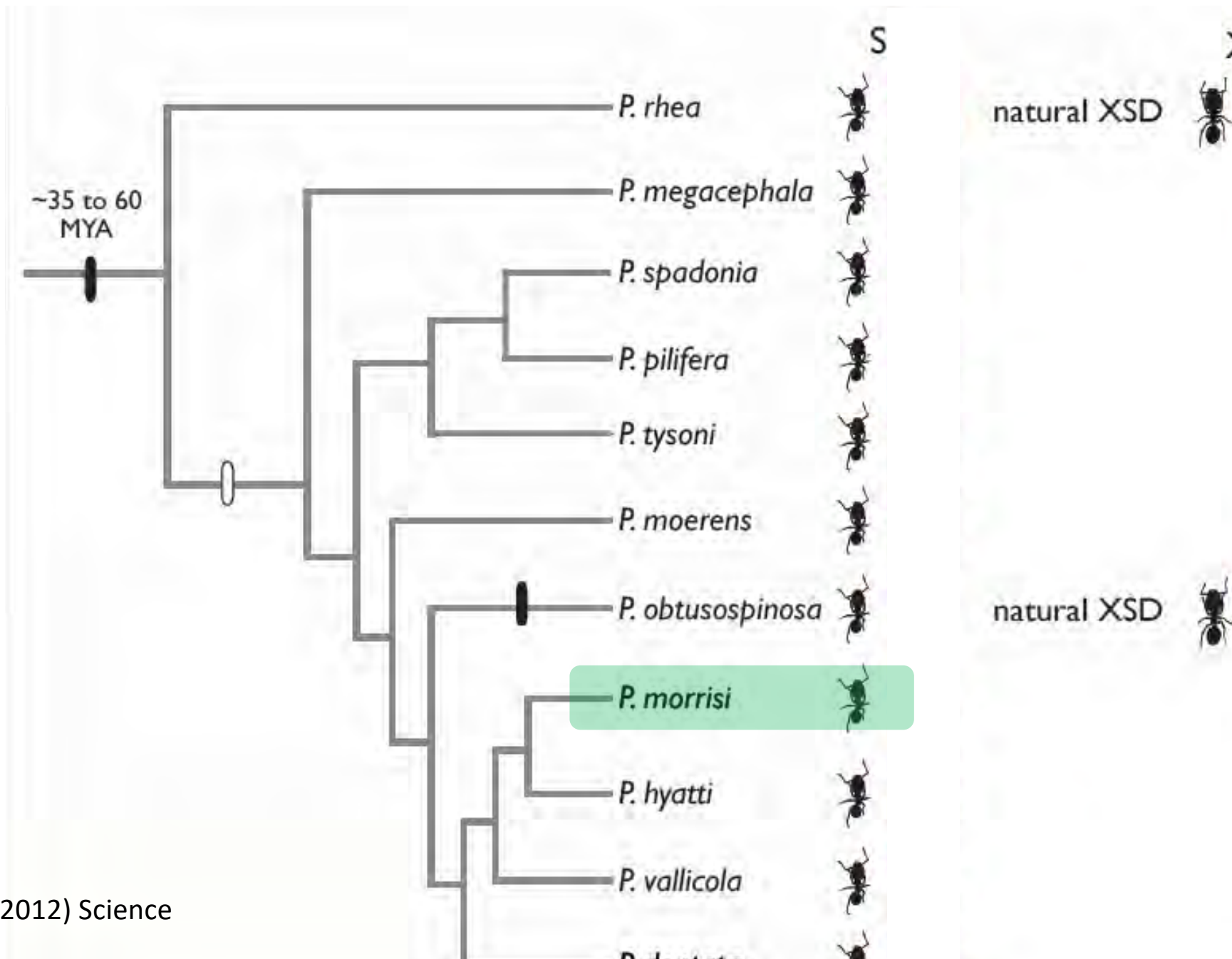


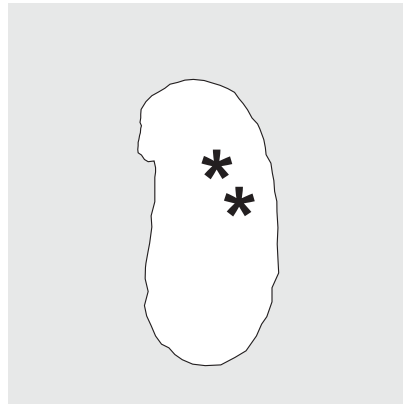
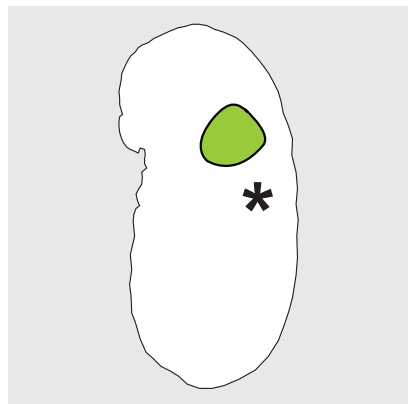


species are disappearing!





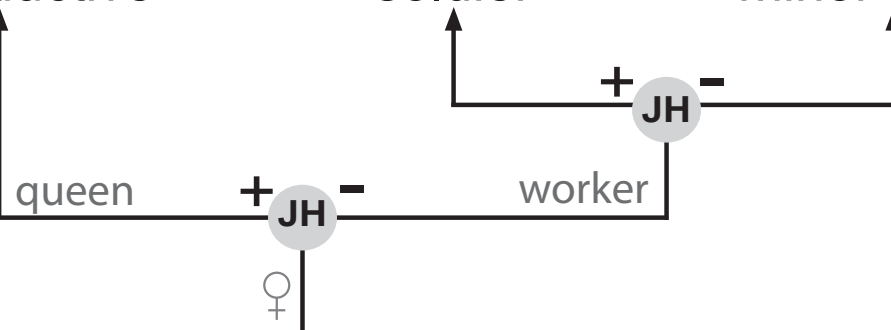


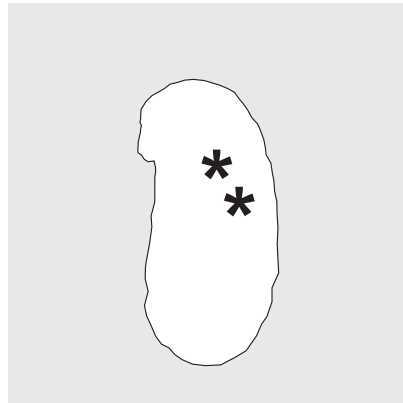
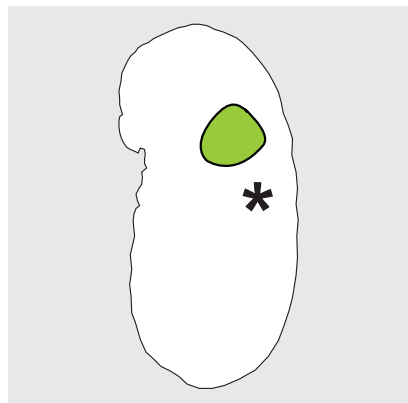


reproductive

soldier

minor worker





reproductive

soldier

minor worker

queen

+

JH

-

worker

+

JH

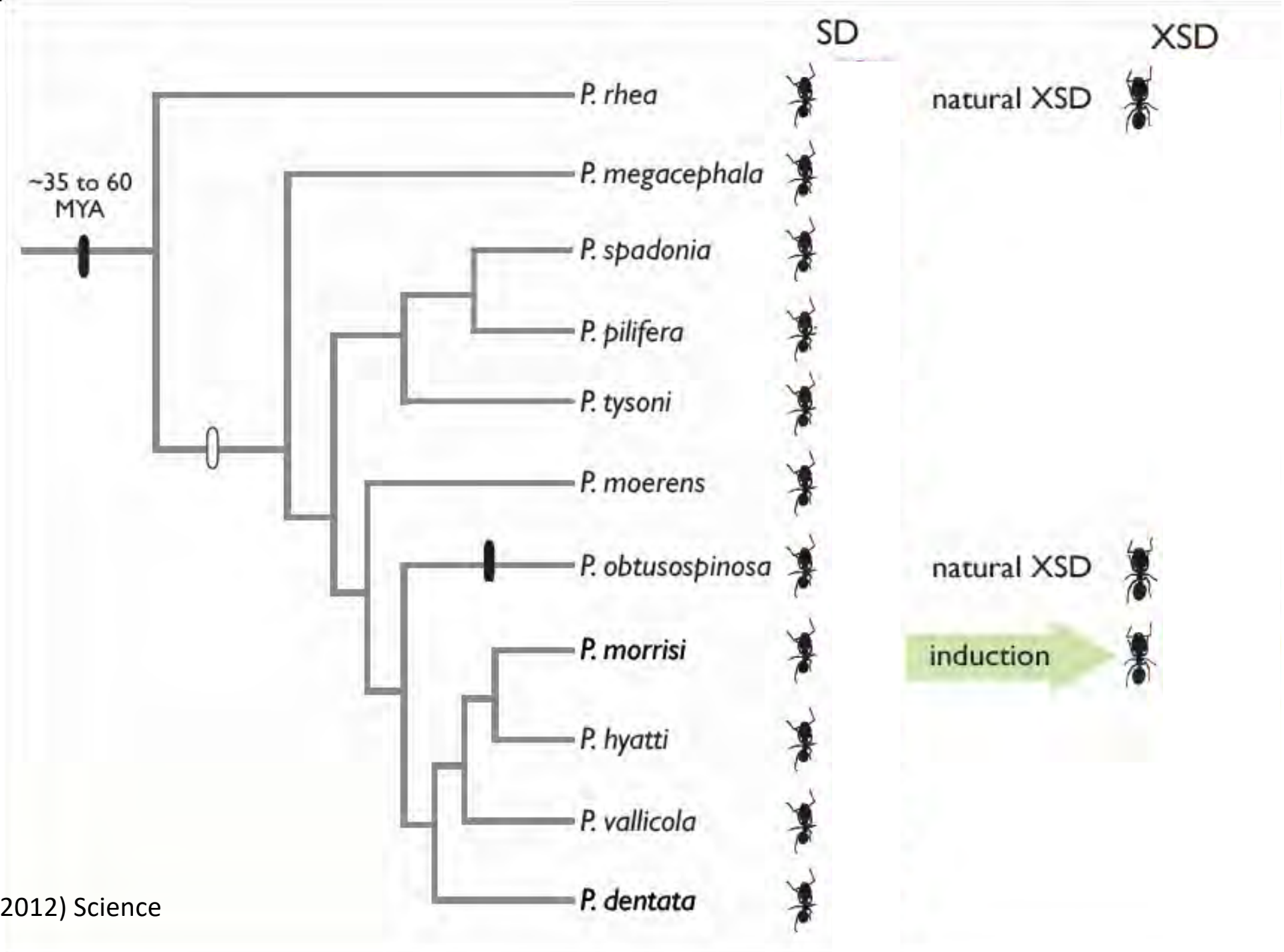
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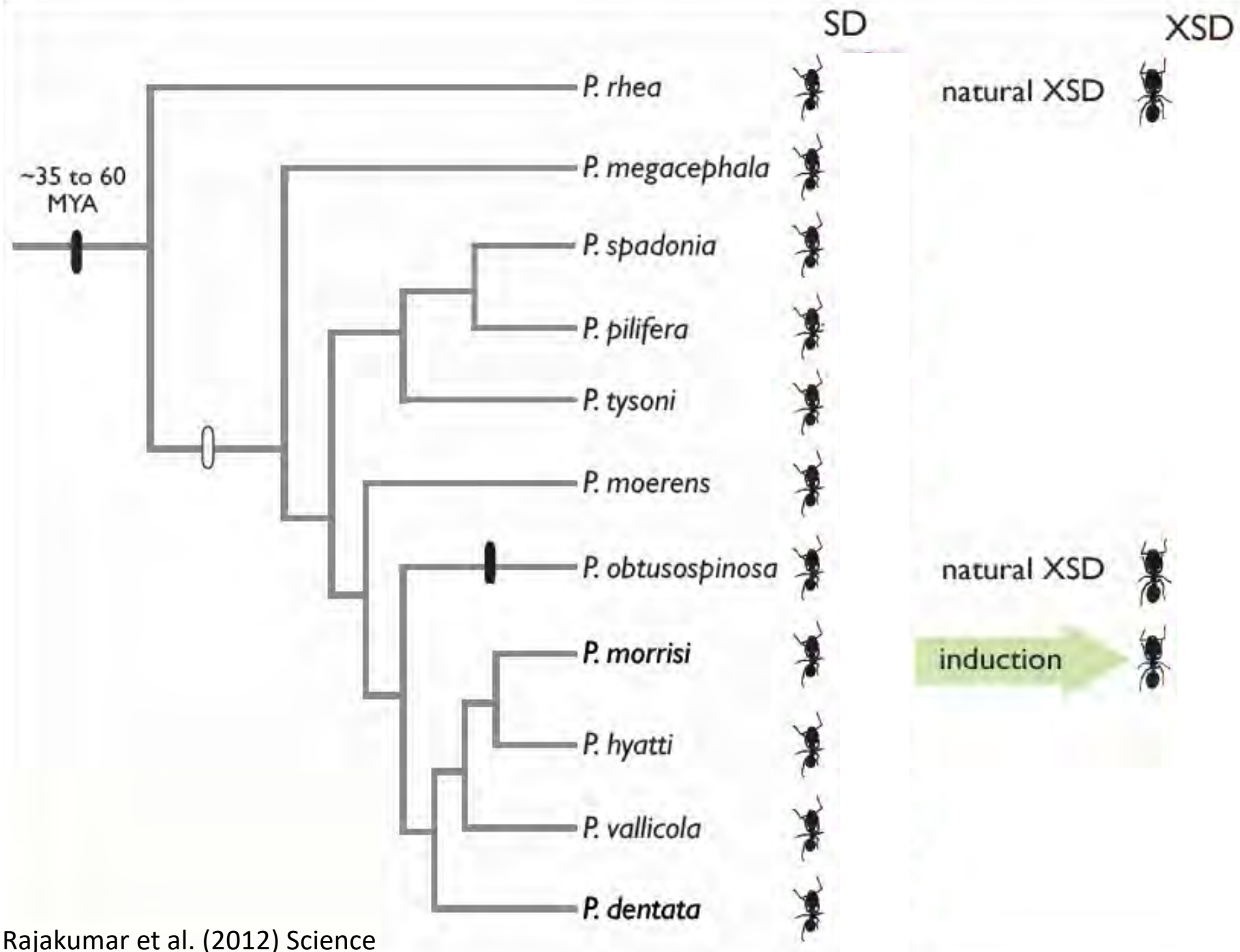
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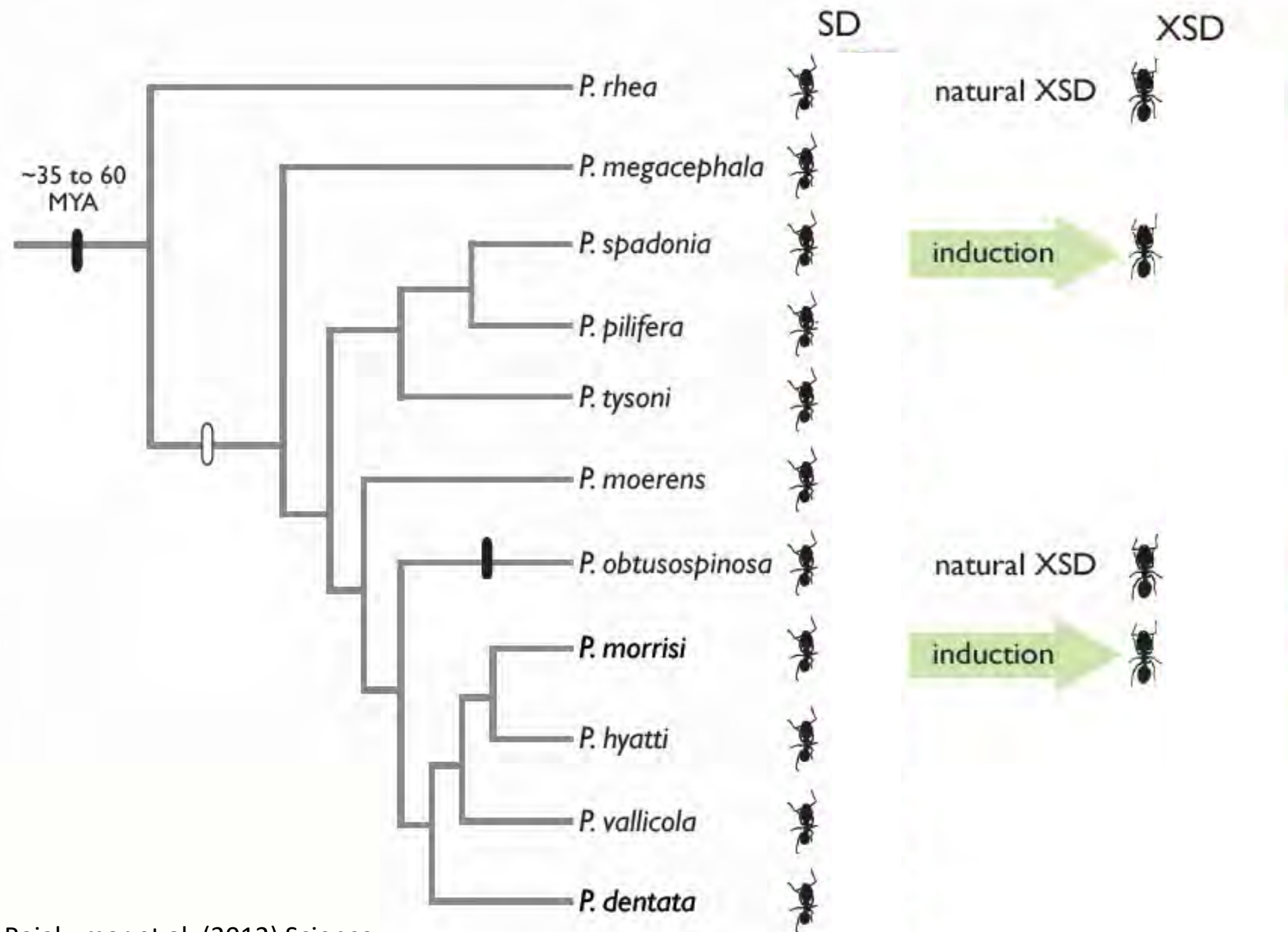


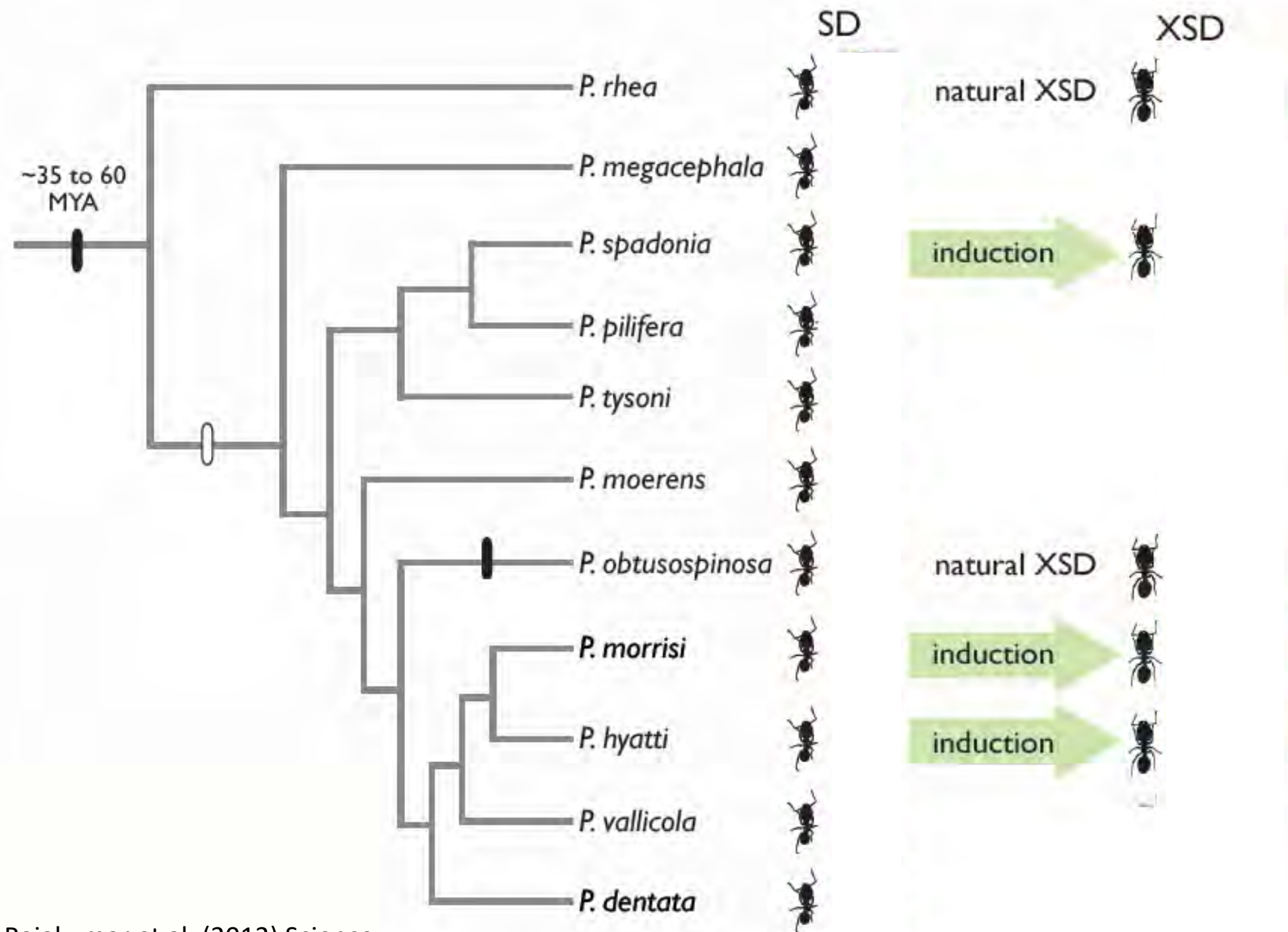
soldier

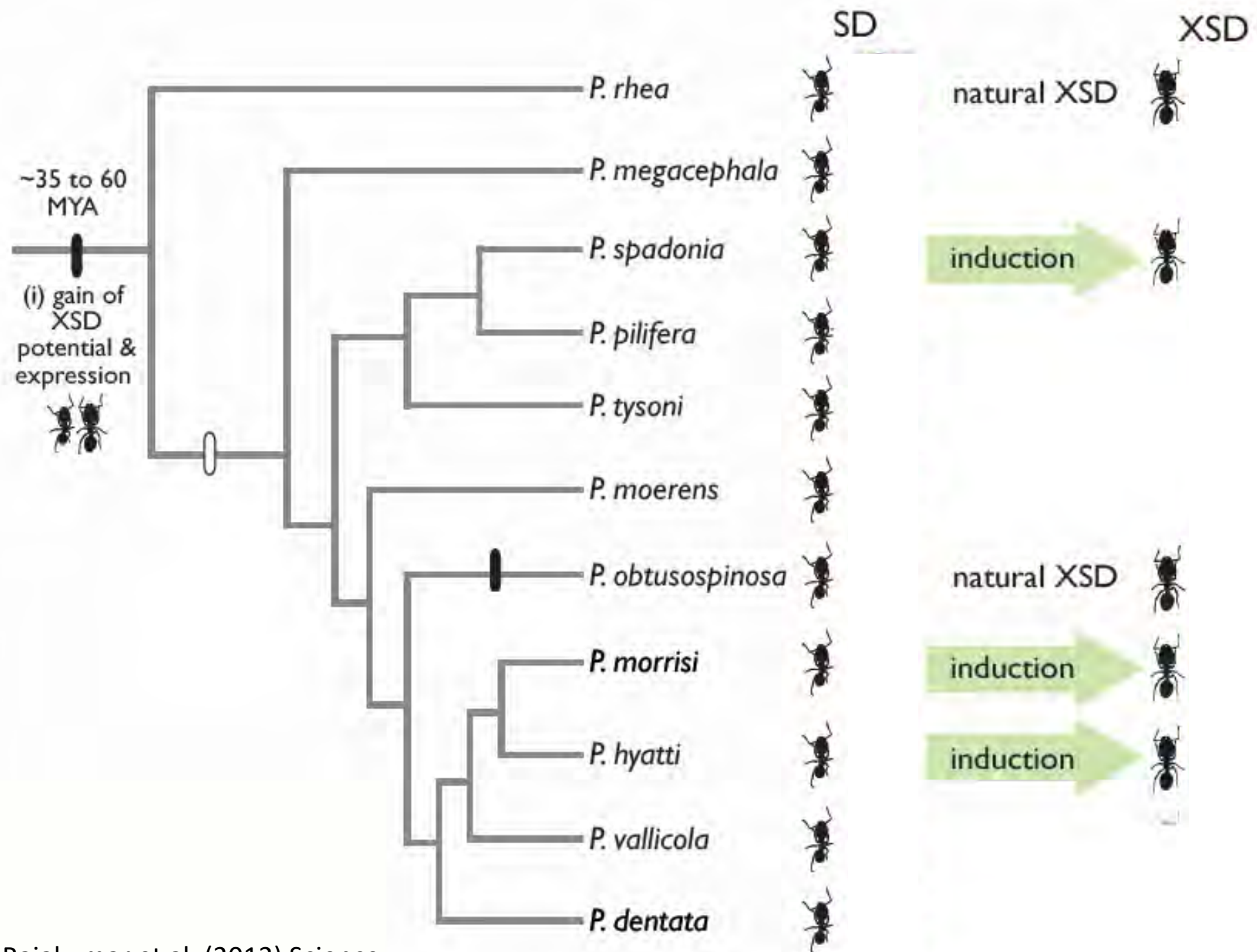
supersoldier

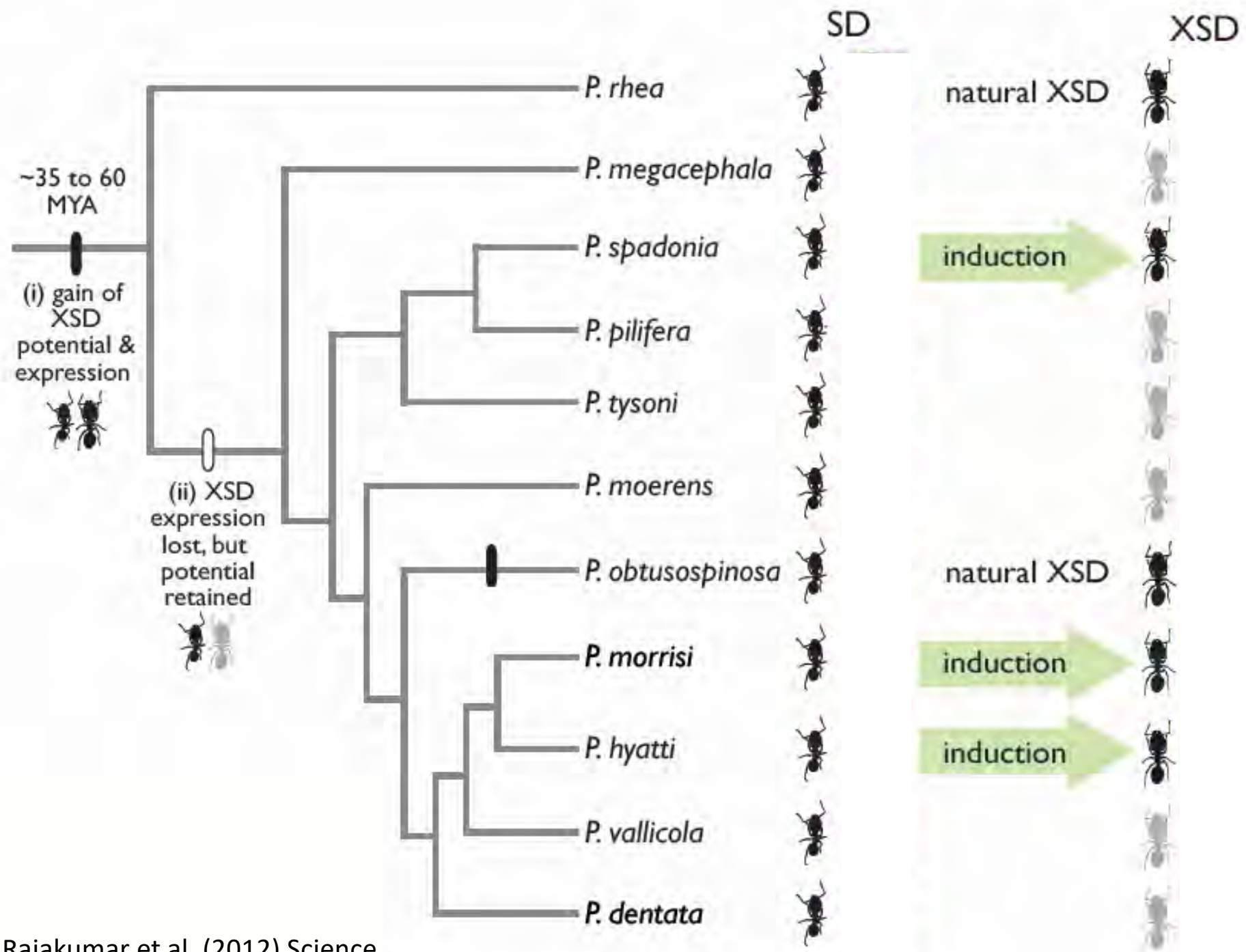


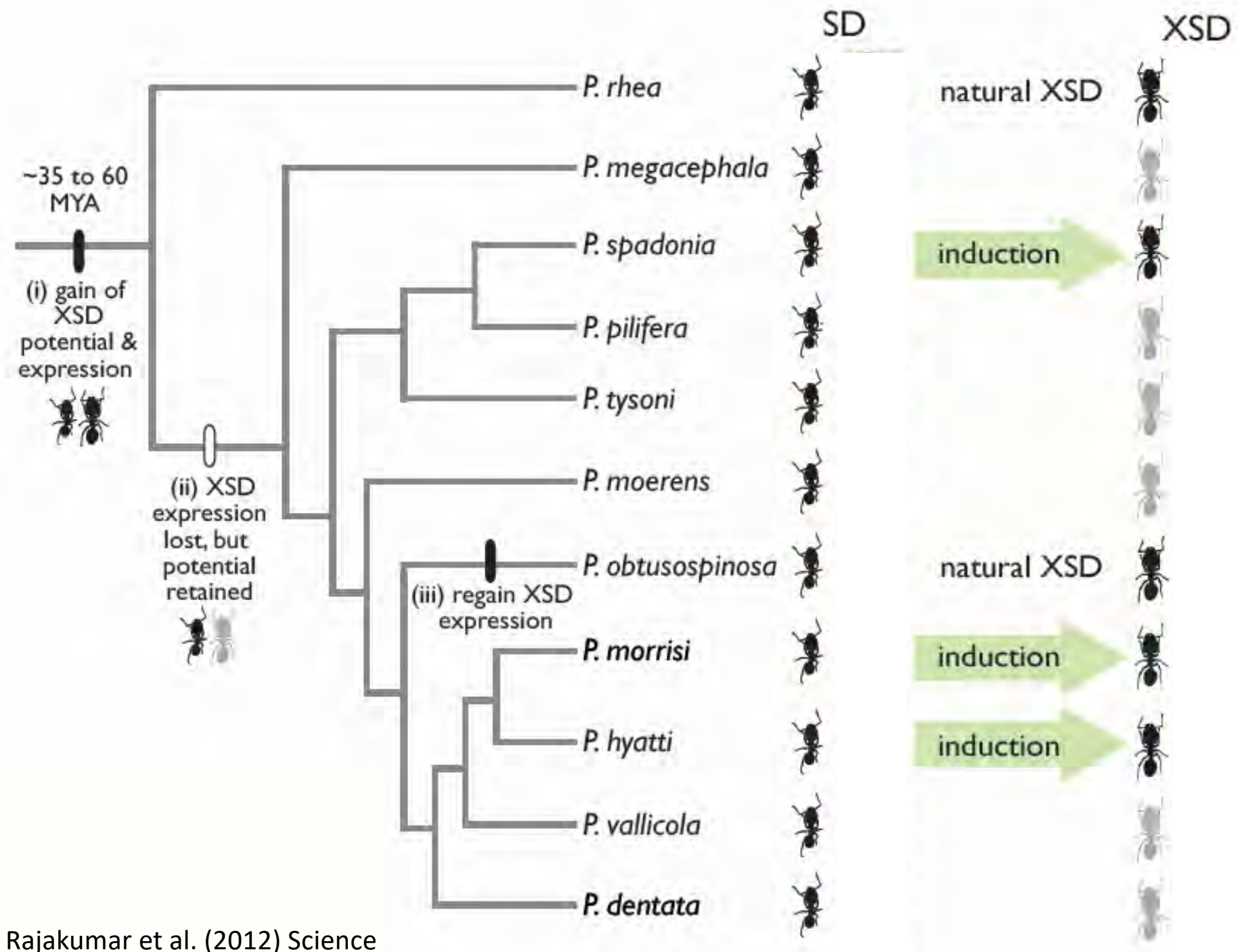












Neuartige Termitensoldaten aus Kunstnestern.

VON WILHELM GOETSCH, Breslau.

(Mit 3 Abbildungen.)

Eingeg. 6. Oktober 1923.

Bei den Termiten kommen in der Hauptsache zwei Arten von Soldaten vor; zunächst die normalen Soldaten oder »Kiefer-Soldaten«, bei welchen die Köpfe und Mandibeln stark vergrößert sind, und zweitens die »Nasen-Soldaten« (Nasuti) mit riesiger Stirndrüse, die ihre Öffnung am Ende eines langen, nasenartigen Zapfens besitzt. Bei den Nasensoldaten sind die Kiefer im allgemeinen völlig rückgebildet. Eine Ausnahme machen neben den ganz anders organisierten »Gabel-Nasuti« von *Rhinotermes* einige Arten der Gattung *Armitermes*, bei welchen lange, schmale gezähnte Kiefer vorkommen und sich unter der »Nase« stark überkreuzen (*Armitermes neotenicus* HOLMGR.).

Wilhelm Goetsch 1937 and 1939

W. Goetsch, Neuartige Termitensoldaten aus Kunstnestern. 209

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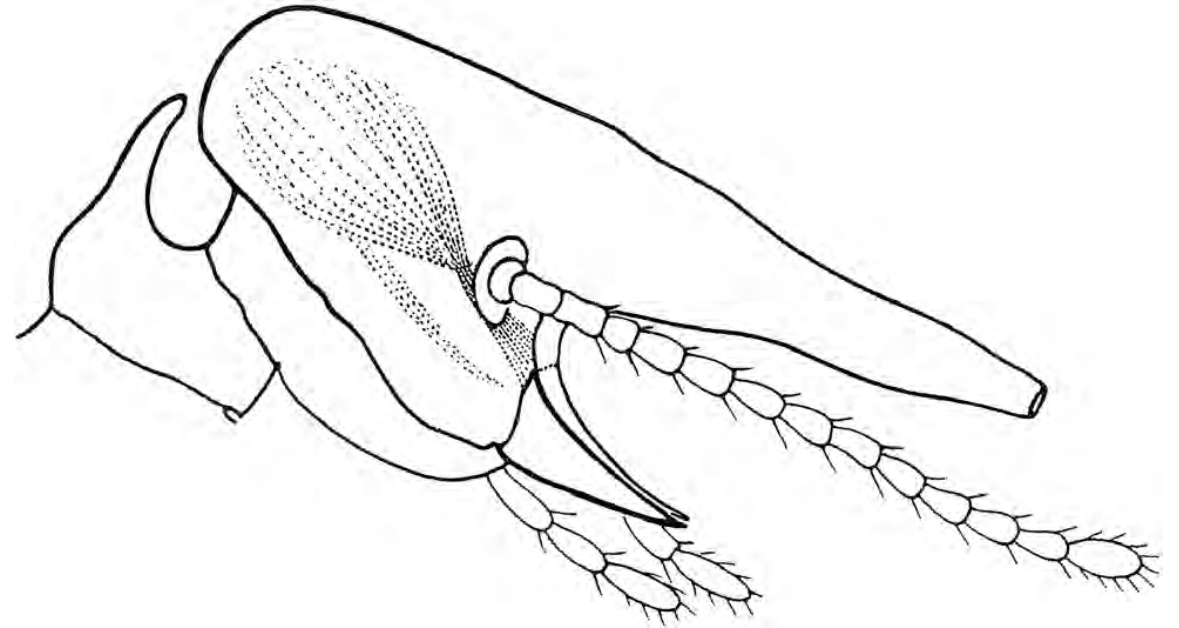
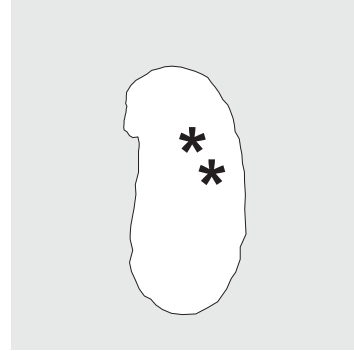
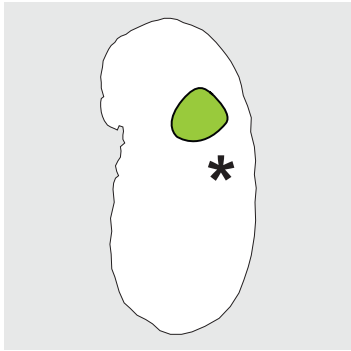
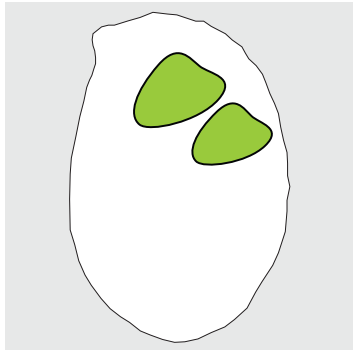


Fig. 1: Head of a soldier of *Anoplotermes cingulatus* (n. var.), attained in an artificial nest. (In the wild, all *Anoplotermes* species are invariably devoid of soldiers.)

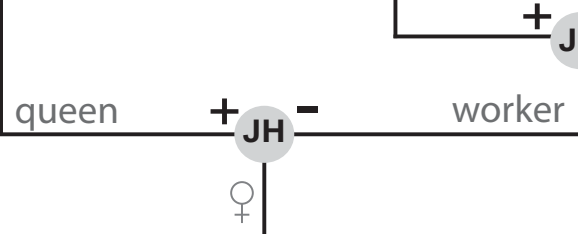
1942, LIGHT 1943). GREGG's (1942) discussion of GOETSCH's (1939a) discovery is particularly insightful: "It would mean that although soldiers do not appear in normal wild colonies and are supposed to have dropped out phylogenetically, their genes are in reality still retained by the species. This can be reinterpreted in favor of environmental control by assuming that, while genes are admittedly present, some change in the physiological thresholds in the particular colony has in part enabled them to come to expression. The anomaly might also be interpreted as the result of phylogenetically suppressed genes which cause the degeneration of certain characters (in this case the soldier caste), but which have not been entirely lost because of other vital influences in the termite colony."



reproductive

soldier

minor worker



Die Entstehung der „Soldaten“ im Ameisenstaat.

Von W. GOETSCH, Breslau.

Bei manchen Ameisenarten sind die Arbeiterinnen von so verschiedener Gestalt, daß man sie, einzeln betrachtet, für besondere Arten halten könnte. Die ganz großen Arbeiterinnen spielen dabei eine besondere Rolle: Es sind dies Tiere, welche oft die Länge der Vollweibchen erreichen,

dann noch Arten mit nur *dimorpher Arbeiterkaste*; bei ihnen stehen den kleinen Formen übergangslos „Giganten“ gegenüber, die dann traditionell „Soldaten“ genannt werden. Wie groß die Unterschiede sein können, zeigt in Fig. 3 *Pheidole pallidula* Nyl., eine mittelmäßige kleine Ameise.

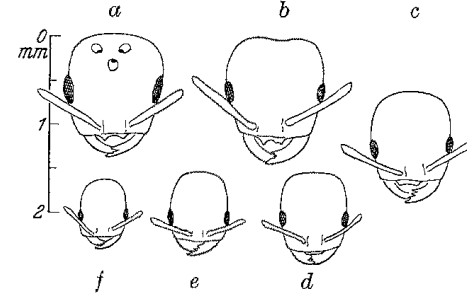
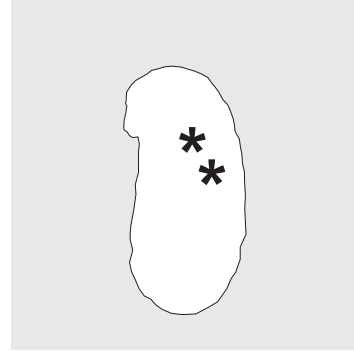
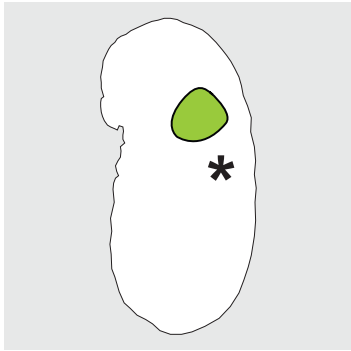
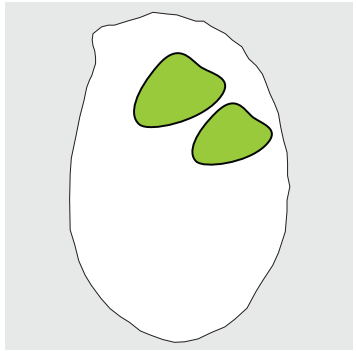


Fig. 1. Chilenische Ameise *Solenopsis gayi* (Spin.). Santiago. Köpfe (ohne Fühlerendglieder). *a* Weibchen (mit 3 Stirn- und 3 Fühleraugen), *b* „Gigant“ (= die Größe der Weibchen erreichender Arbeiter), *c–e* Übergangsformen, *f* kleinster Arbeiter (= Polymorphismus des Arbeiterstandes). Links Maßstab in Millimeter.

Über die Entstehung eines solchen Polymorphismus und Dimorphismus ist schon viel gestritten worden. Es stehen sich 2 Anschauungen gegenüber: Die einen nehmen an, daß die Bedingungen zu bestimmter Größe oder Gestalt schon im Keim oder Ei zu suchen sind (= blastogene Entstehung), während die anderen den Grund in besonders reicher oder besonders gearteter Nahrung sehen (= trophogene Ausbildung).

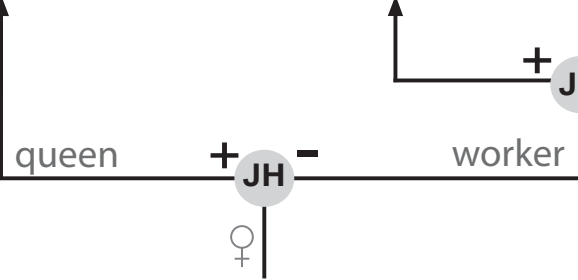
Um diese Frage ihrer Klärung näherzubringen, unternahm ich Versuche mit *Pheidole pallidula*, von denen ich in Capri Mitte und Ende Juli 1936 etwa 100 junge, gerade ausgeflogene Weibchen erbeuten konnte. In manchen Fällen war es mir möglich, bei einzelnen Tieren das Abfliegen vom Nest sowie die Befruchtung in der Luft zu beob-



reproductive

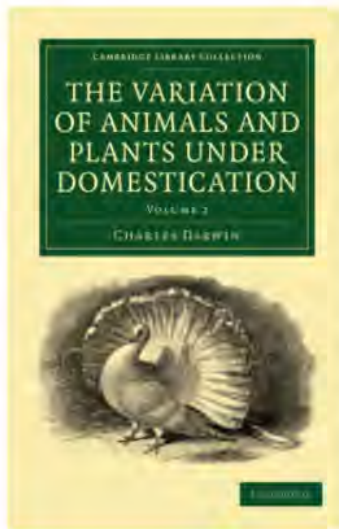
soldier

minor worker



ting fed, but each receiving only a little food. Therefore, I commenced feeding liquid meat and solid sugar, i.e., frog or rabbit blood, meat juice and raw egg white on one side, and hard bread crumbs soaked in sugar water on the other side.

After four weeks, soldiers developed only in cultures that had been fed meat chunks, whereas all larvae raised with liquid protein became workers. Later experiments, carried out for half a year, showed again that it is always the solid texture of the meat which is to be made responsible for the generation of soldiers (Tab. 5). This, in turn, is caused by the



But on the doctrine of reversion, as given in this chapter, the germ becomes a far more marvellous object, for, besides the visible changes to which it is subjected, we must believe that it is crowded with invisible characters, ... and to a long line of male and female ancestors separated by hundreds or even thousands of generations from the present time; and these characters, like those written on paper with invisible ink, all lie ready to be evolved under certain known or unknown conditions.



LETTER

<https://doi.org/10.1038/s41586-018-0613-1>

Social regulation of a rudimentary organ generates complex worker–caste systems in ants

Rajendhran Rajakumar^{1,2}, Sophie Koch¹, Mélanie Couture¹, Marie–Julie Favé^{1,3}, Angelica Lillico–Ouachour¹, Travis Chen¹, Giovanna De Blasis¹, Arjuna Rajakumar¹, Dominic Ouellette¹ & Ehab Abouheif^{1*}

Montreal biologist resolves Darwin's unanswered question: Why do some ants become soldiers?



New discovery about ants' wings may have implications for most living species, including us

Minaz Kerawala · CBC News · Posted: Oct 21, 2018 10:00 AM ET | Last Updated: October 21, 2018

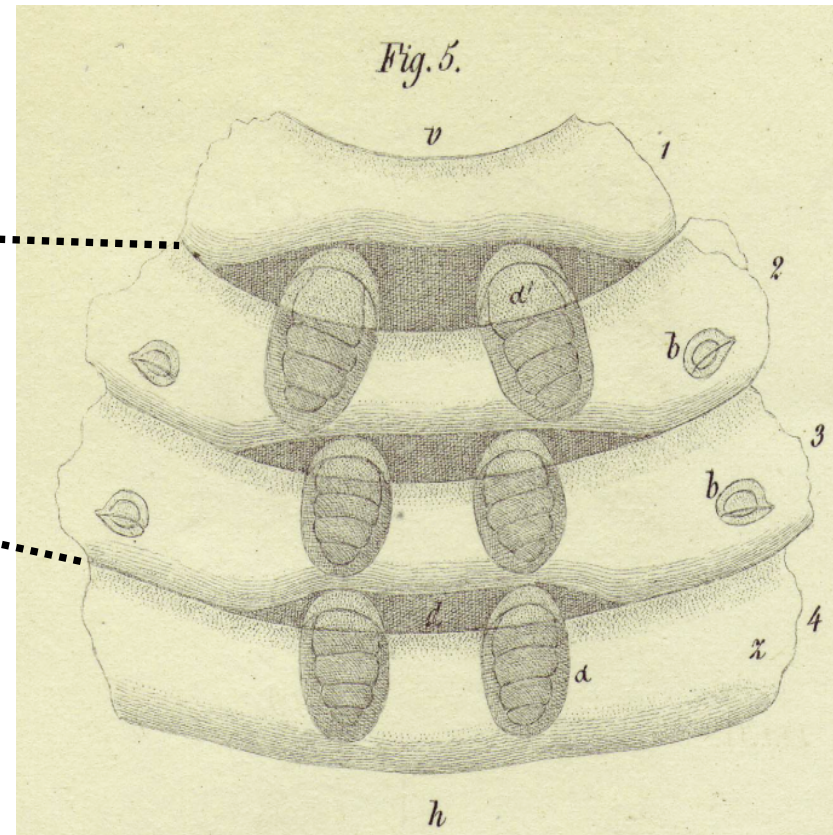
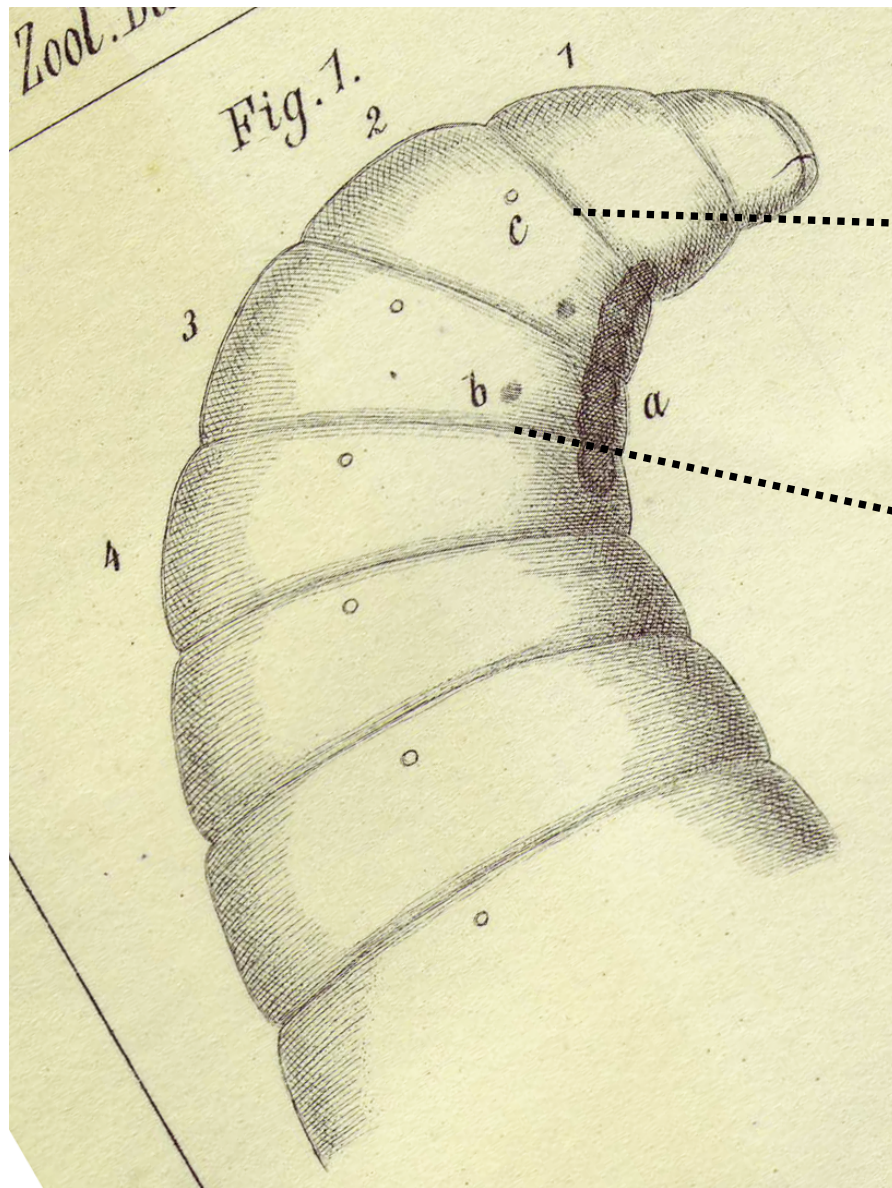


In the *Pheidole* genus, like in all ants, soldiers like the specimen on top are much larger than minor

Dewitz (1878):

“In his ‘Origin of Species,’ Darwin speaks of the difficulty imposed onto his theory by the so-called ‘neuters’ of eusocial insects, in particular worker ants with a morphology differing greatly from reproductive animals, caused by the complete lack of wings. This prompted me to investigate whether at least rudiments of these limbs, which are encountered so often in Orthopterans, can be found. For a long time my search was in vain, until I examined larvae and found imaginal disks at the sides of the two back thoracic rings.”

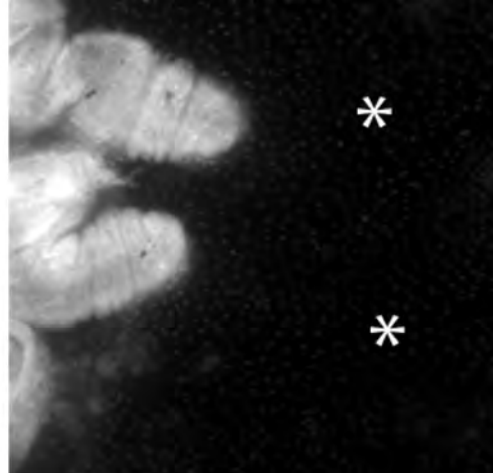
workers have vestigial wing discs



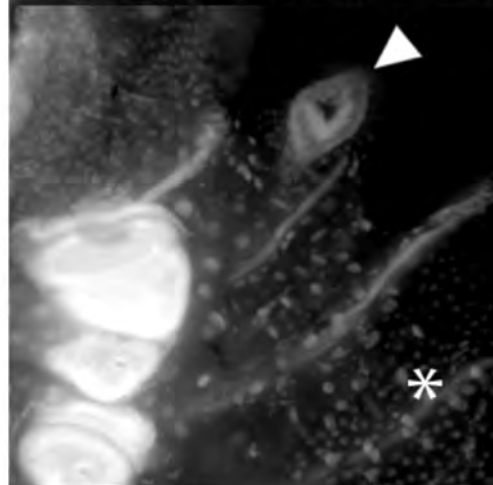
Dewitz, 1878



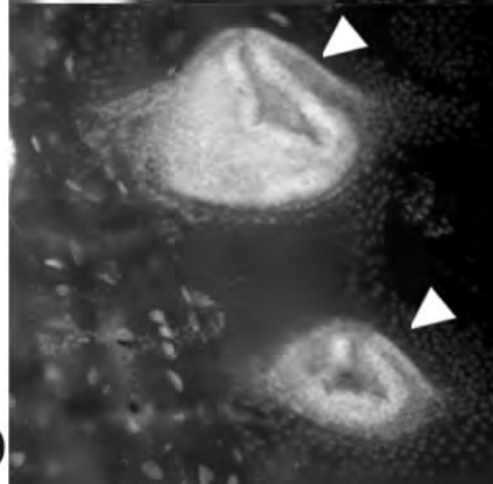
MW

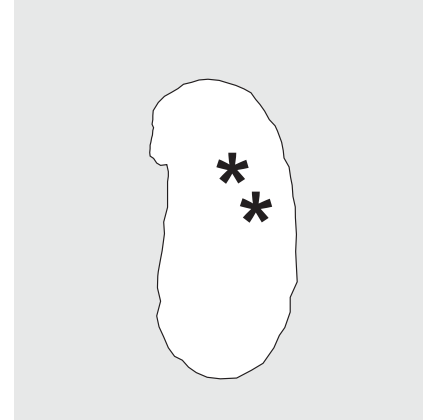
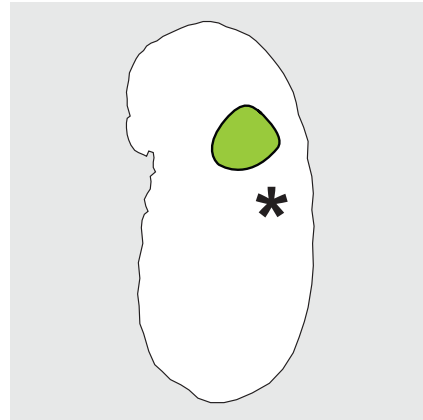
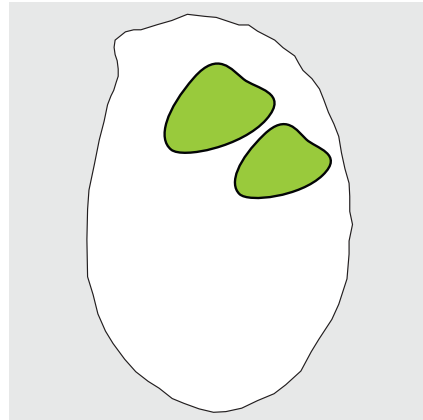


SD



XSD

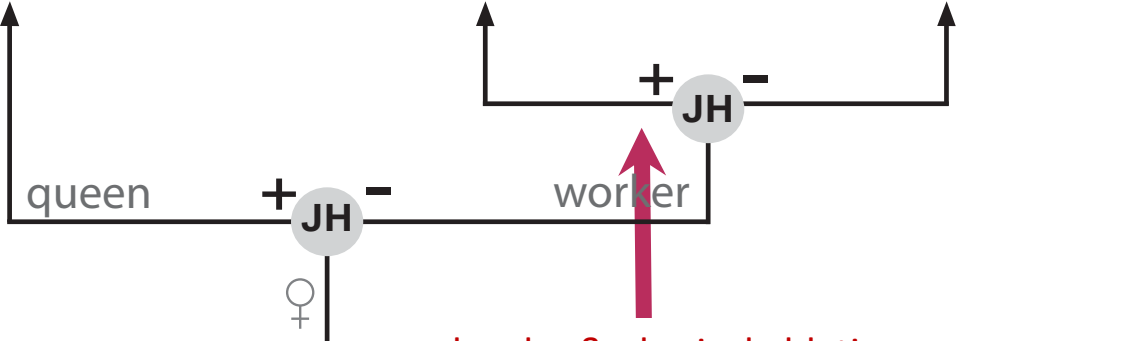




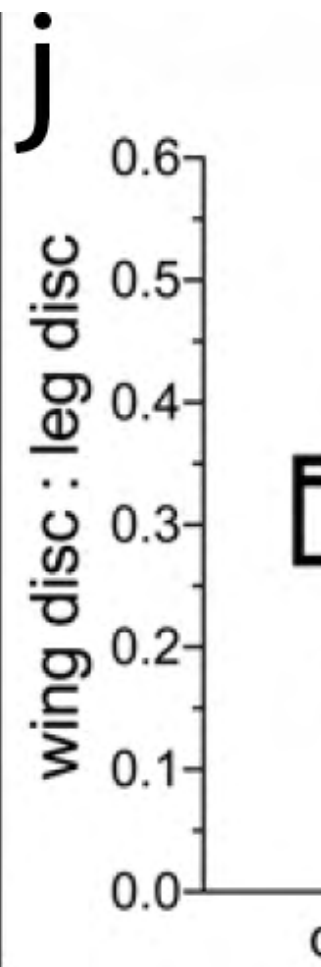
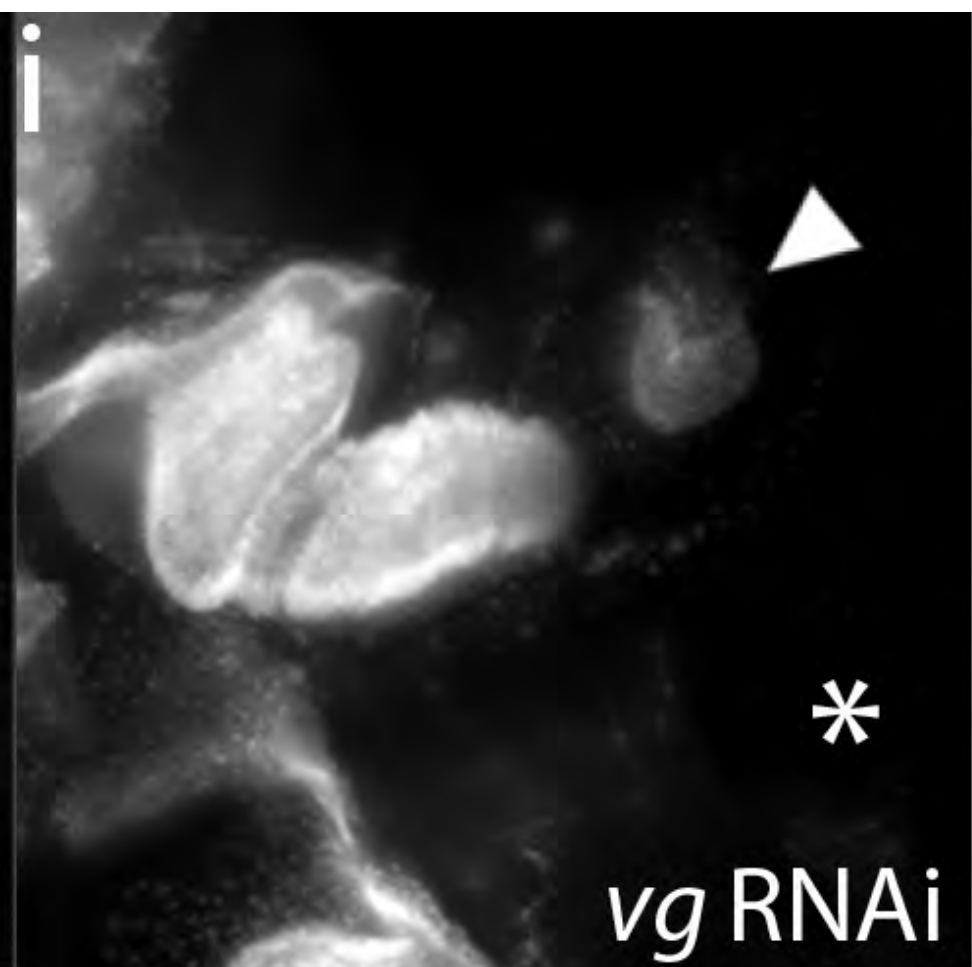
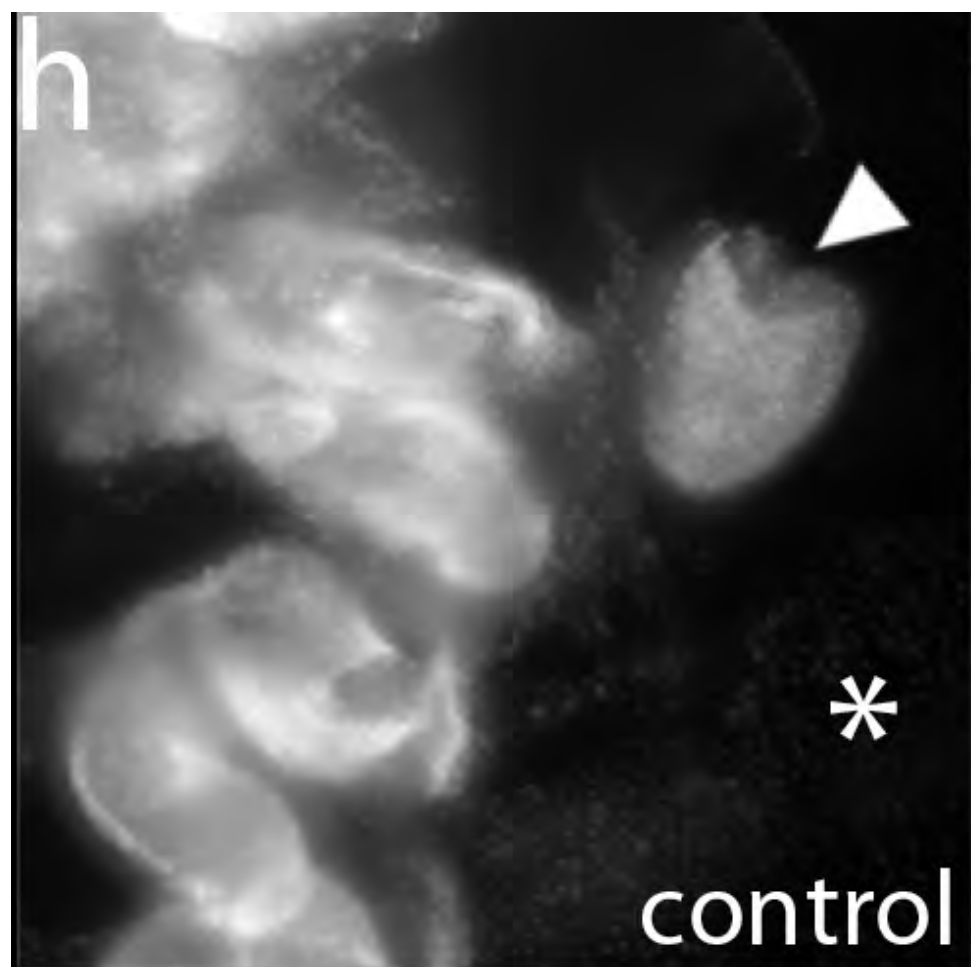
reproductive

soldier

minor worker



molecular & physical ablation



k



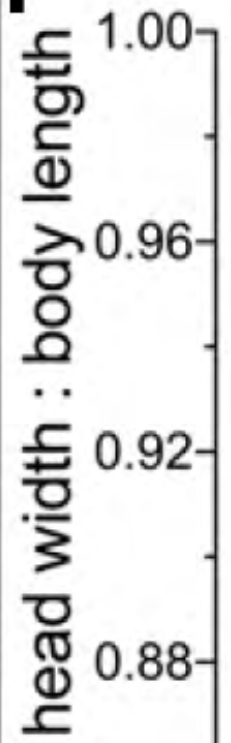
control MW



vg RNAi



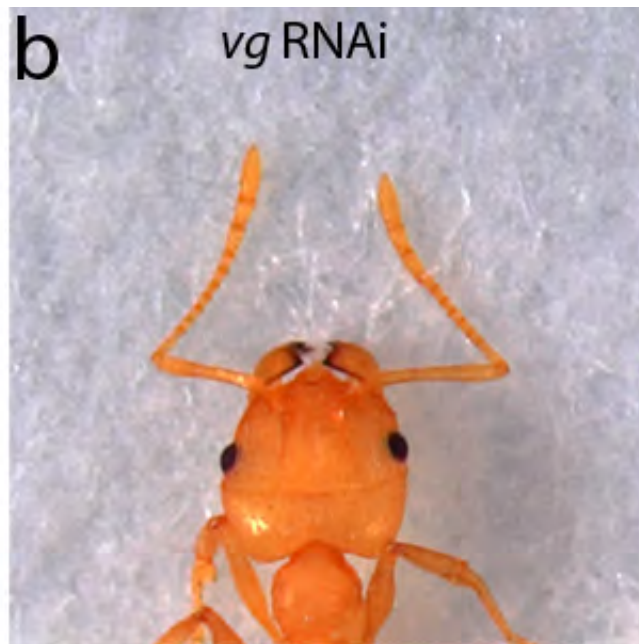
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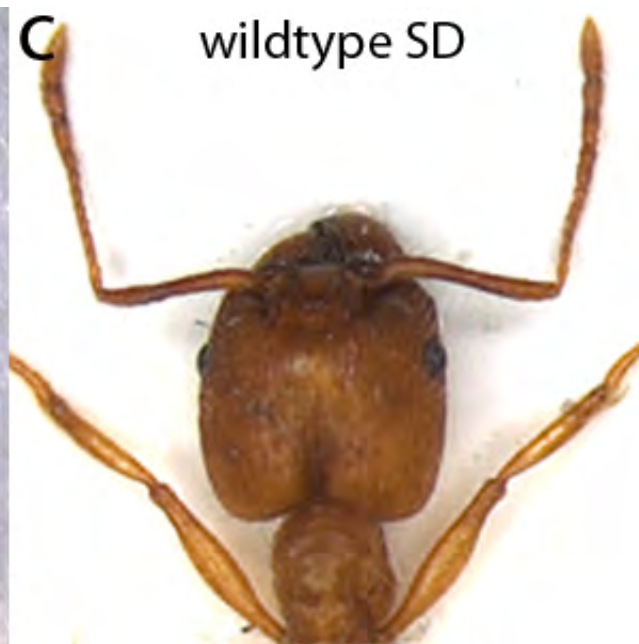
a wildtype MW

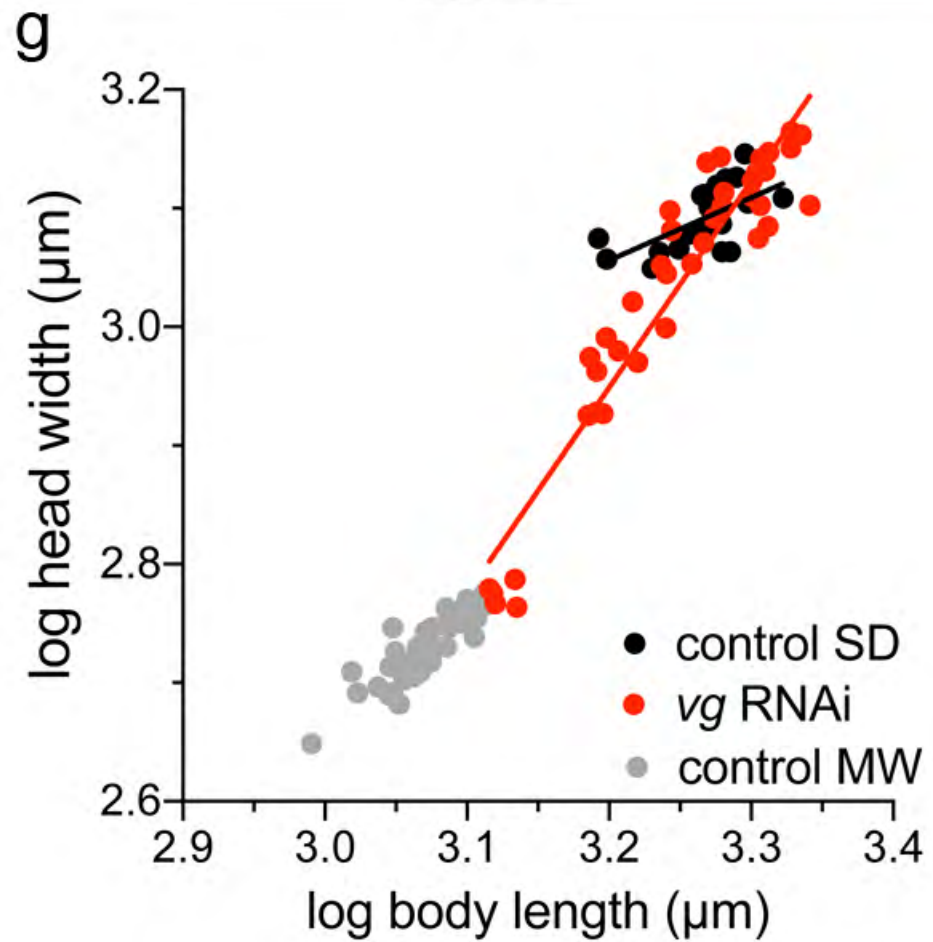
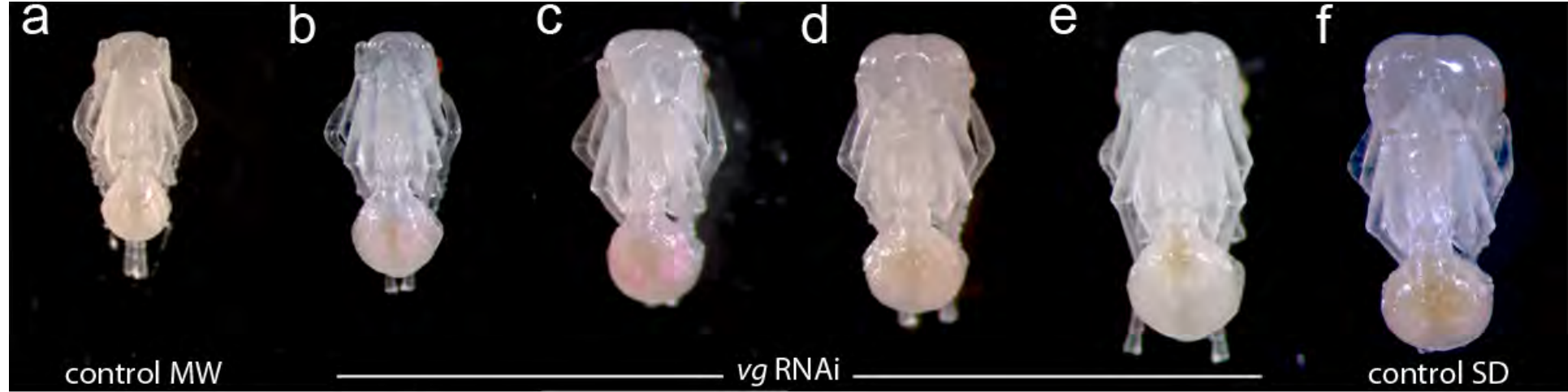


b *vg* RNAi



c wildtype SD





ARTICLE

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Epigenetic variation in the *Egfr* gene generates quantitative variation in a complex trait in ants

Sebastian Alvarado^{1,*†}, Rajendhran Rajakumar^{2,*†}, Ehab Abouheif² & Moshe Szyf¹





News · Canada

Canadian scientists double the size of ants in experiment

By The Canadian Press
Thu., March 12, 2015



IN THE TRADITION OF PULITZER, HEARST, AND WERTHAM:
THE OUTHOUSES

The journalism the comics industry deserves.



TUESDAY, FEBRUARY 26, 2019 • R.I.P. EDITION • VOTED BEST HAIR IN HIGH SCHOOL.

IDIOT SCIENTISTS TO BRING ABOUT END OF WORLD WITH CREATION OF GIANT ANTS

Written by Jude Terror on Wednesday, March 11 2015 and posted in News with Benefits



WHY WOULD YOU DO THIS?!?! WHY WOULD ANYONE DO THIS?!?!

**IT HAS BEEN
12 DAYS
SINCE DC
COMICS DID
SOMETHING
STUPID.**

Read more about DC's PR goofs at Bleeding Cool.

SEARCH THE OUTHOUSE ARCHIVES

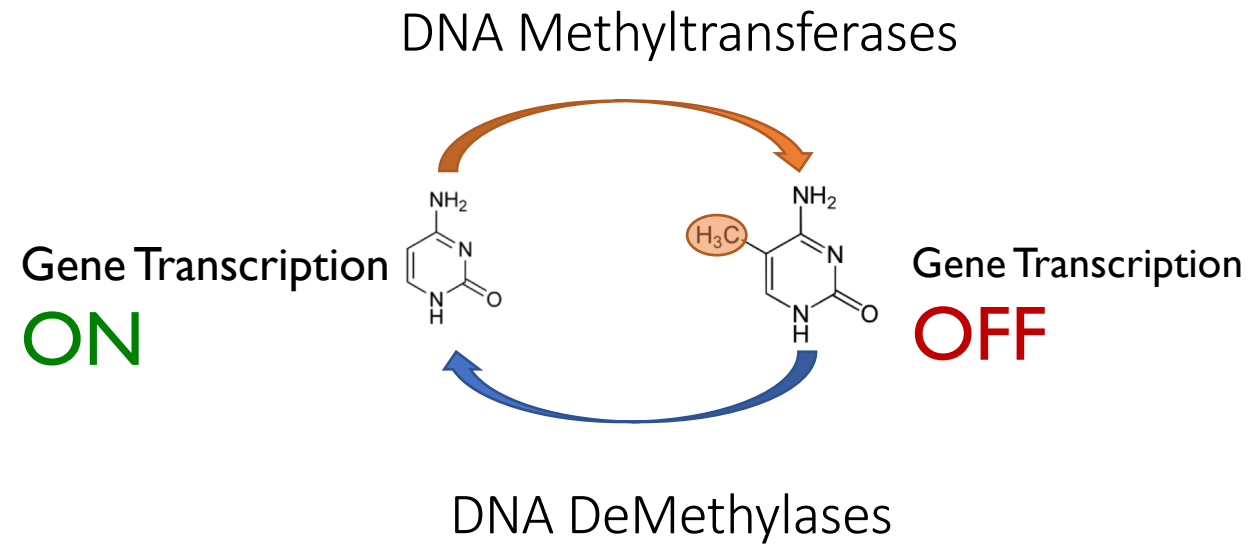
VISIT THE FORUMS AT COMICS PIT,
WHERE THE OUTHOUSE LIVES ON

Camponotus floridanus

Minor worker

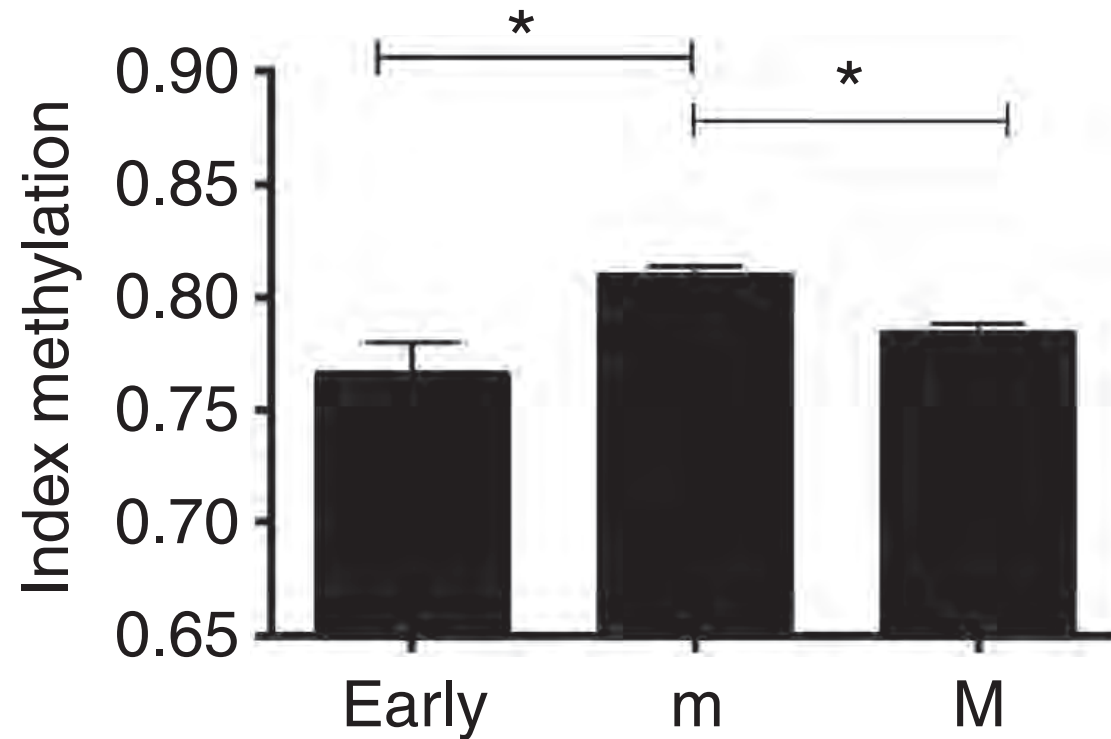
Major worker



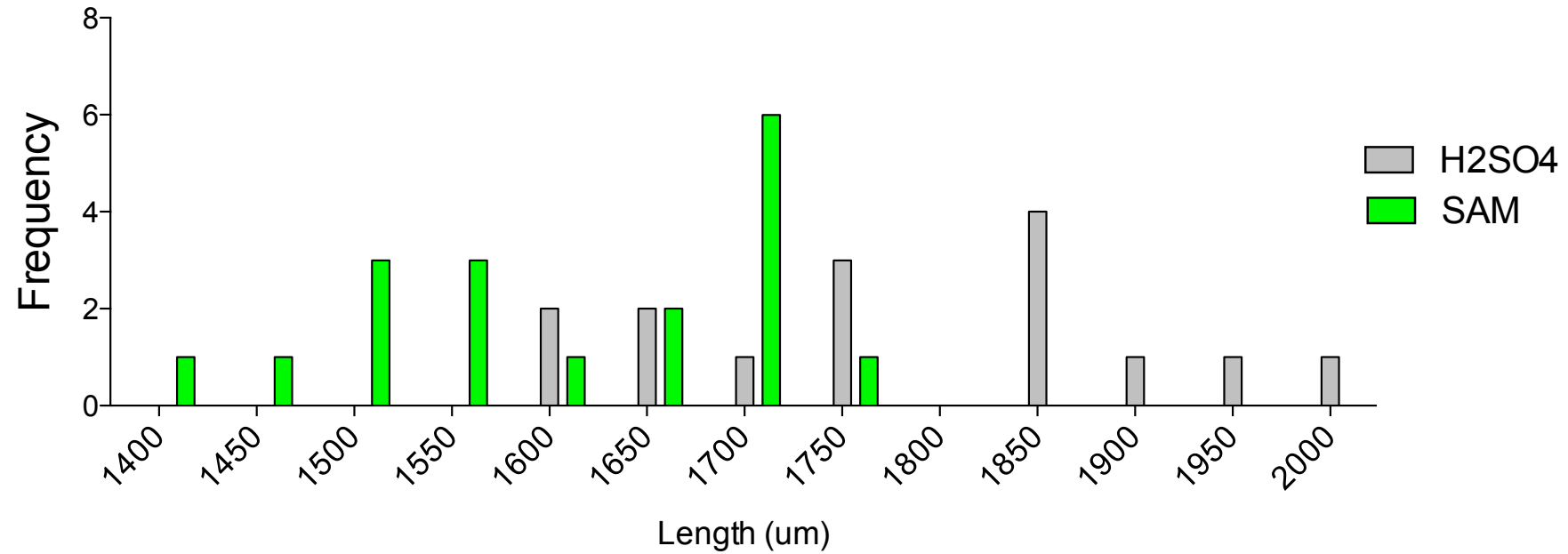


(Szyf et al., 2007; Jablonka & Raz, 2009)

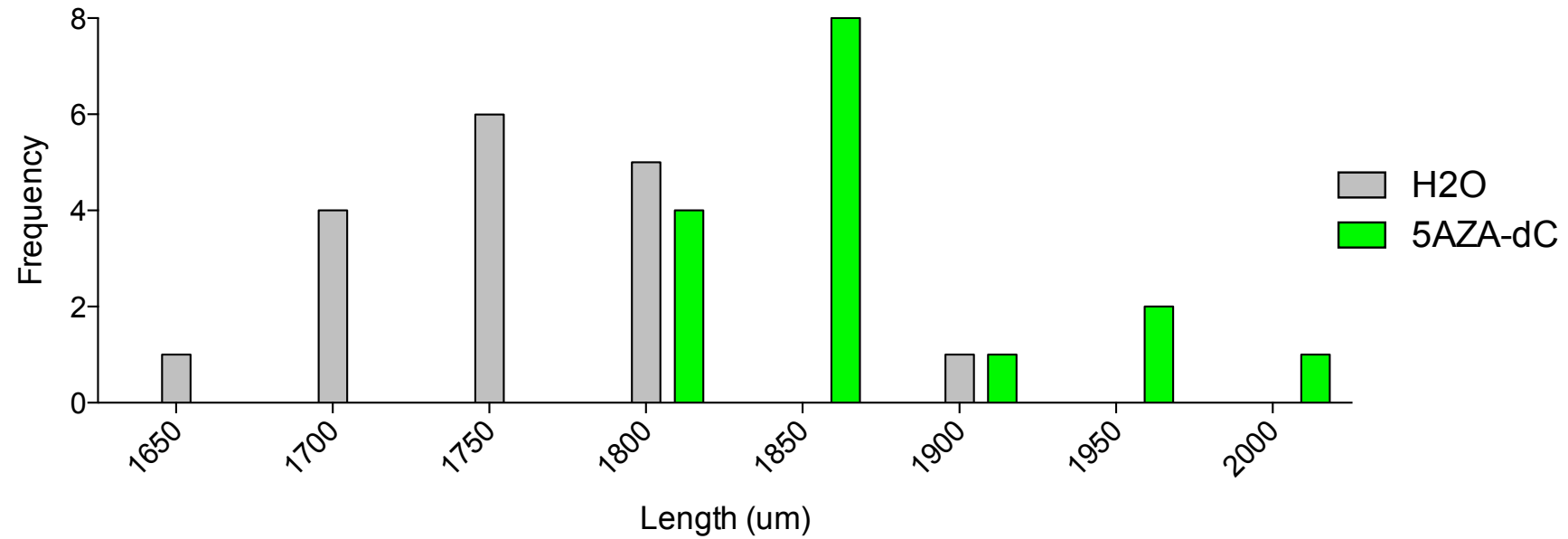
Genomic methylation and epigenetic toolkit expression levels



Increasing global methylation leads to decrease in size



Decreasing global methylation leads to increase in size





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