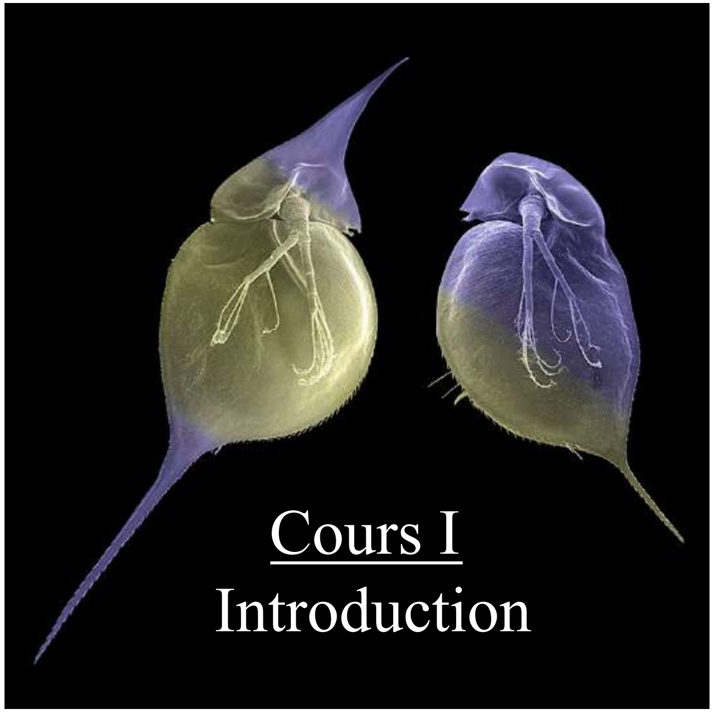
CHAIRE ÉPIGÉNÉTIQUE ET MÉMOIRE CELLULAIRE

Année 2023-2024 : 4 mars, 2024

L'épigénétique à l'interface organisme-environnement



E. Heard

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L'épigénétique à l'interface organisme-environnement

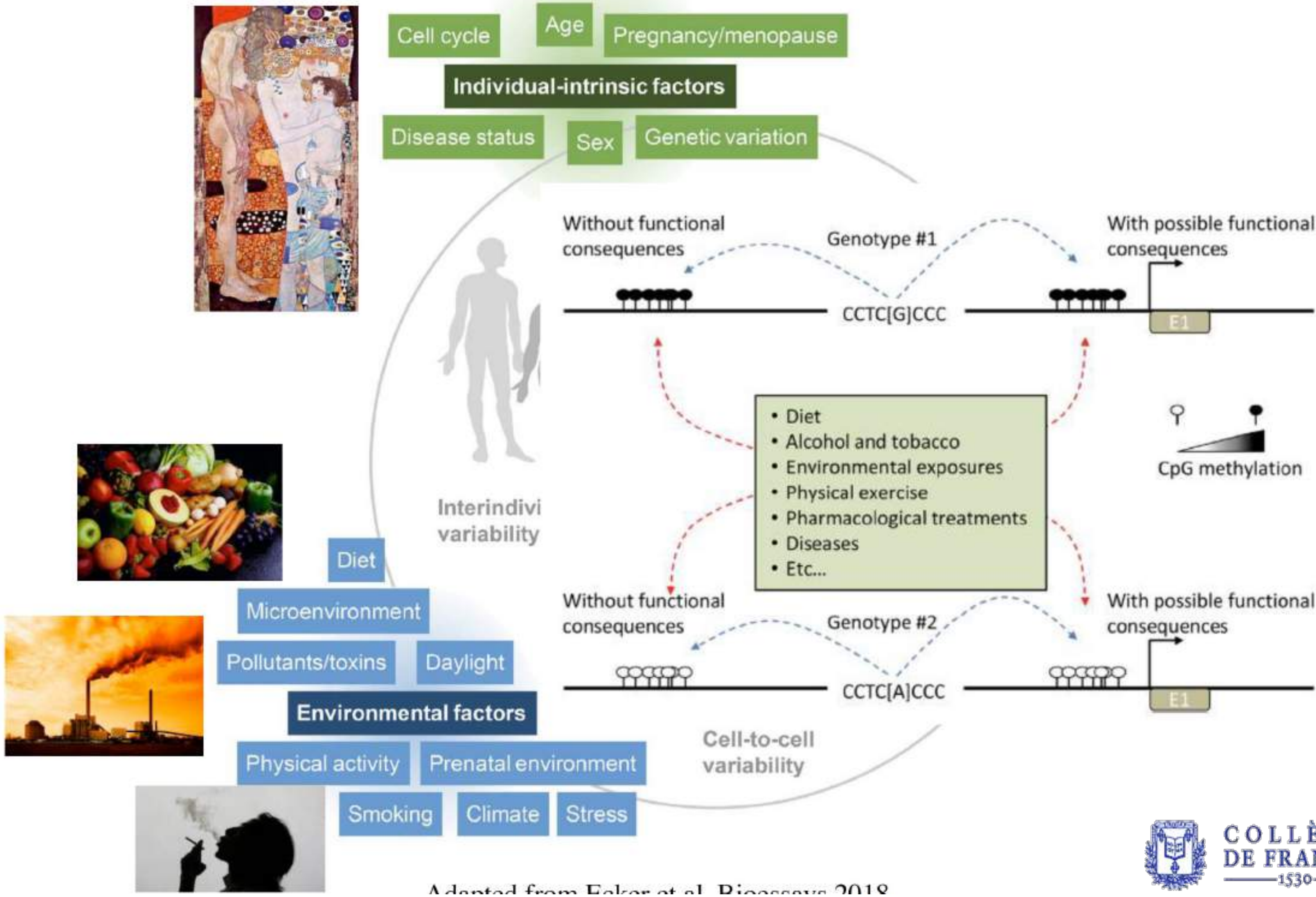
4 mars
Cours 1: Introduction

11 mars
Cours 2: Comment l'environnement influence-t-il les phénotypes ?

18 mars
Cours 3: Exemples d'impacts environnementaux sur le règne animal

25 mars
Cours 4: Exemples d'impacts environnementaux sur le règne végétal

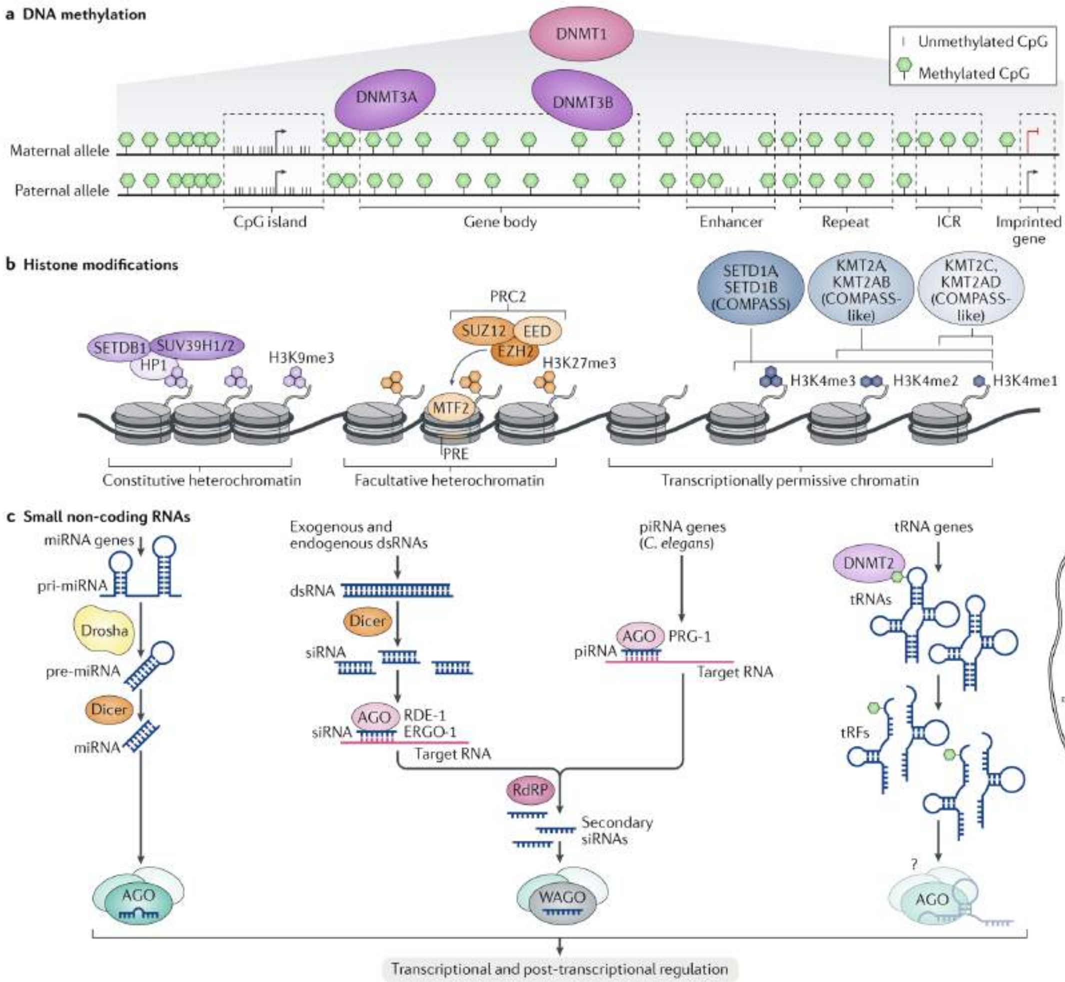
Epigenetics at the interface of the organism and its environment

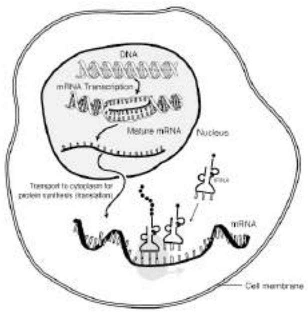


E. Hear

Adapted from Ecker et al. Bioessays 2018

Epigenetic modifications are sensitive to environmental stimuli, transmissible and potentially heritable





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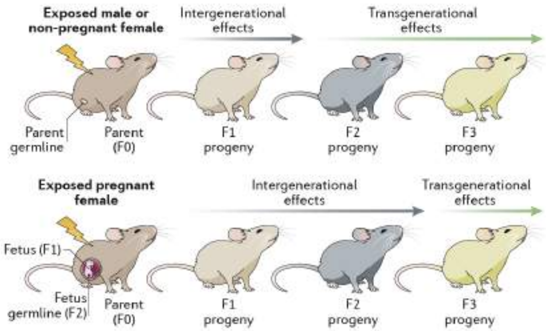
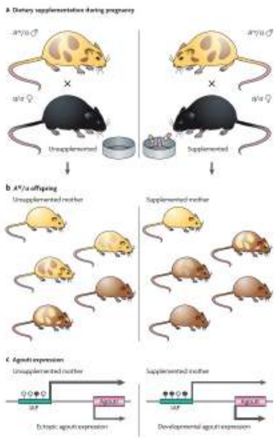
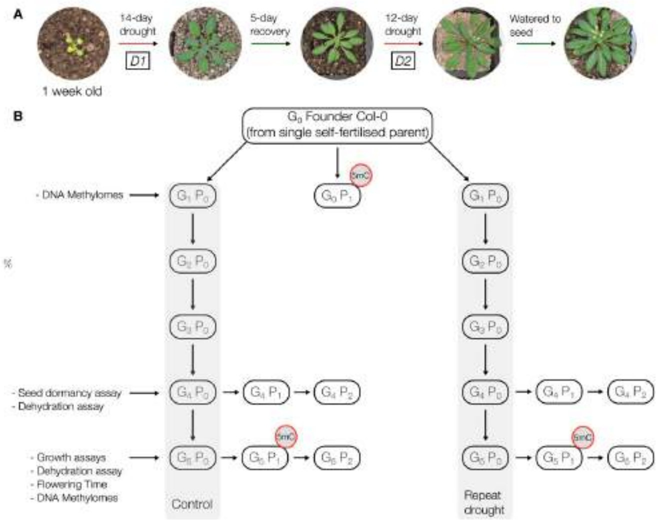
Can the environment induce epigenetic memory across generations? How "adaptive" is this?



Transposable Elements: Targets for Early Nutritional Effects on Epigenetic Gene Regulation
Robert A. Waterland and Randy L. Jirtle*

Diet-induced hypermethylation at *agouti viable yellow* is not inherited transgenerationally through the female
Robert A. Waterland, Michael Travisano, and Kajal G. Tahiliani*





- Evidence of transgenerational drought stress memory for seed dormancy – elevated in both the direct seed of drought-stressed parents (72% enhanced dormancy) and to a lesser extend in seed produced from P1 progeny, from drought-exposed lineages, grown in the absence of stress (31% enhanced dormancy).
- DNA methylome is relatively *unaffected* by stress-induced changes….

E. Heard,

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Human-driven impact on life on earth

Rapidly changing environments and their impact on organisms?

The speed of environmental changes, due to the impact of humans through farming, deforestation, chemical pollution and fossil fuels that induce climate change, is threatening biodiversity: ecosystems are being destroyed and some life forms are unable to adapt and are lost. Major impact for human health and human economies.

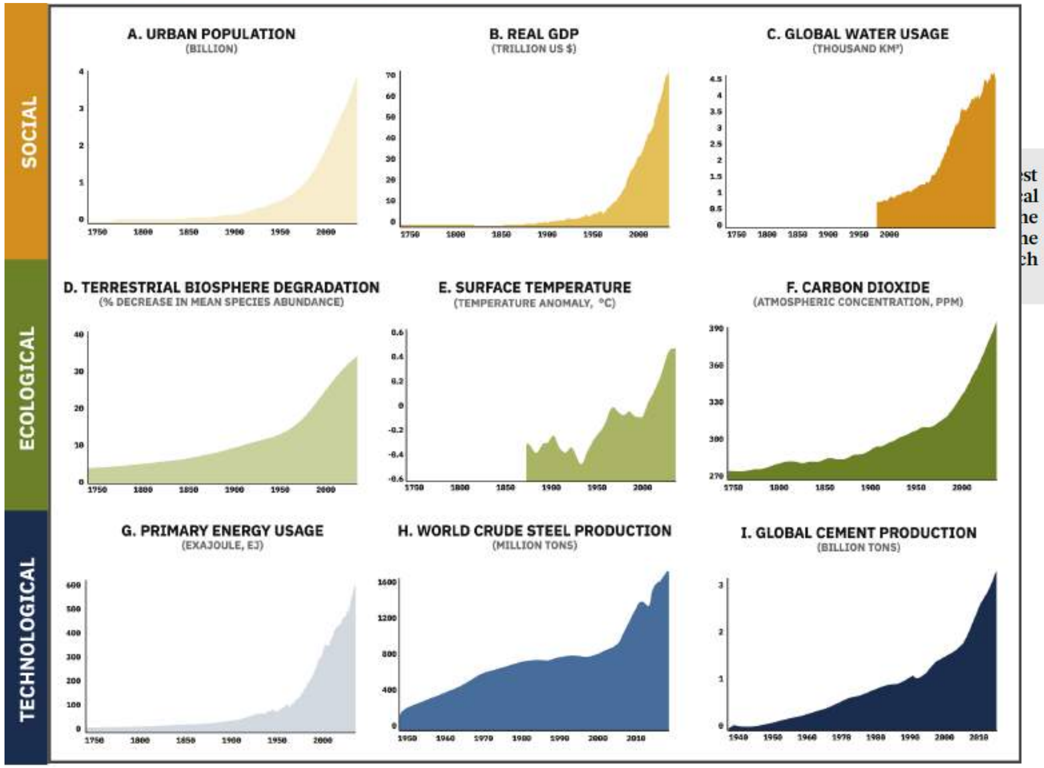
Human-driven impact on life on earth
"Anthropocene"?

***Anthropocene* is derived from Greek and means the "recent age of man."**

Quaternary Period with the Anthropocene Epoch

Eonothem/ Eon	Erathem/ Era	System/ Period	Series/ Epoch	Stage/ Age	millions of years ago
Phanerozoic	Cenozoic	Quaternary	Anthropocene[1]		1950 CE
			Holocene		0.0117
			Pleistocene	Upper	0.126
				Middle	0.781
				Calabrian	1.806
				Gelasian	2.588

[1] In August 2016 the Anthropocene Working Group (AWG), a special body created within the International Commission on Stratigraphy (ICS), recommended that the Anthropocene Epoch be made a formal interval within the International Chronostratigraphic Chart. The AWG recommended that the year 1950 be used as the starting point of the Anthropocene Epoch.



McPhearson et al, NPJ (2021)

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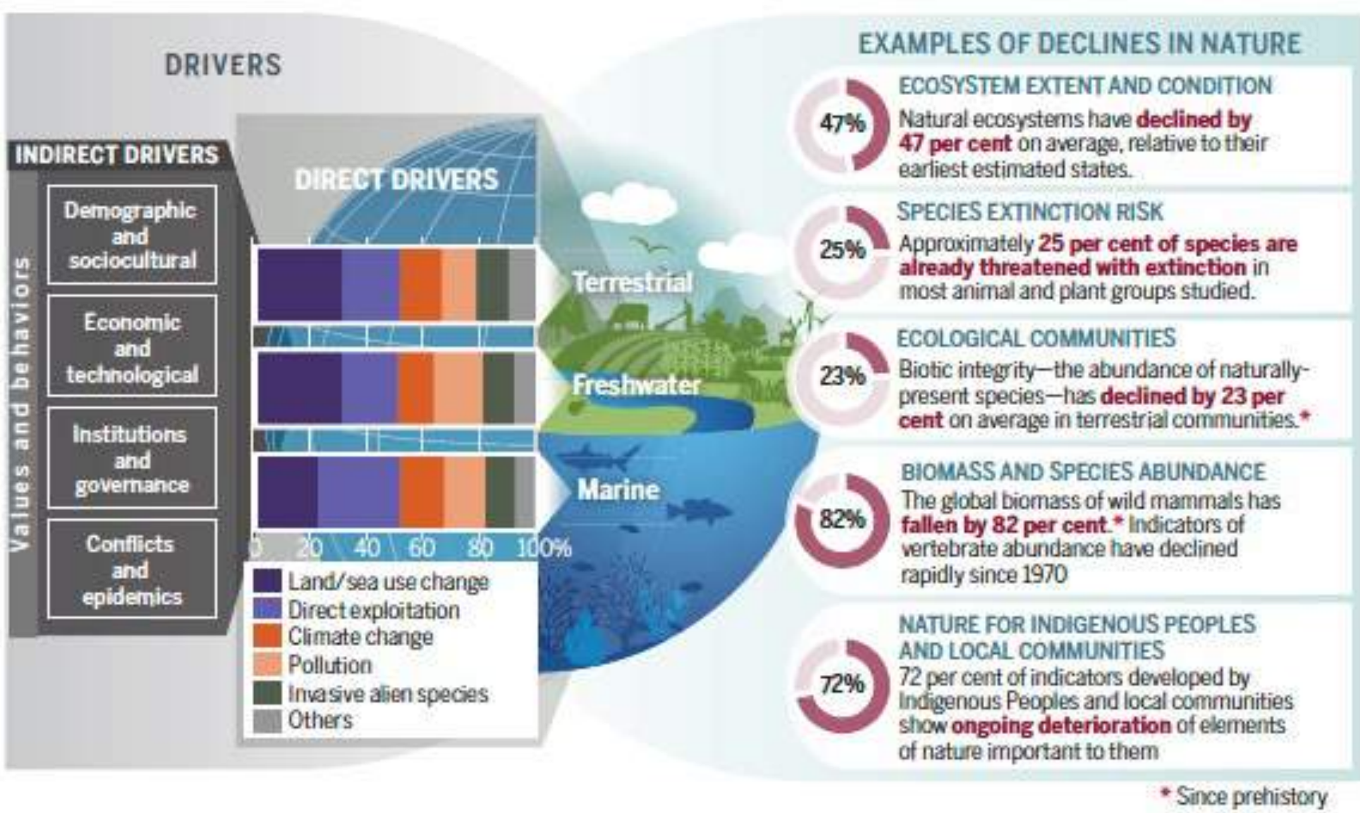
Human-driven impact on life on earth

Pervasive human-driven decline of life on Earth points to the need for transformative change

Sandra Díaz[1,2]*, Josef Settele[3,4], Eduardo S. Brondízio[5], Hien T. Ngo[6], John Agard[7], Almut Arneth[8], Patricia Balvanera[9], Kate A. Brauman[10], Stuart H. M. Butchart[11,12], Kai M. A. Chan[13], Lucas A. Garibaldi[14], Kazuhito Ichii[15,16], Jianguo Liu[17], Suneetha M. Subramanian[18,19], Guy F. Midgley[20], Patricia Miloslavich[21,22], Zsolt Molnár[23], David Obura[24,25], Alexander Pfaff[26], Stephen Polasky[27,28], Andy Purvis[29,30], Jona Razzaque[31], Belinda Reyers[32,33], Rinku Roy Chowdhury[34], Yunne-Jai Shin[35,36], Ingrid Visseren-Hamakers[37,38], Katherine J. Willis[39,40], Cynthia N. Zayas[41]

All life forms across the globe are experiencing drastic changes in environmental conditions as a result of global climate change.

These environmental changes are happening rapidly, incur substantial socioeconomic costs, pose threats to biodiversity and diminish a species' potential to adapt to future environments. Understanding and monitoring how organisms respond to human-driven climate change is therefore a major priority for the conservation of biodiversity in a rapidly changing environment.



Human-driven impact on life on earth "Anthropocene"?

Table 1 Threats to global biodiversity and their impacts

Factors	Impacts on biodiversity
Habitat loss and fragmentation Invasive alien species Overexploitation Climate change Pollution Anthropogenic threats	• At threat of extinction are • 1 out of 8 birds • 1 out of 4 mammals • 1 out of 4 conifers • 1 out of 3 amphibians • 6 out of 7 marine turtles • 75% of genetic diversity of agricultural crops has been lost • 75% of the world's fisheries are fully or over exploited • Up to 70% of the world's known species risk extinction if global temperatures rise by more than 3.5°C • Deforestation of closed tropical rain forests may lead to up to100 species being lost every day. • 1/3 of reef-building corals are threatened with extinction • Over 350 million people suffer from severe water scarcity

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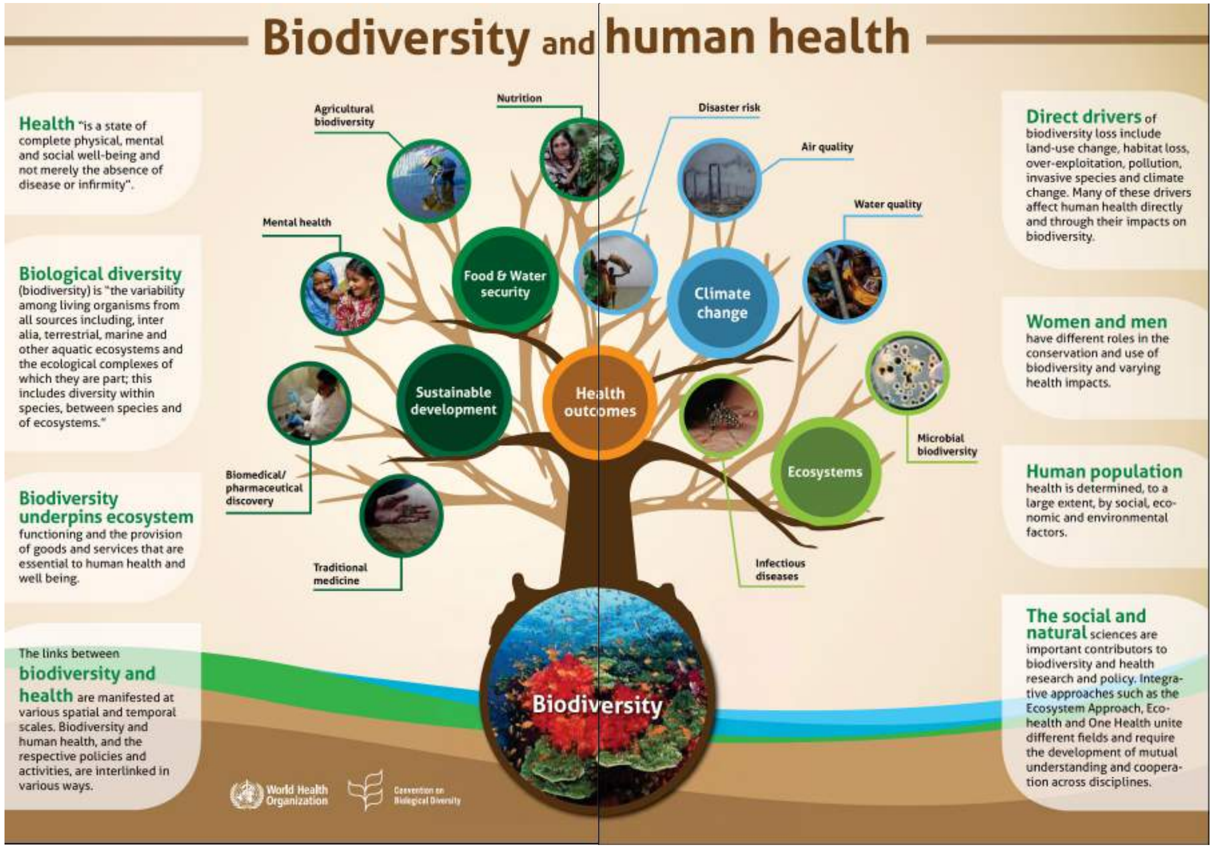
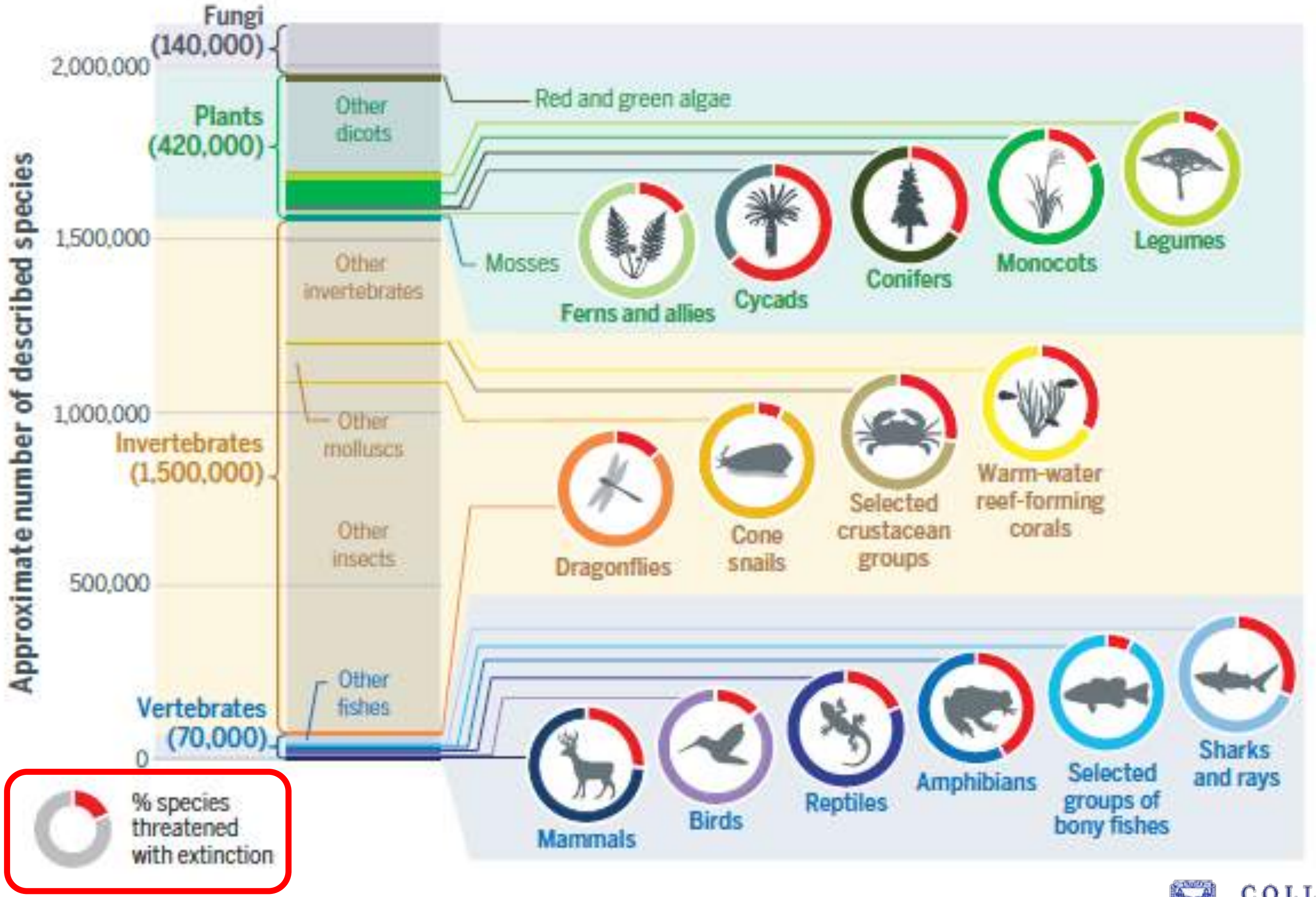
Impacts on Human health and well-being



Extinction risk and diversity in different taxonomic groups



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Human impact on Biodiversity

Biodiversity is comprised of several levels - genes, species, populations and individuals within them, communities of creatures, entire ecosystems, where life interplays with the physical environment.

These interactions have made Earth habitable for billions of years.
Biodiversity can be considered as the knowledge "learned" through evolution of species over millions of years about how to survive through the vastly varying environmental conditions Earth has experienced.

"*Humanity is « burning the library of life » by destroying ecosystems on a massive scale, through impact of climate change, accelerating pollution, deforestation, and other manmade factors...*"

World Wildlife Fund, Living Planet Report 2018

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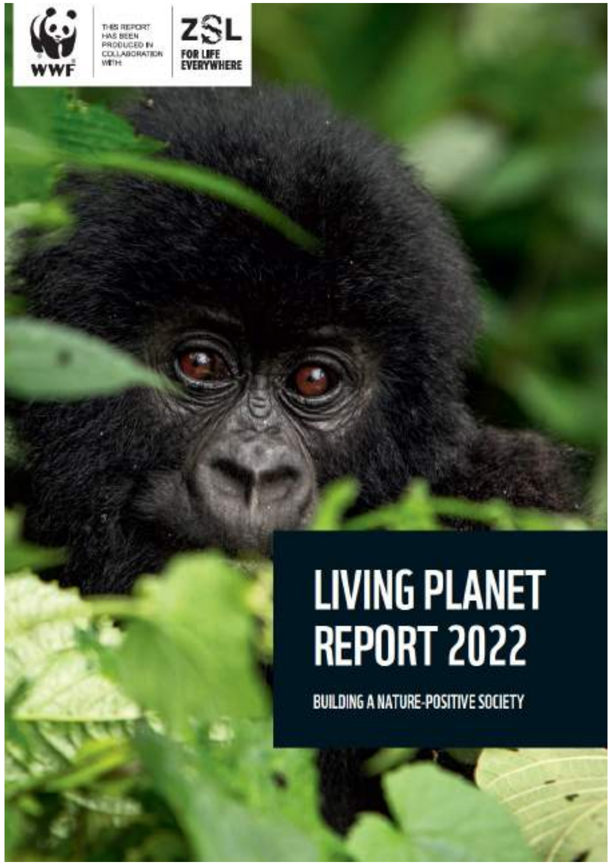
Human impact on Biodiversity



It is key to mobilizing and aligning governments, communities, businesses, financial institutions and even consumers towards contributing to the same shared global goal, inspiring a whole-of-society approach. And it is key to injecting the same high degree of accountability that we are beginning to witness around climate action.

Just as the global goal of 'net-zero emissions by 2050' is disrupting the energy sector so that it shifts towards renewables, 'nature positive by 2030' will disrupt the sectors that are drivers of nature loss – agriculture, fishing, forestry, infrastructure and extractives – driving innovation and acceleration towards sustainable production and consumption behaviours.

Our society is at the most important fork in its history, and is facing its deepest systems change challenge around what is perhaps the most existential of all our relationships: the one with nature. And all this at a time when we are beginning to understand that we depend on nature much more than nature depends on us. The COP15 biodiversity conference can be the moment when the world comes together on nature.

Marco Lambertini,

Director General
WWF International

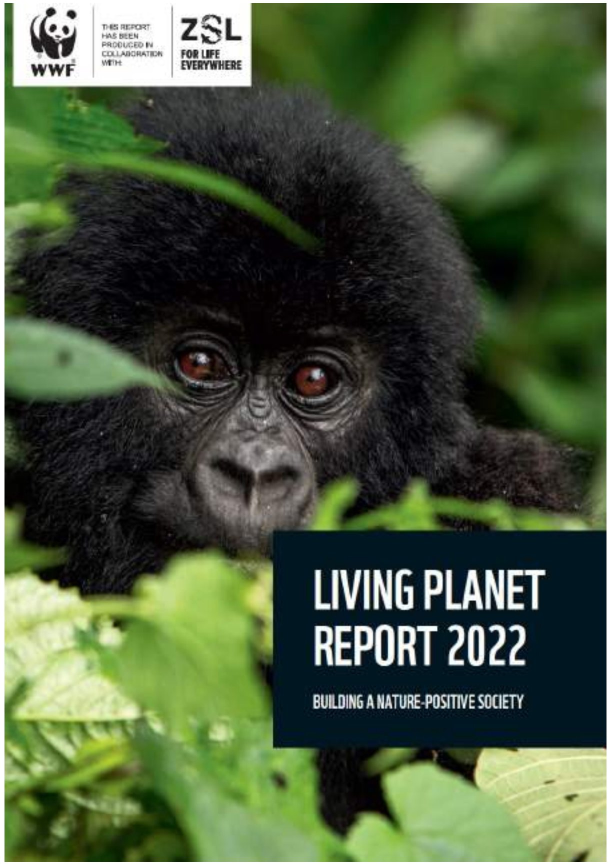
THE CLIMATE AND BIODIVERSITY CRISES - TWO SIDES OF THE SAME COIN

Today we face the double, interlinked emergencies of human-induced climate change and the loss of biodiversity, threatening the well-being of current and future generations.

The speed and scale of change

- Indicators help us to build up a picture of both the speed and scale of change in biodiversity around the world, and the impacts of this change.
- The Living Planet Index acts as an early warning indicator by tracking trends in the abundance of mammals, fish, reptiles, birds and amphibians around the world.
- The 2022 global Living Planet Index shows an average 69% decrease in monitored wildlife populations between 1970 and 2018.
- Latin America shows the greatest regional decline in average population abundance (94%).
- Population trends for monitored freshwater species are also falling steeply (83%).
- New mapping analysis techniques allow us to build up a more comprehensive picture of both the speed and scale of changes in biodiversity and climate, and to map where nature contributes most to our lives.
- This edition has been written by 89 authors from around the world, and they have drawn on a range of different knowledge sources.

Human impact on Biodiversity



Changes in biodiversity vary in different parts of the world

The global Living Planet Index does not give us the entire picture – there are differences in abundance trends between regions, with the largest declines in tropical areas.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) divides the world into different geographic regions [39, 45]. This breakdown is designed to support the monitoring of progress towards the targets developed under the Convention on Biological Diversity.

Valentina Marconi, Louise McRae and Robin Freeman (Zoological Society of London)

The LPI trends presented here follow the IPBES regional classifications, with all terrestrial and freshwater populations within a country assigned to an IPBES region. The Americas are further subdivided into North America, and Latin America and the Caribbean (Mesoamerica, the Caribbean and South America combined).

Trends for each species group are weighted according to how many species are found in each IPBES region. More details about these regional trends and the other cuts of the Living Planet Index can be found in the *2022 Living Planet Report: Deep dive into the Living Planet Index.*

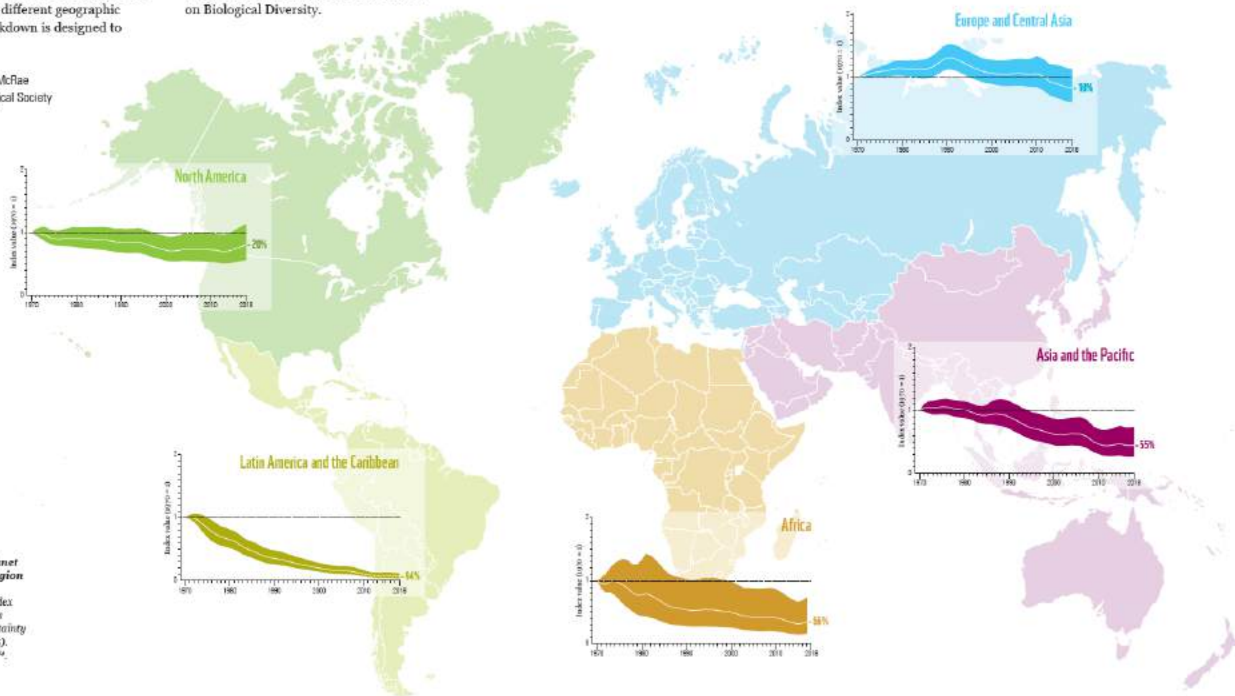


Figure 4: The Living Planet Index for each IPBES region (1970 to 2018)
The white line shows the index values and the shaded areas represent the statistical certainty surrounding the trend (95%). Source: WWF/ZSL (2022)[184].

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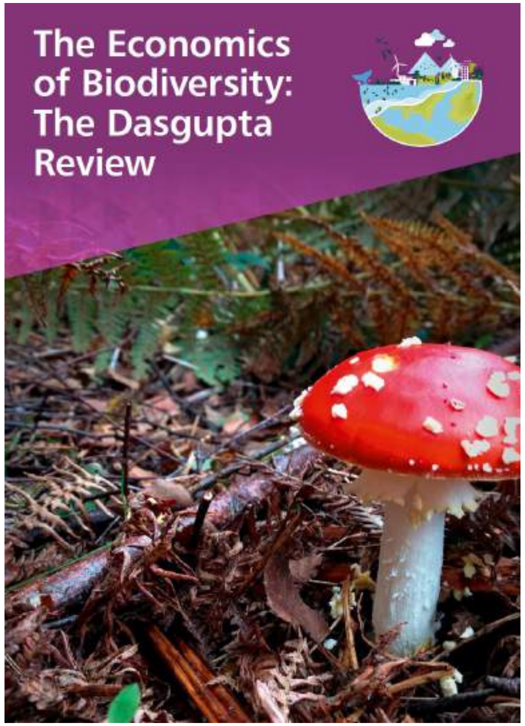
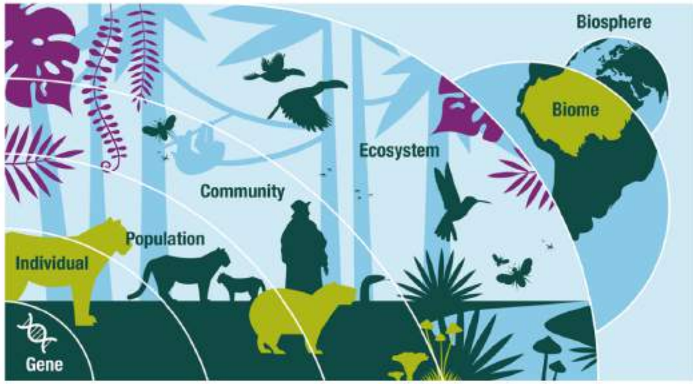
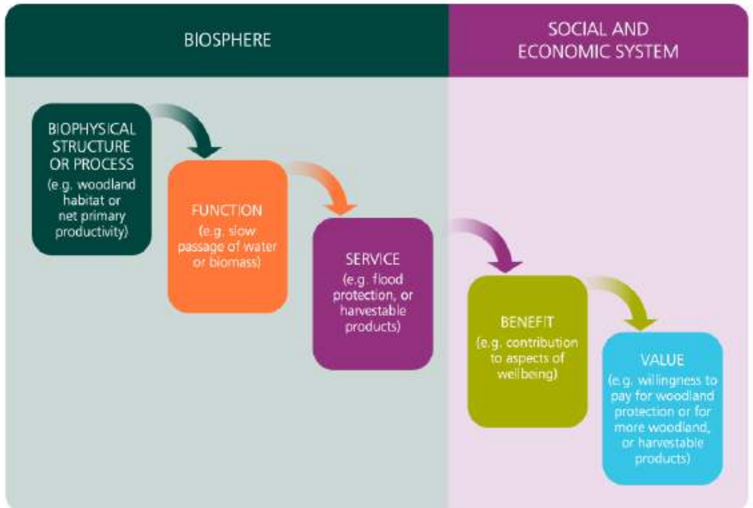
The Economics of Biodiversity



The Economics of Biodiversity:
The Dasgupta Review **2021**

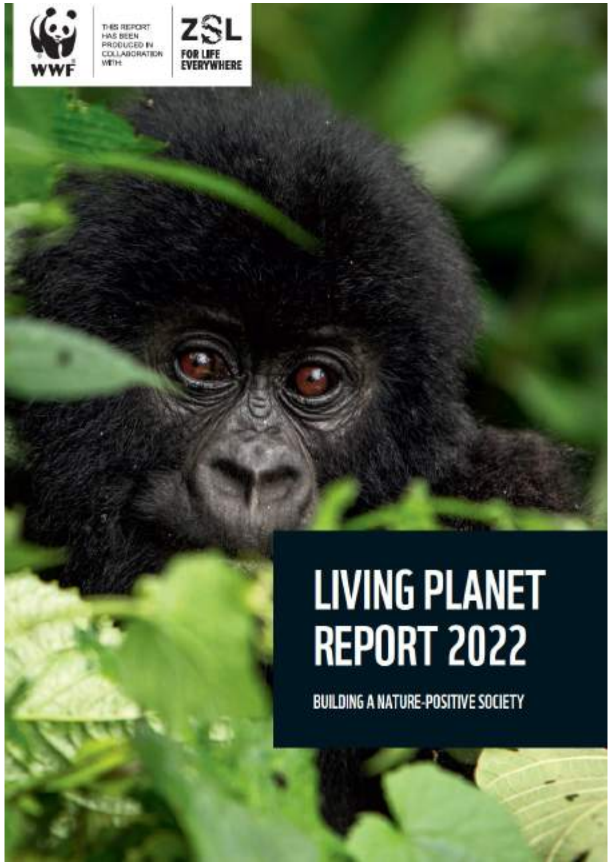
Figure 2.1 From the Micro to the Macro





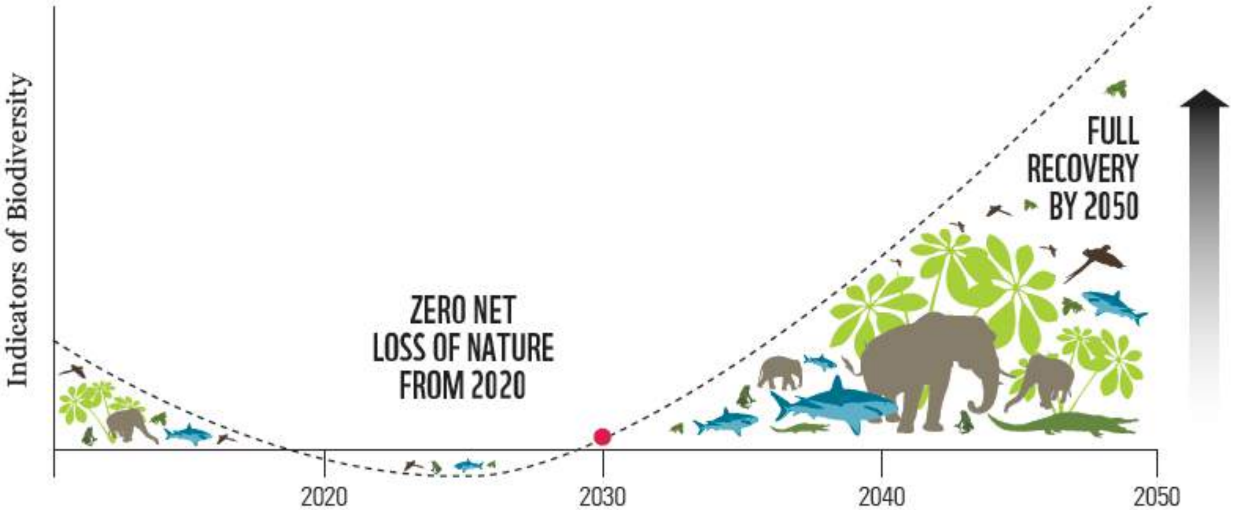
Source: Adapted from Potschin and Haines-Young (2016).

Human impact on Biodiversity



We are the first generation of scientists with the tools to address the dimensions of biodiversity on Earth… and ironically we may be the last generation with the opportunity to discover and understand Earth's biodiversity before it is irrevocably changed or lost.

James Collins, February 13, 2009



The struggle for life in rapidly changing environments

Darwin's theory of evolution (from E. Mayr):

- •Every species is fertile enough that if all offspring survived to reproduce, the population would grow (fact).
- •Despite periodic fluctuations, populations remain roughly the same size (fact).
- •Resources such as food are limited and are relatively stable over time (fact).
- •A <u>struggle for survival</u> ensues (inference).
- •Individuals in a population vary significantly from one another (fact).
- •Much of this variation is <u>heritable</u> (fact).
- •Individuals less suited to the environment are less likely to survive and less likely to reproduce; individuals more suited to the environment are more likely to survive and more likely to reproduce and leave their heritable traits to future generations, which produces the process of <u>natural selection</u> (fact).
- •This slowly effected process results in populations changing to adapt to their environments, and ultimately, these variations accumulate over time to form new species (inference).

The struggle for life in rapidly changing environments

Through evolution and natural selection, living organisms are typically adapted to their environments.

In other words, their appearance, behaviour, their physiology and metabolism, or their way of life make them suited to survive and reproduce in their habitats.

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Organisms in their natural context can also respond to specific, acute environmental changes.
Organisms have adapted to live and reproduce within the range of environmental conditions experienced by their ancestors.

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Organisms in their natural context can also respond to specific, acute environmental changes.
Organisms have adapted to live and reproduce within the range of environmental conditions experienced by their ancestors.

If the environment changes outside these conditions, then population fitness (i.e. the average fitness of individuals in the population) is predicted to decline.

The current speed of environmental changes means that some life forms are unable to adapt and are lost, and many species' potential to adapt to future environments is lost.

Faced with such rapid environmental change, populations could go extinct, migrate to more suitable environments or stay and adapt to the novel conditions

Understanding the processes that underlie adaptation in changed environments is crucial.

The struggle for life in rapidly changing environments

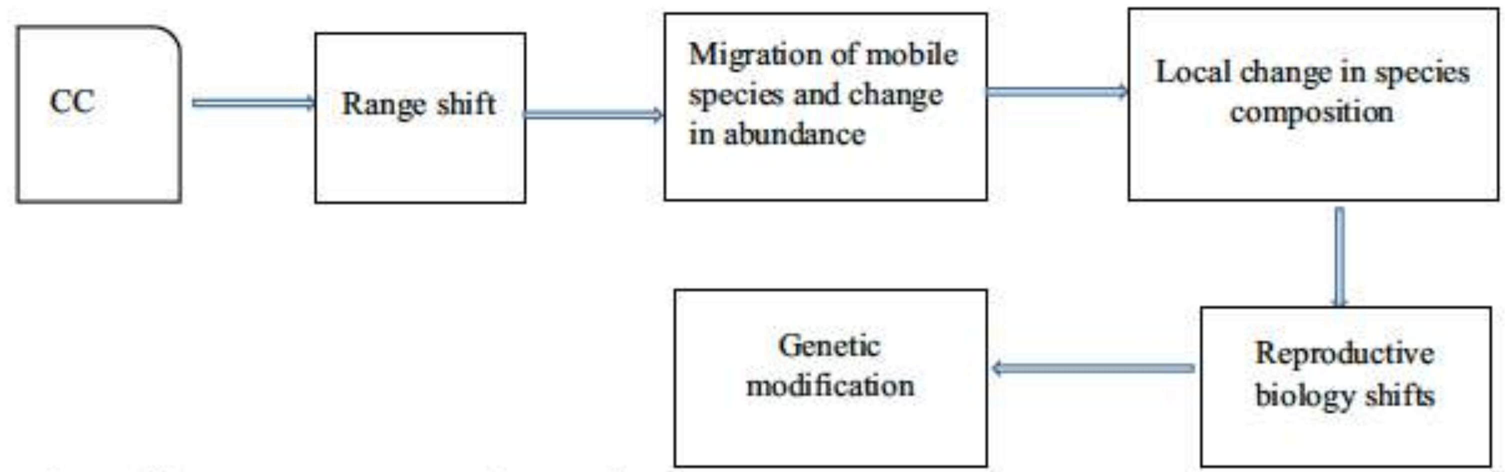

Fig. 1 Strategies that enable species to persist in a changing climate

Muluneh Agric & Food Secur (2021) 10:36 https://doi.org/10.1186/s40066-021-00318-5

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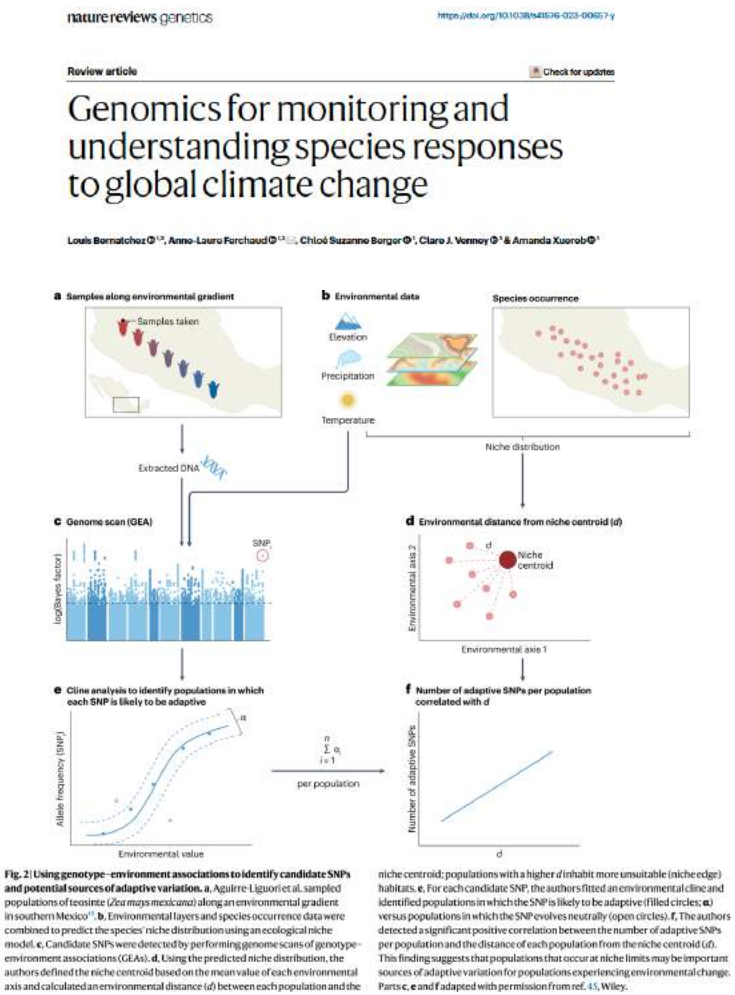
Monitoring and understanding species responses to environmental change


nature reviews genetics https://doi.org/10.1038/s41576-023-00657-y

Review article Check for updates

Genomics for monitoring and understanding species responses to global climate change

Louis Bernatchez[1,2], Anne-Laure Ferchaud[1,2], Chloé Suzanne Berger[1], Clare J. Venney[1] & Amanda Xuereb[1]

Fig. 2 | Using genotype–environment associations to identify candidate SNPs and potential sources of adaptive variation. a, Aguirre-Liguori et al. sampled populations of teosinte (*Zea mays mexicana*) along an environmental gradient in southern Mexico[45]. **b**, Environmental layers and species occurrence data were combined to predict the species' niche distribution using an ecological niche model. **c**, Candidate SNPs were detected by performing genome scans of genotype–environment associations (GEAs). **d**, Using the predicted niche distribution, the authors defined the niche centroid based on the mean value of each environmental axis and calculated an environmental distance (*d*) between each population and the niche centroid; populations with a higher *d* inhabit more unsuitable (niche edge) habitats. **e**, For each candidate SNP, the authors fitted an environmental cline and identified populations in which the SNP is likely to be adaptive (filled circles; **α**) versus populations in which the SNP evolves neutrally (open circles). **f**, The authors detected a significant positive correlation between the number of adaptive SNPs per population and the distance of each population from the niche centroid (*d*). This finding suggests that populations that occur at niche limits may be important sources of adaptive variation for populations experiencing environmental change. Parts **c**, **e** and **f** adapted with permission from ref. 45, Wiley.

Global, drastic changes in environmental conditions as a result of global climate change and other human impacts.

These environmental changes are happening rapidly, with major socioeconomic costs, and threaten biodiversity, hence diminishing a species' potential to adapt to future environments.

Understanding and monitoring how organisms respond is key for the conservation of biodiversity in a rapidly changing environment.

Recent developments in genomic, transcriptomic and epigenomic technologies are enabling unprecedented insights into the evolutionary processes and molecular bases of adaptation.

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Assessing the effects of global climate change using -omics approaches

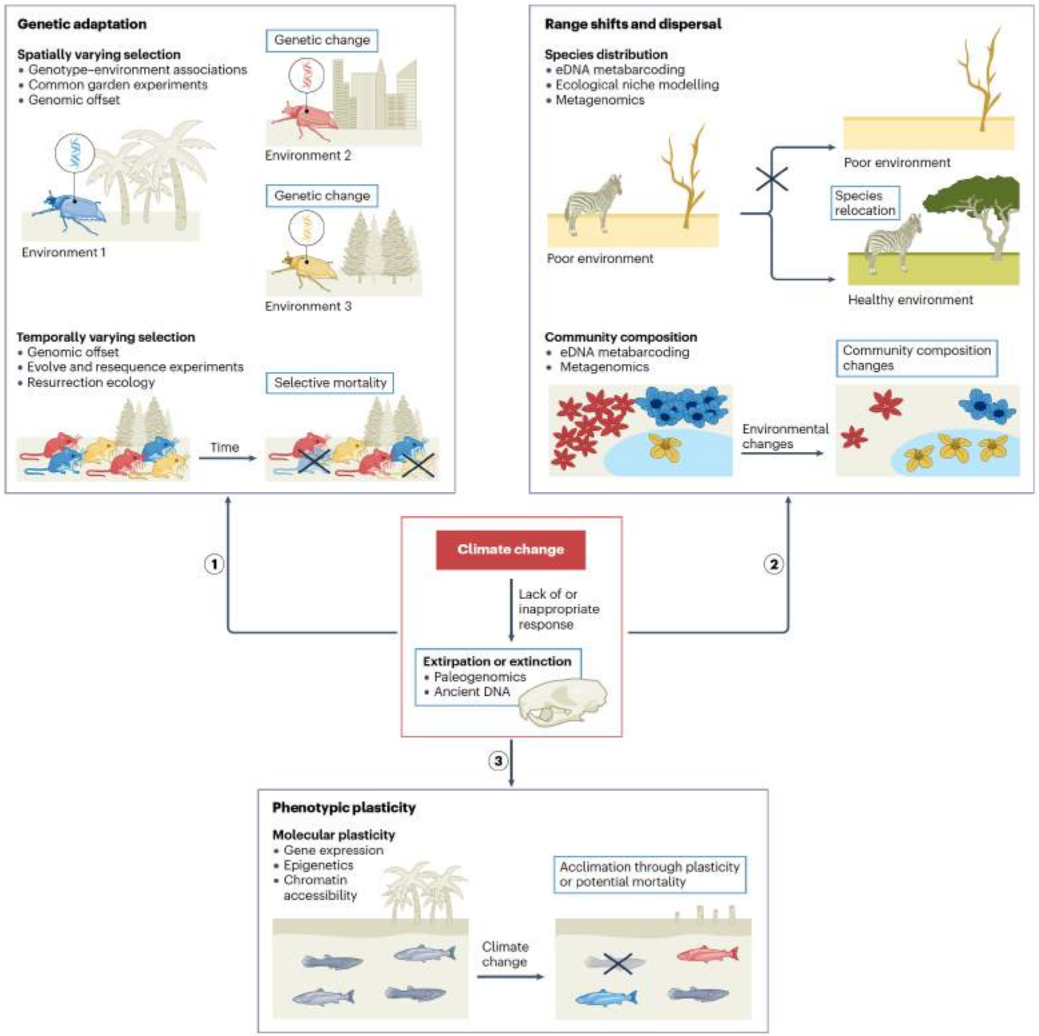
nature reviews genetics
https://doi.org/10.1038/s41576-023-00657-y
Review article

Check for updates

Genomics for monitoring and understanding species responses to global climate change

Louis Bernatchez[1,2], Anne-Laure Ferchaud[1,2], Chloé Suzanne Berger[1], Clare J. Venney[1] & Amanda Xuereb[1]

Global climate change (GCC) poses a significant threat to species, although they can adapt genetically through spatially or temporally varying selection (response 1), cope through range shifts and dispersal when possible to avoid extirpation (response 2) or acclimate to GCC through phenotypic plasticity (response 3). Various methods that integrate genomic and/or epigenomic tools (listed as bullet points) can be used in both natural environments and experimental laboratory conditions to assess how species are responding to GCC (Table 1). Lack of or inappropriate responses can result in extirpation or extinction (red box), which can also inform on the historical effects of GCC on species and communities. eDNA, environmental DNA.



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Exploring Life in its rapidly changing Natural Context

A personal take on science and society

World view

By Edith Heard

Molecular biologists: let's reconnect with nature

A New Year's resolution for bench scientists is to step out of the lab to study how life really works.

Charles Darwin's voyage on HMS *Beagle* led to a treasure trove of observations: the behaviour of cuttlefish, a parasitic ichneumon wasp feasting inside live caterpillars, fossils of extinct giant sloths and 'mastodons'. The result, of course, was his theory of natural selection.

Darwin needed the complex natural world to inspire his theory. Today's molecular biologists usually focus on specific organisms in isolation and in carefully controlled environments that have as few variables as possible. To be

> **"Darwin's 'struggle for life' has been largely unexplored at the molecular level."**

culture free-living symbionts mimicking the host microhabitat, and understand how their metabolism and morphology shift, could prompt fresh thinking around carbon fixation.

Technological advances will also allow researchers to explore organisms from volcanic coasts to the ocean depths. Sampling at sites that vary in pH, pollution, nutrients and salinity will offer insights into biodiversity and how natural and human-made changes influence it. Metabolic pathways are often at the heart of environmentally induced change. Such work can and should inspire metabolomics analysis to assess how toxins work, or prompt high-throughput biological imaging to catalogue morphological effects.

All of this means applying tools of basic research – in the wild and in the lab – to decipher molecular mechanisms that

Nature | Vol 601 | 6 January 2022

Molecular biology for green recovery—A call for action

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PERSPECTIVE

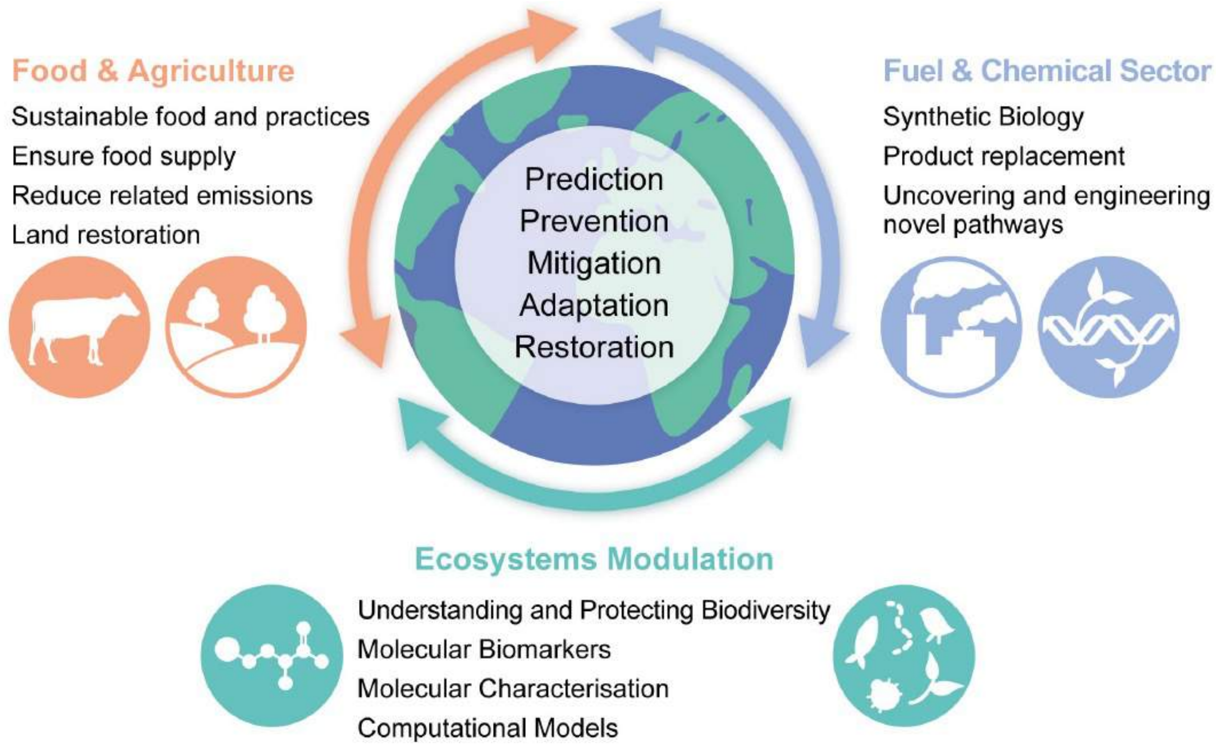
Molecular biology for green recovery—A call for action

Marta Rodríguez-Martínez[1], Jens Nielsen[2], Sam Dupont[3,4], Jessica Vamathevan[1], Beverley J. Glover[5], Lindsey C. Crosswell[6], Brendan Rouse[1], Ben F. Luisi[7], Chris Bowler[8], Susan M. Gasser[9], Detlev Arendt[1], Tobias J. Erb[10], Victor de Lorenzo[11], Edith Heard[1]*, Kiran Raosaheb Patil[12]*

1 European Molecular Biology Laboratory, Heidelberg, Germany, 2 BioInnovation Institute, Copenhagen, Denmark, 3 Department of Biological and Environmental Sciences, University of Gothenburg, The Sven Lovén Centre for Marine Infrastructure, Kristineberg, Sweden, 4 International Atomic Energy Agency, Principality of Monaco, Monaco, 5 Department of Plant Sciences, University of Cambridge, Cambridge, United Kingdom, 6 European Bioinformatics Institute (EMBL-EBI), European Molecular Biology Laboratory, Wellcome Genome Campus, Hinxton, United Kingdom, 7 Department of Biochemistry, University of Cambridge, Cambridge, United Kingdom, 8 Institut de Biologie de l'École Normale Supérieure (IBENS), Département de Biologie, École Normale Supérieure, CNRS, INSERM, Université de Recherche Paris Sciences et Lettres (Université PSL), Paris, France, 9 ISREC Foundation Agora Cancer Research Center, Lausanne, Switzerland, 10 Max Planck Institute for Terrestrial Microbiology, Marburg, Germany, 11 Systems and Synthetic Biology Department, Centro Nacional de Biotecnología (CNB-CSIC), Madrid, Spain, 12 MRC Toxicology Unit, University of Cambridge, Cambridge, United Kingdom

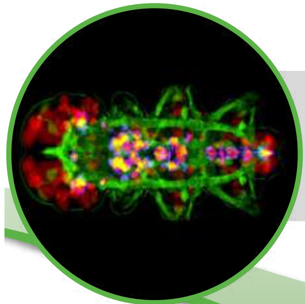
* edith.heard@embl.org (EH); kp533@mrc-tox.cam.ac.uk (KRP)

Molecular biology holds a vast potential for tackling climate change and biodiversity loss. Yet, it is largely absent from the current strategies. We call for a community-wide action to bring molecular biology to the forefront of climate change solutions.



European Molecular Biology Laboratory (EMBL)

EMBL is Europe's only intergovernmental laboratory for life sciences research



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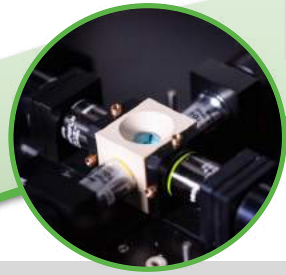

Innovation and Translation

Integrating life sciences

2000 people	**29** member states	**850** publications	**3600** annual users of experimental services	**107 million** daily web requests to EMBL-EBI data services	**8700** course and conference participants

2022 metrics

EMBL

Monitoring and understanding species responses to environmental change

From Atoms to Ecosystems:

Towards an understanding of organisms in their environment

EMBL wants to measure and understand:

- Dynamic behaviours of living systems
- Changes over different scales of time
- Perturbation effects
- Population effects
- Genes x Environment

Molecular and mechanistic levels

Quantitative methods and new technologies

Theory to understand complexity

E. Heard

https://www.embl.org/about/programme/

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Biodiversity Portal

- New EMBL service, to collate, standardise, track and present the worlds public biodiversity data across hundreds of projects
- Funded by EMBL's Planetary Biology Transversal Theme, shares technology across our portals.
- Crucially has been endorsed by Earth BioGenome Project.
- Showcases EMBL archives, data standards, research, and Ensembl standardised annotation.

https://www.ebi.ac.uk/biodiversity

Global Biodiversity Initiatives

Darwin TREE of LIFE

EARTH BIOGENOME PROJECT CANADA

EARTH BIOGENOME PROJECT

sequencing life for the future of life

African BioGenome Project

eRGA

EUROPEAN REFERENCE GENOME ATLAS

B10K

i5K

VGP VERTEBRATE GENOMES PROJECT

A PROJECT OF THE G10K CONSORTIUM

GENOME 10K

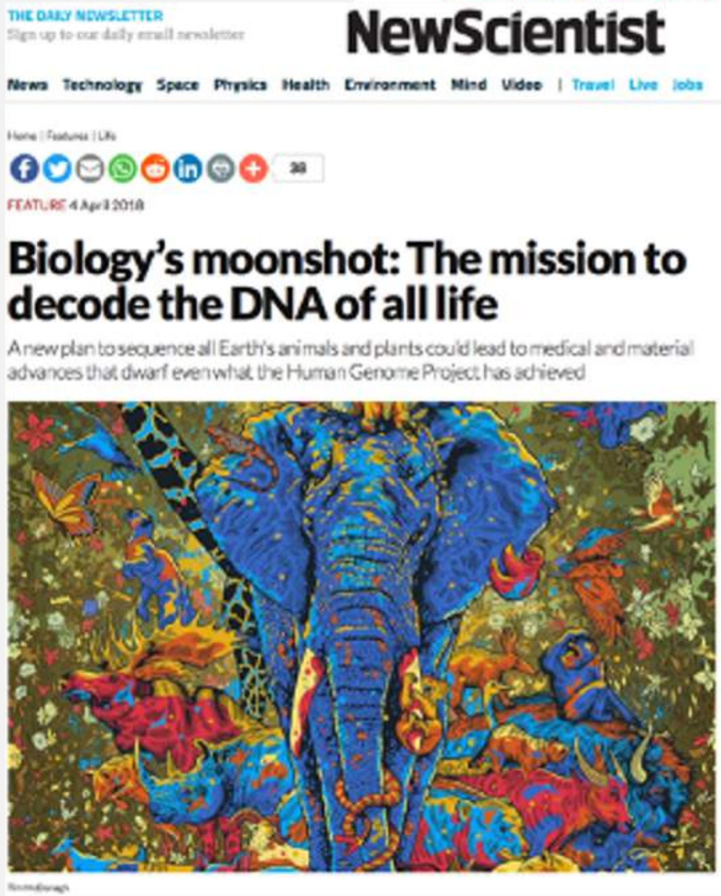
CATALAN INITIATIVE FOR THE EARTH BIOGENOME PROJECT

AQUATIC SYMBIOSIS GENOMICS

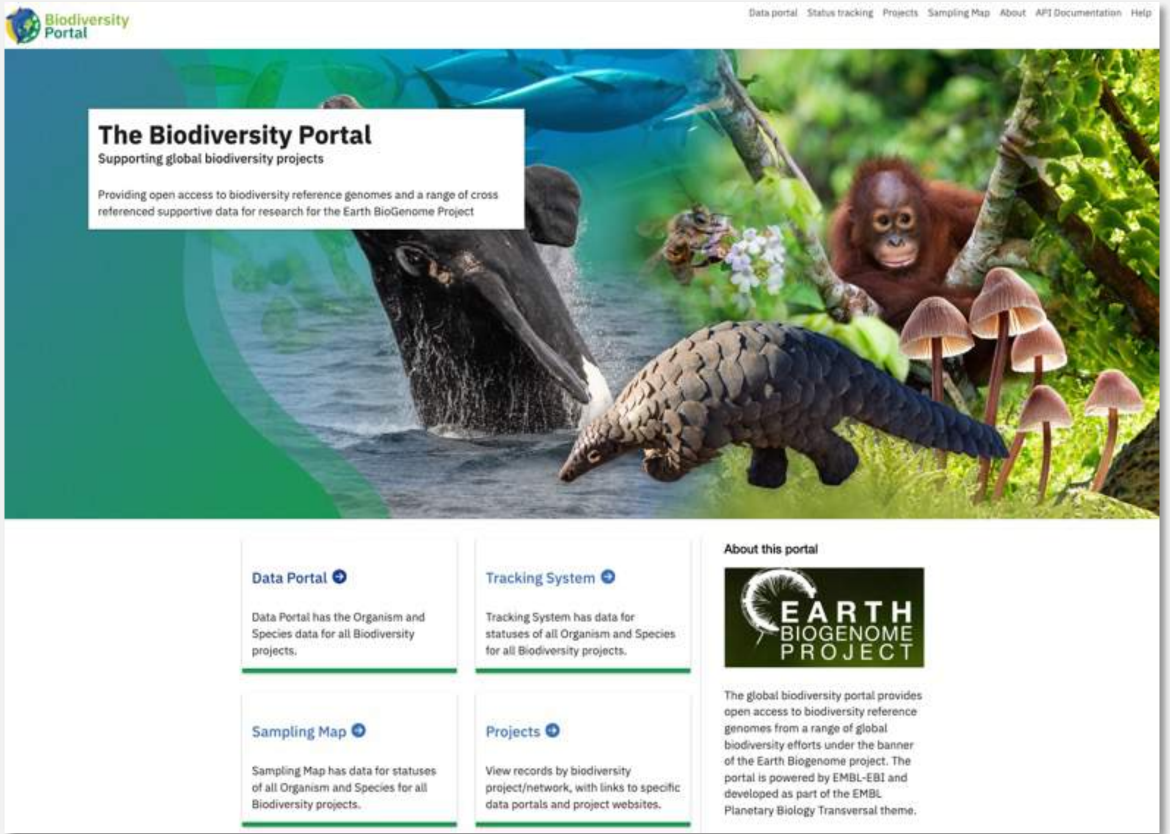
EMBL-EBI

To sequence all life for the future of life

- **Biology’s moonshot: sequence, catalogue and characterize the genomes of all of Earth’s eukaryotic biodiversity.**
- Coordinated collection of over 50 biodiversity networks.
- Sequencing more than a million taxonomically classified eukaryotic species.



Biodiversity Portal



- Single access point to fully open high quality reference genomes, raw data, publications, and Ensembl annotation.
- Status tracking key for coordination with other global projects.
- Already presenting > 7500 species.

https://www.ebi.ac.uk/biodiversity

EMBL-EBI

EMBL Flagship Project

TRaversing European Coastlines (TREC)

The Scientific Expedition and Scientific Project

- Environmental Sampling
- Across environmental gradients: natural and man-made
- Across scales: from viruses to animal and plants
- Across life complexity: from molecules to ecosystems
- Huge operation: > 200 scientist in the field
- Mobile infrastructure

https://www.embl.org/about/info/trec/

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EMBL Flagship Project

TRaversing European Coastlines (TREC)

Mobile Infrastructure

EMBL customised fleet of mobile laboratories

Schooner Tara

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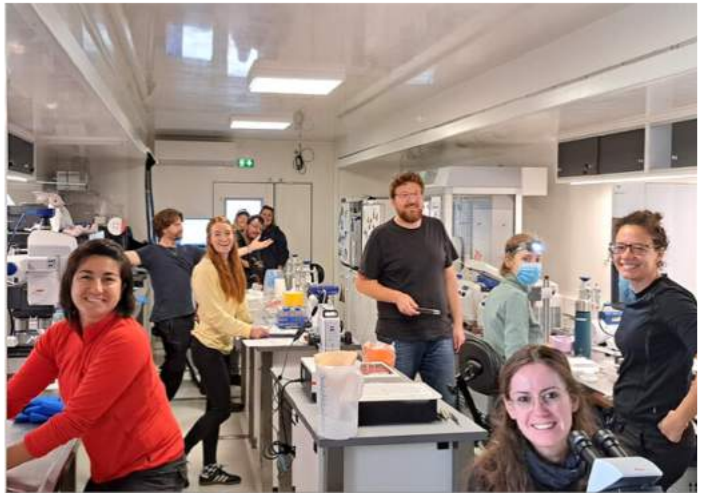
EMBL Flagship Project

TRaversing European Coastlines (TREC)

Mobile Infrastructure: Advanced Mobile Lab






12 meters long | ~22 tons weight | Hosts up to 15 scientists

High pressure freezing	Culturing	Tissue processing	Single cell transcriptomics	Feedback microscopy	Image-enabled cell sorting

Manfred Lautenschläger Stiftung | ThermoFisher Scientific | ZEISS | eppendorf | TED PELLA, INC. | SIXT | Supported by Friends of EMBL

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TRaversing European Coastlines (TREC)

> 100 Sampling Sites

Pristine Nature

Agricultural sites

Cities

River outputs

Touristic areas

Ports

https://www.embl.org/about/info/trec/

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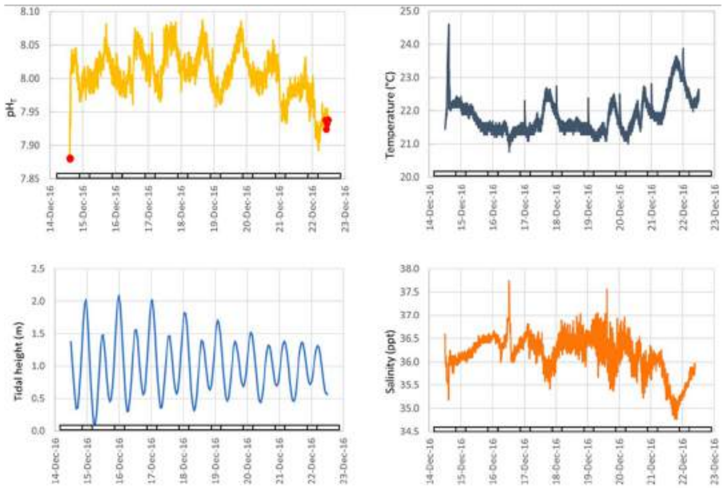
TRaversing European Coastlines (TREC)

Linked to Historical Data

Pristine Nature | **Agricultural sites** | **Cities**

Local monitoring sites



River outputs | **Touristic areas** | **Ports**

https://www.embl.org/about/info/trec/

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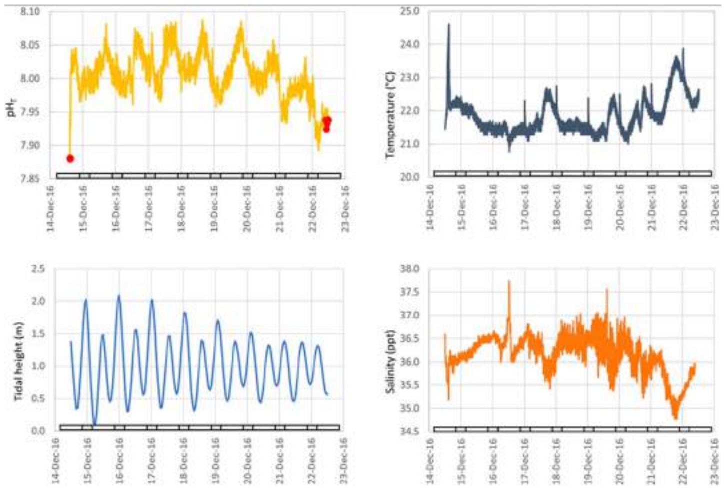
TRaversing European Coastlines (TREC)

Follow up with Time Series

Pristine Nature | **Agricultural sites** | **Cities**

TREC monitoring sites



River outputs | **Touristic areas** | **Ports**

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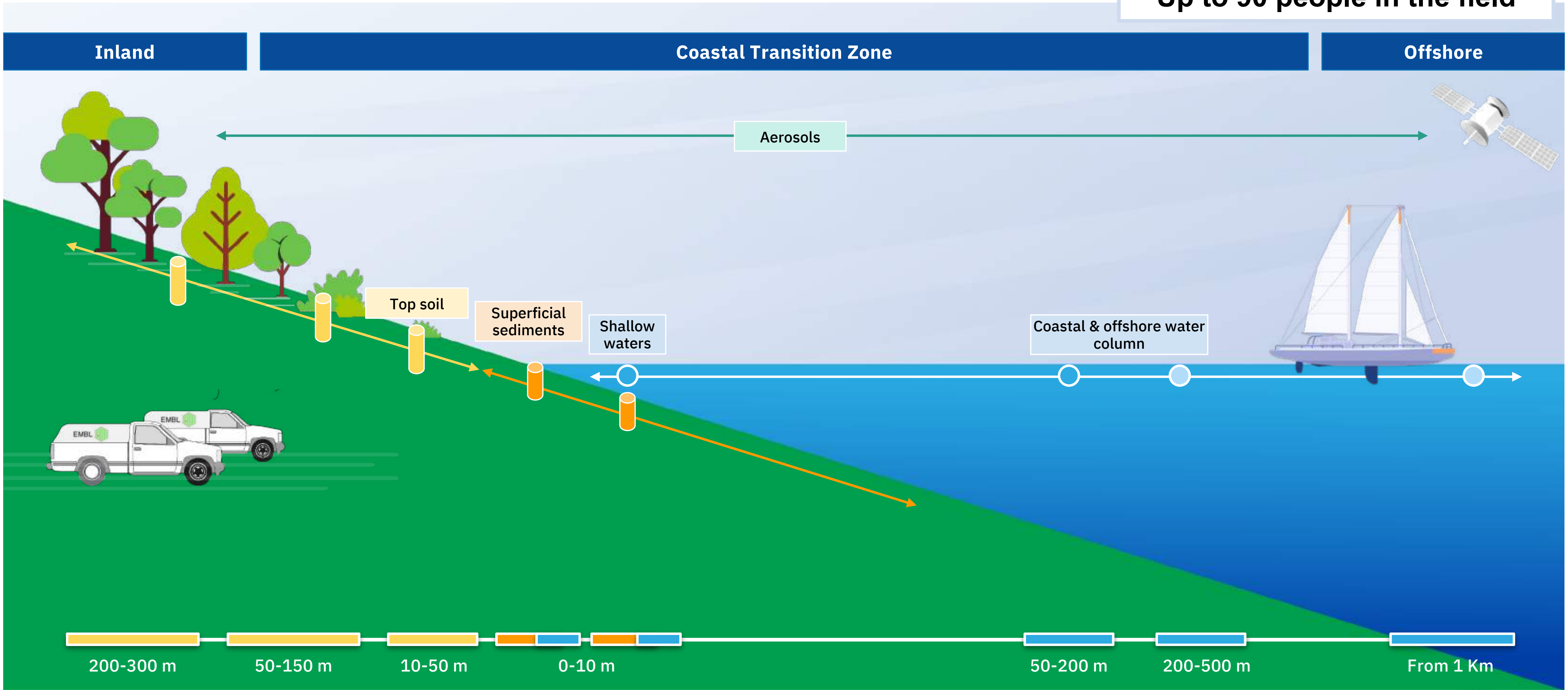
TRaversing European Coastlines (TREC)

Up to 90 people in the field



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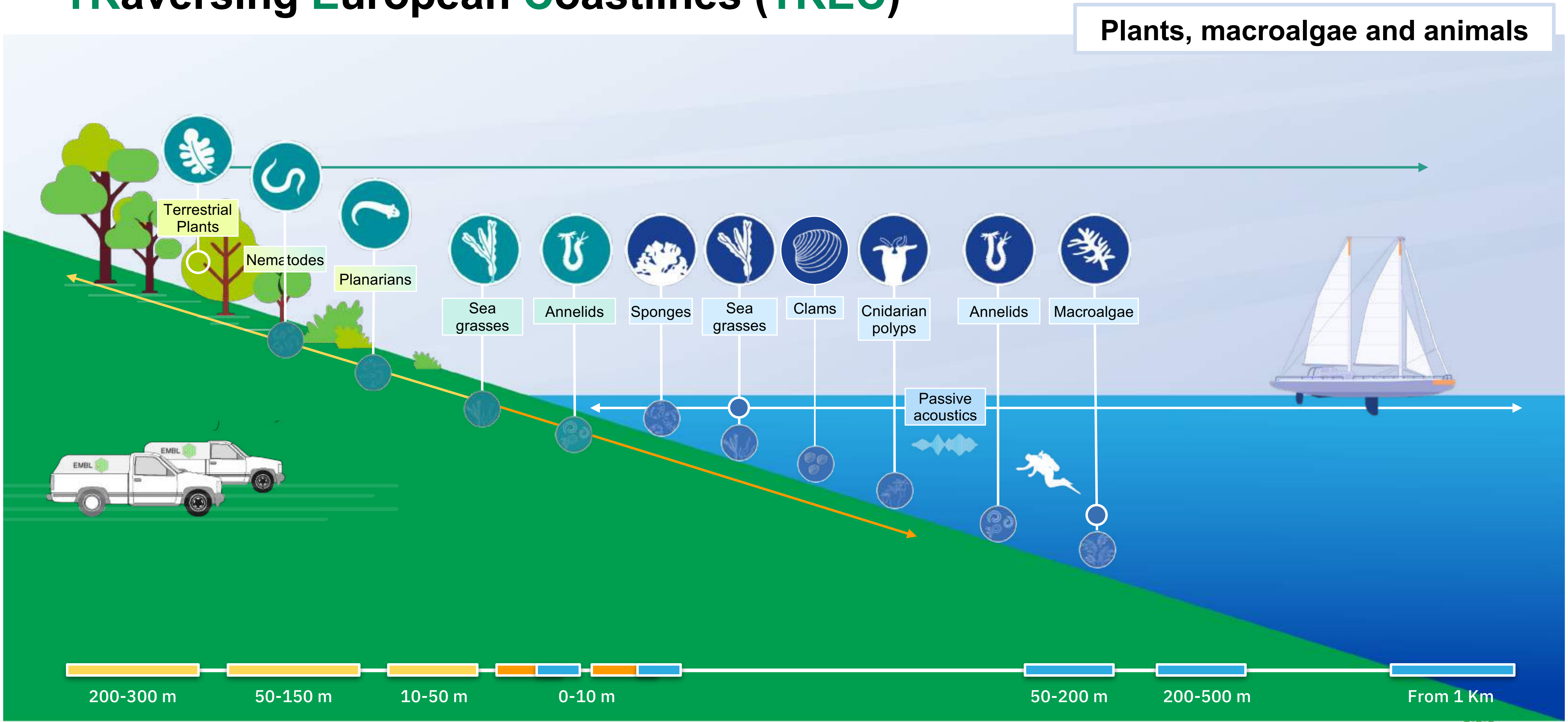
TRaversing European Coastlines (TREC)



https://www.embl.org/about/info/trec/

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TRaversing European Coastlines (TREC)

What has been done in 2023?

33.000 samples

- Performing > 200 protocols
- 65 LSI sampling sites
- 99 Tara stations
- 7 selected species subtidal sampling sites
- 11 selected intertidal species sampling sites
- 5 super sites AML

30.000 expected

https://www.embl.org/about/info/trec/

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What happens to organisms in the face of sudden acute environmental change: New or extreme stimulus, or unexpected fluctuations in the environment?

What processes underlie successful responses to cope with acute stress (more next week):

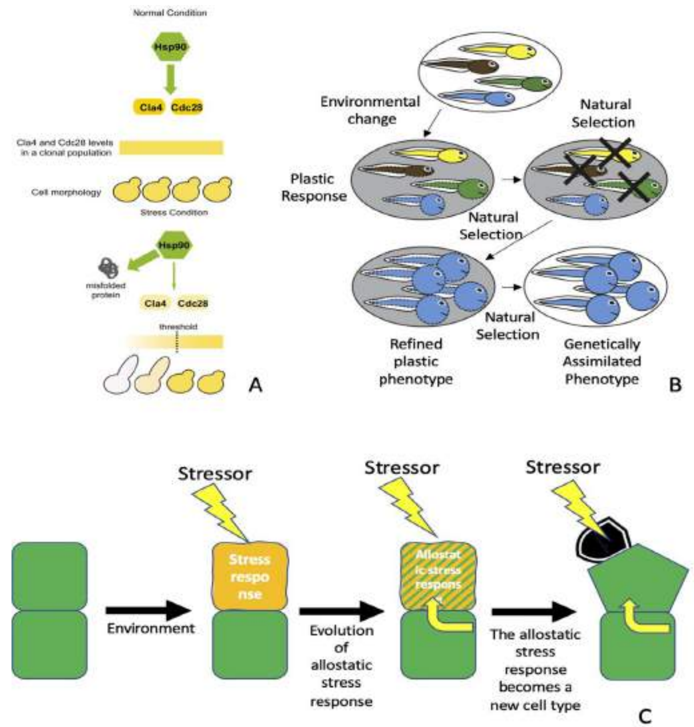
A major physiological response to environmental change is **cellular stress**, which is counteracted by generic stress reactions detoxifying the cell. If stress is minor, the cellular homeostasis response is deployed to ensure homeostasis.

However, the capacity of this response may be exceeded if the magnitude of stress is too great or arises to rapidly.

Under these circumstances, the CSR can employ physiological mechanisms of stress-induced evolution (SIE).

These are strategies by which individuals rapidly generate new heritable phenotypes.

At the population level, SIE produces widespread phenotypic variation and therefore accelerates evolutionary processes.

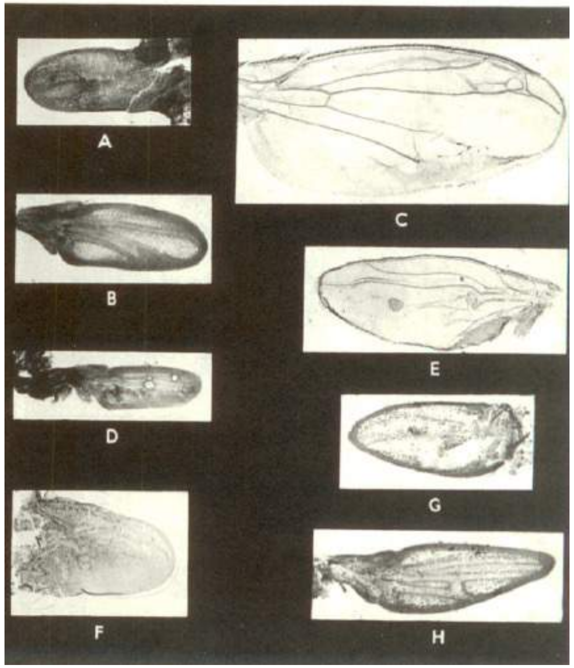


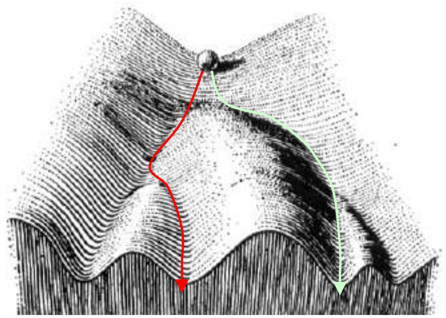
DOI: (10.1111/evo.14421)

COLLÈGE DE FRANCE 1530

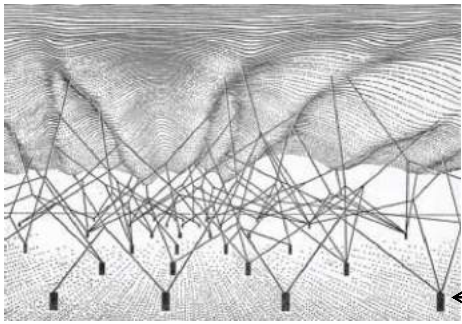
Returning to Waddington

Drosophila wing development – affected by 30 loci.
In first 48h after larva enters pupa, wings undergo at least 15 different processes, each of which is affected by a known gene





Different fates



Buffering (canalization):
Up to a certain threshold, genetic or environmental variation will not affect the pathway

'Canalization' means that, up to a certain threshold, any genetic variation or environmental noise will be 'buffered' and not affect the pathway, but above this threshold, the cell would flip over into an adjacent pathway.

By representing a pathway as a valley in a surface, Waddington provided a simple mechanical analogy for the rather complex biochemical/genetic buffering that occurs in organisms during development.

This representation has its limitations though particularly in the conceptualisation of the role that the environment plays (refs. L. Loison)
more next week

Some genes can change the **topology** of the landscape
- Leading to alternate paths if activated
- Changing cell pathways if mutated

Conrad H. Waddington (1957)
The strategy of the genes (London: Allen and Unwin)

E. Heard,

Returning to Waddington

Genetic Assimilation

Genetic assimilation is a process by which a phenotype originally produced in response to an environmental condition, such as exposure to thermal shock or ether, later becomes genetically "fixed" either via artificial selection or natural selection.

more next week

GENETIC ASSIMILATION

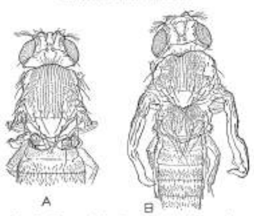


FIG. 2. Two typical phenocopies (medium and extreme in grade). Mesothoracic wings removed in 2a, metathoracic wings partly concealed by the abdomen in 2b.

ASSIMILATION OF ACQUIRED CHARACTER

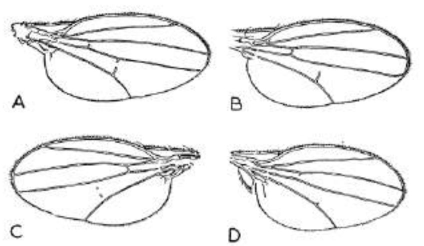


FIG. 1. Four crossveinless wings: a grade 4, b grade 3, c grade 2, d grade 1.

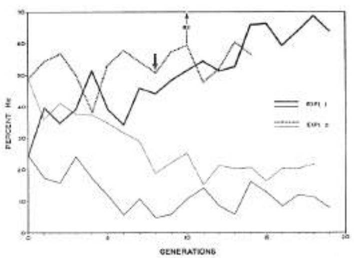


FIG. 1. Percentage of He (= bithorax-like) phenocopies in successive generations of upward and downward selection, following ether treatment of the eggs. The figures relate to flies which emerged from the puparia. At generation 10 in Experiment II, a count was made of all flies in a sample, including those failing to emerge and a percentage of 82 He found. The arrow at gen. 8 in Experiment II indicates the point at which the first assimilated stocks appeared.

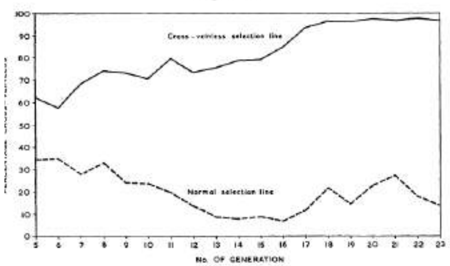
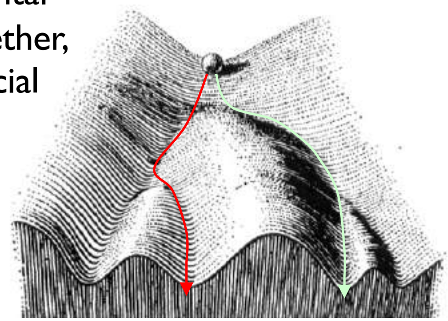


FIG. 2. The response to selection, from generation 5 onwards, for crossveinless wings ("upward" selection) and normal wings ("downward" selection).

E. Heard,



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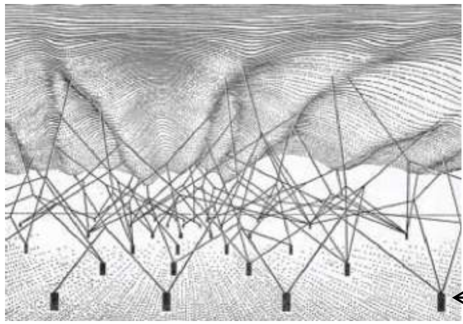

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more next week

Some genes can change the **topology** of the landscape

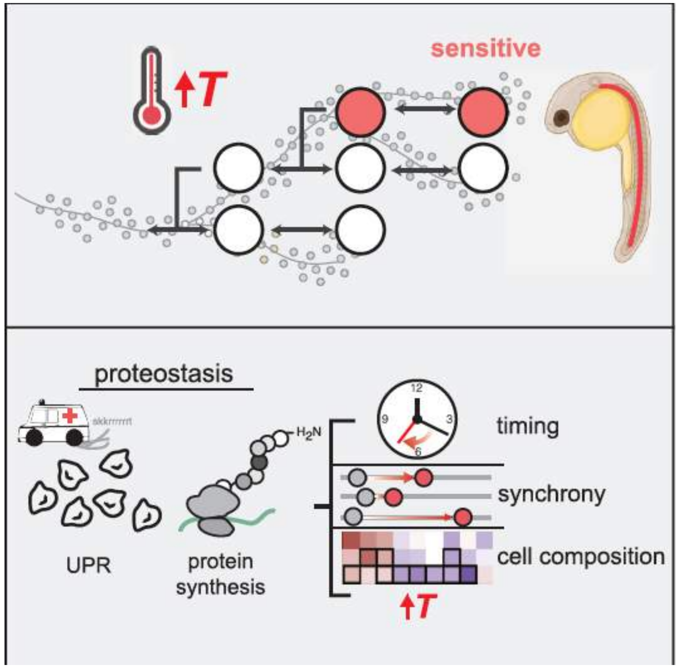
- Leading to alternate paths if activated
- Changing cell pathways if mutated

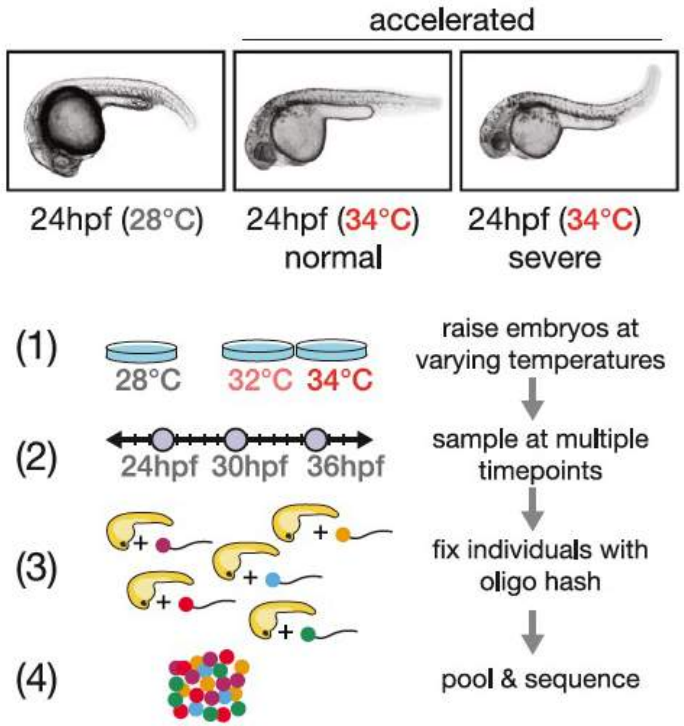
What happens to organisms in the face of sudden acute environmental change

Article

Proteostasis governs differential temperature sensitivity across embryonic cell types

Michael W. Dorrity,[1,2,*] Lauren M. Saunders,[1] Madeleine Duran,[1] Sanjay R. Srivatsan,[1] Eliza Barkan,[1] Dana L. Jackson,[1] Sydney M. Sattler,[1] Brent Ewing,[1] Christine Queitsch,[1] Jay Shendure,[1,5,6] David W. Raible,[4] David Kimelman,[3] and Cole Trapnell[1,7,*]





Highlights

- Individual-level scRNA quantifies variability in embryogenesis
- Digital embryo staging permits time-controlled statistical analysis
- Temperature accelerates developmental rate non-uniformly across cell types
- Sensitivity of notochord sheath cells via UPR-dependent control of proteostasis

E. Heard

COLLÈGE DE FRANCE 1530

Maladaptive response to increased temperature can lead to reduced fitness

Article

Proteostasis governs differential temperature sensitivity across embryonic cell types

Michael W. Dorrity,[1,2,*] Lauren M. Saunders,[1] Madeleine Duran,[1] Sanjay R. Srivatsan,[1] Eliza Barkan,[1] Dana L. Jackson,[1] Sydney M. Sattler,[1] Brent Ewing,[1] Christine Queitsch,[1] Jay Shendure,[1,5,6] David W. Raible,[4] David Kimelman,[3] and Cole Trapnell[1,7,*]

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- Study shows that zebrafish embryos raised at elevated temperature have altered cell type composition and differential gene expression at important junctures of organogenesis.
- The study was performed on lab population, with high time resolution and cellular coverage of many biological replicate embryos from the commonly studied AB laboratory strain
- However the adaptive relevance in wild zebrafish remains to be ascertained (lab populations of zebrafish may show reduced plasticity and so, be less resilient than wild counterparts?)
- Warming water systems create an urgent need for further studies in natural populations and related species to explore this question.

E. Heard

COLLÈGE DE FRANCE 1530

Adaptation to novel environmental conditions

How populations and species respond to modified environmental conditions is critical to their survival and persistence both now and into the future, particularly given the increasing pace of environmental change.

Adaptation concerns the genetic changes that are passed on from one generation to the next that <u>improve a species' ability to survive in its environment</u>

The process of adaptation to novel environmental conditions can occur via at least two mechanisms:

(1) evolution via selection for particular phenotypes, resulting in the modification of genetic variation in the population.

(2) the expression of phenotypic plasticity (the ability of one genotype to express varying phenotypes when exposed to different environmental conditions)

Plasticity, because it acts at the level of the individual, is often hailed as a rapid-response mechanism that will enable organisms to adapt and survive in our rapidly changing world.

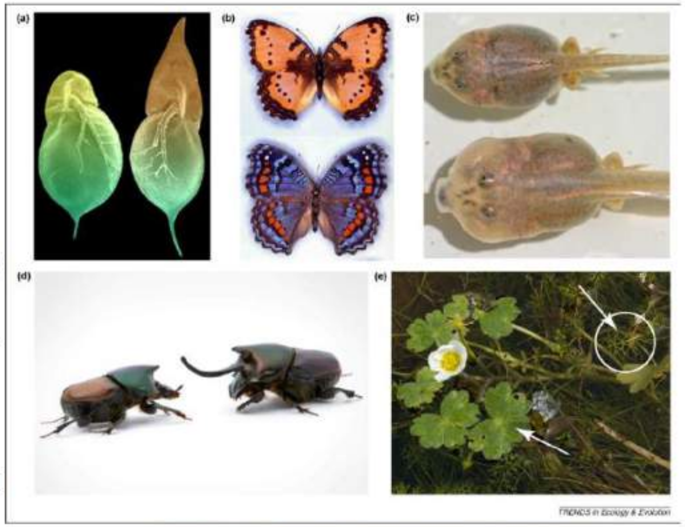
However, plasticity can also retard adaptation by shifting the distribution of phenotypes in the population, shielding it from natural selection. Furthermore, not all plastic responses are adaptive. Plasticity can be maladaptive, meaning that it does not always facilitate selection for adaptive genotypes.

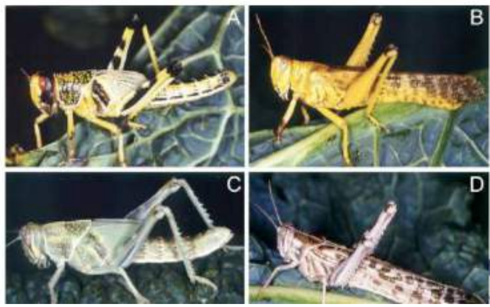
Adapted from Fox et al, 2019 Proc of the Royal Society

Phenotypic Plasticity and Polyphenism

Developmental and Phenotypic Plasticity, Polyphenism

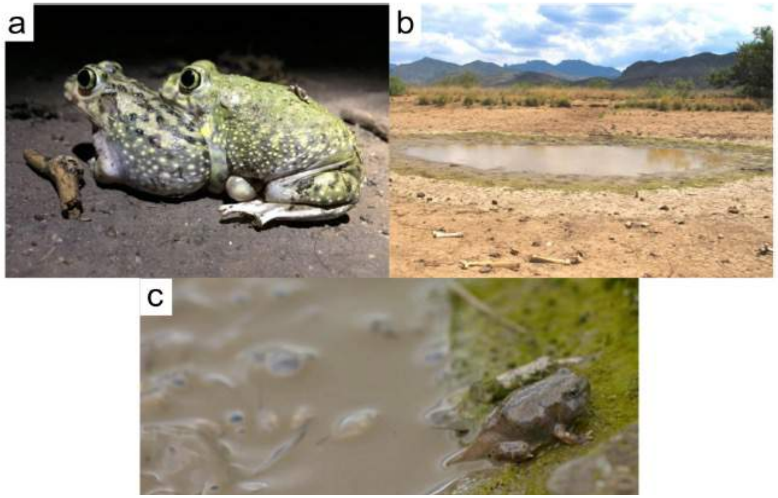
- Most species can display some degree of phenotypic plasticity – either distinctly stable « morphs » - or continuum of traits
- It can be functional (and potentially adaptive), inevitable (neutral or deleterious)
- It can an be restricted to a few minutes, to a whole life time, or to many generations
- How one genotype can give rise to different phenotypes through environmental effects is clearly an EPIGENETICS question
- Back to Waddington's original definition – but actual mechanisms are still elusive



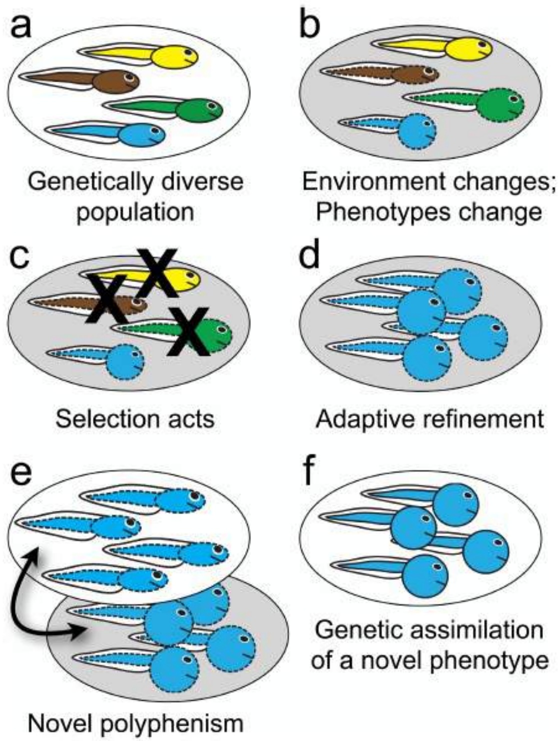


What happens to organisms in the face of sudden acute environmental change: New or extreme stimulus, or unexpected fluctuations in the environment?

- What processes underlie successful responses to cope with novel conditions?
- Phenotypic plasticity is an immediate response that enables individuals to survive under rapid change



(a) Spadefoots from the southwestern U.S. (such as this Couch's spadefoot toad, Scaphiopus couchii) typically breed in (b)temporary rain-filled ponds. (c) This harsh environment has favored rapid, but environmentally sensitive, development (here, a metamorph of a Mexican spadefoot toad,Spea multiplicata, emerges from a drying pond).



N.A. Levis, D.W. Pfennig / Seminars in Cell & Developmental Biology 88 (2019) 80–90

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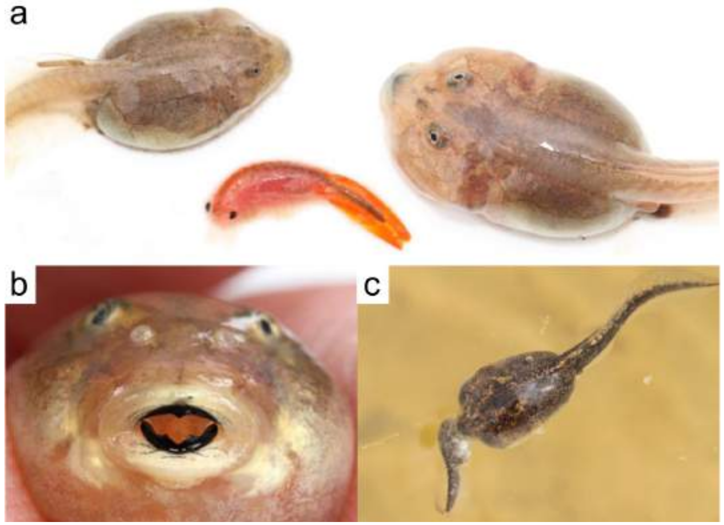

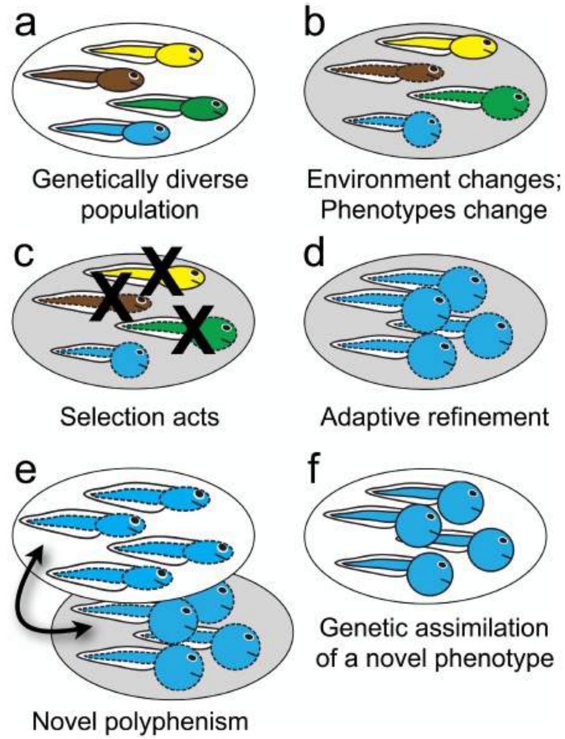

North American spadefoot toads of the genus Spea have evolved a unique resource polyphenism. (a) Like most anuran tadpoles, spadefoots normally develop into atypical 'omnivore' morph by default (pictured on the left). However, if a young tadpole ingests large animal prey, such as Anostracan fairy shrimp (center), it might developinto a novel carnivore morph (right). (b) Among other novel features, carnivores develop a keratinized beak, which they use to grasp large prey, such as (c) other tadpoles.

N.A. Levis, D.W. Pfennig / Seminars in Cell & Developmental Biology 88 (2019) 80–90

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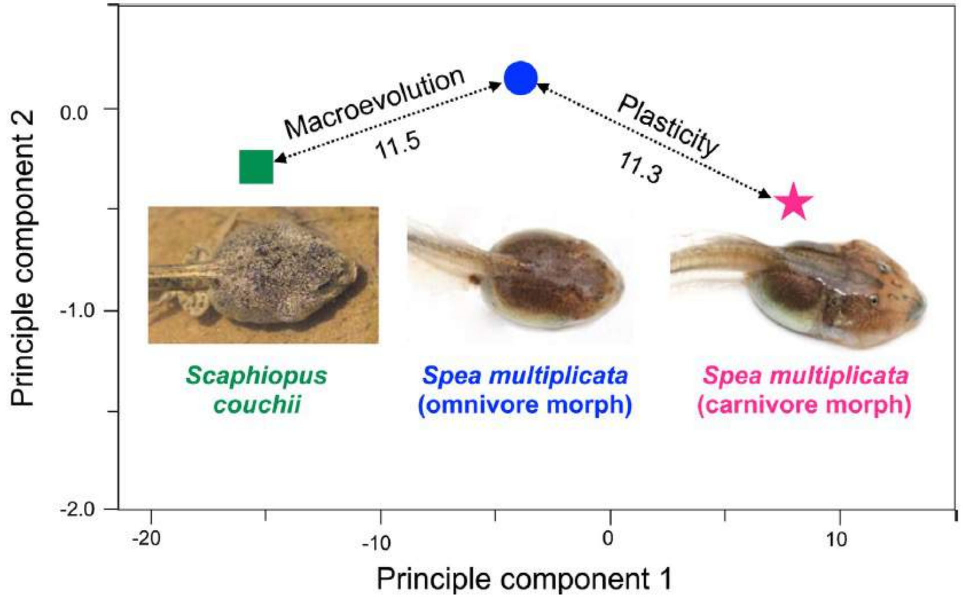
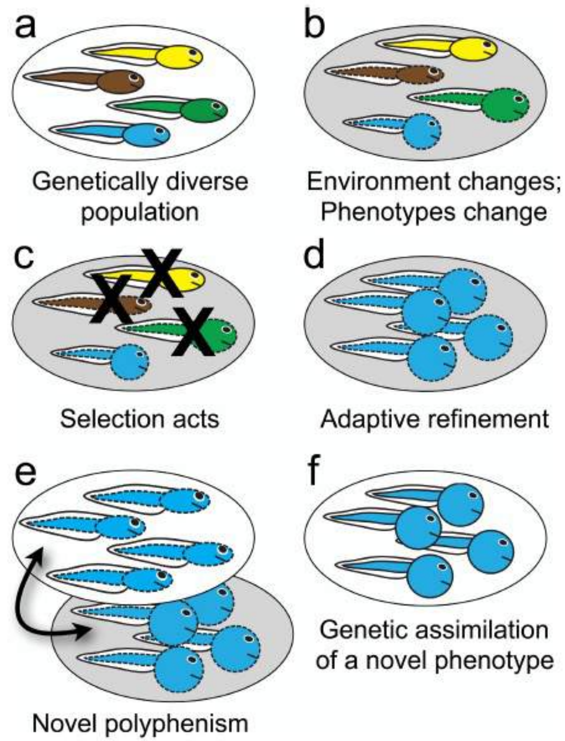


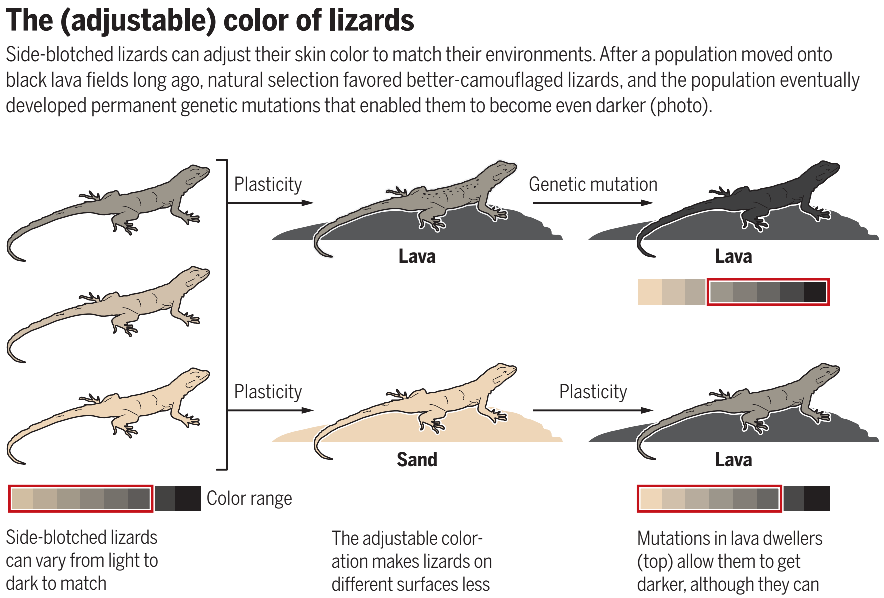


Plasticity can generate phenotypic divergence within species as great as that between species.
Depending on their diet, spadefoot toad tadpoles in the genus Speadevelop into either an omnivore morph or a carnivore morph.
An analysis of body shape reveals that these two morphs (in this case, within Sp. multiplicata) are as divergent as are the tadpoles of different genera of spadefoot toads (numbers denote least squares mean differences between morphs/species in principle component space).

N.A. Levis, D.W. Pfennig / Seminars in Cell & Developmental Biology 88 (2019) 80–90

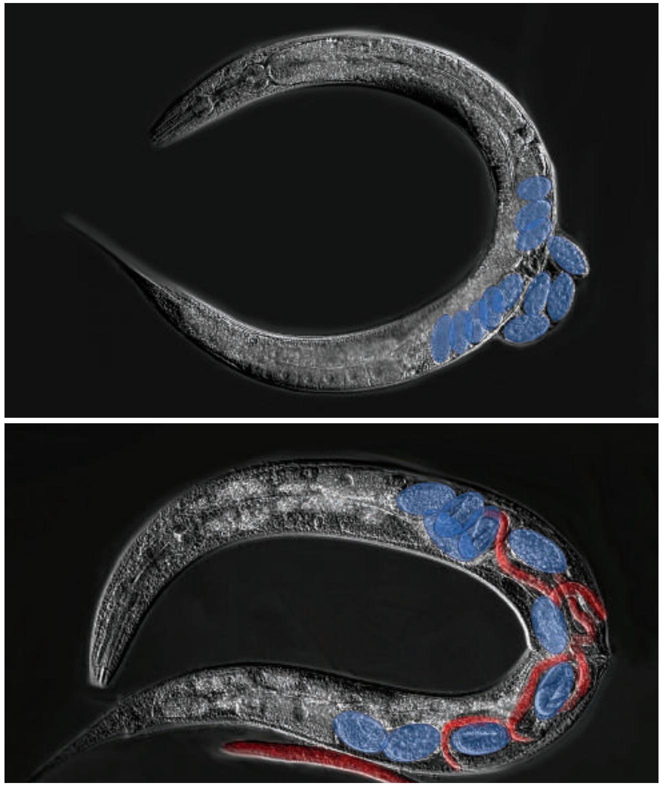
1530

A plastic response can pave the way for permanent adaptations



- Individual side-blotched lizards can change colors in a new environment - darker on lava, lighter on sand – in weeks
- However some lizards from a sandy environment did not get as dark on lava as the regular lava dwellers, suggesting a genetic difference in the lizards' ability to change color.
- PREP and PRKA1A genes regulate coloration and differ between populations on and off the lava
- <u>Mutations</u> in the population adapted to the lava flow make these lizards darker than others.
- However this fixation probably took 20 000 years…

A plastic response can pave the way for permanent adaptations



The millimeter-long nematode Caenorhabditis elegans normally lays eggs (top), but when food is scarce the eggs (blue) hatch internally and the young (red) consume their mother from within (bottom).

E. Heard

How are apparently "acquired" traits inherited (Lamarck)?

Phenotypic plasticity is built in fact built into the genetic code/

When an "acquired" trait becomes permanent, it is because of mutations that "fixed" the plastic trait—a process call genetic assimilation.

Are these mutations, new ones (de novo), or existing mutations in the population (standing genetic variation), or even trans-generational heritable epimutations?

Mary Jan West-Eberhad (2002) proposed that in the face of an environmental challenge, plasticity built into the genome (of some species) enables at least some members of a species to cope.

This would "buy time" for adaptive mutations to arise and be selected. In the populations.

Some of those (pre-existing or de novo) genetic changes would simply increase the proportion of the most flexible individuals. Others might favor a specific trait.

COLLÈGE DE FRANCE 1530

Plasticity and epigenetic mechanisms in evolutionary responses to novel conditions

- Phenotypic plasticity is an immediate response that enables individuals to survive under rapid change
- Yet, it might also be limited and associated with costs.
- Moreover, ancestral plasticity in the old environment might not be adaptive in the new environment
- Evolution may be needed to avoid population extinction under new conditions
- Phenotypic plasticity may both slow down or accelerate evolutionary responses to novel conditions – ie "buying time" until a genetic mutation or combination comes about
- Plasticity can clearly be important in the context of species' adpation to man-made environmental change – but the timescale of different types of plasticity may be more or less useful for adaptation to different types of rapid evironmental changes.

- Epigenetic mechanisms might contribute to more rapid adaptive plasticity in a new environment
- Environmentally-induced epigenetic modifications (e.g., DNA methylation) might particularly contribute during the initial phases of exposure to a new environment (buying time... also more flexible/reversible)

doi:10.1002/evl3.273

Pollution induces epigenetic effects that are stably transmitted across multiple generations

Ewan Harney,[1,2,3,*] Steve Paterson,[1,4,*] Hélène Collin,[1] Brian H.K. Chan,[1,5] Daimark Bennett,[6] and Stewart J. Plaistow[1,7]

E. Heard

OXFORD

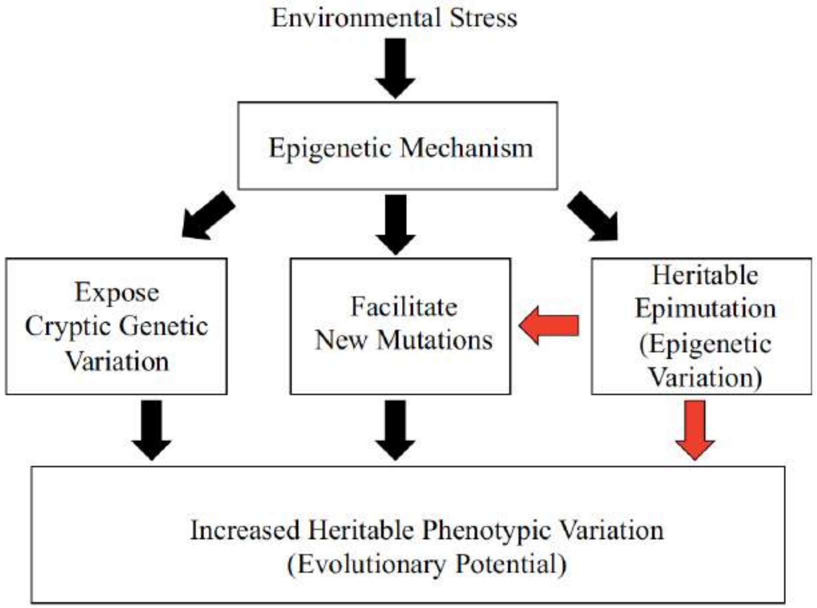
Evolution Letters, 2024, 8(1), 76–88
https://doi.org/10.1093/evlett/qrac007
Advance access publication 31 January 2023
Letter

Plasticity and associated epigenetic mechanisms play a role in thermal evolution during range expansion

Janne Swaegers[1], Simon De Cupere[1], Noah Gaens[1], Lesley T. Lancaster[2], José A. Carbonell[3], Rosa A. Sánchez Guillén[4], Robby Stoks[1]

1530

Different ways in which environmental change could increase heritable phenotypic variation



- Exposing cryptic genetic variation (eg demethylation or chromatin remodeling – activate silent gene)
- Generating genetic variation (eg epigenetic mechanisms control transposable tlement (TE) activity and TE-mediated mutations)
- Creating more heritable epigenetic variation

O'Dea et al, 2012