« Nature's Unifying patterns » à la lumière de l'évolution

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Nature's Unifying Patterns

Learning from nature's overarching design lessons.

biomimetics

Review

Revisiting Nature's "Unifying Patterns": A Biological Appraisal

Guillaume Lecointre [1,*], Annabelle Aish [2], Nadia Améziane [1], Tarik Chekchak [3], Christophe Goupil [4], Philippe Grandcolas [1], Julian F. V. Vincent [5] and Jian-Sheng Sun [6]

10 of nature's unifying patterns to consider

Click any of the patterns below for a detailed explanation and examples.

- **Nature uses only the energy it needs and relies on freely available energy.**
- **Nature recycles all materials.**
- **Nature is resilient to disturbances.**
- **Nature tends to optimize rather than maximize.**
- **Nature provides mutual benefits.**
- **Nature runs on information.**
- **Nature uses chemistry and materials that are safe for living beings.**
- **Nature builds using abundant resources, incorporating rare resources only sparingly.**
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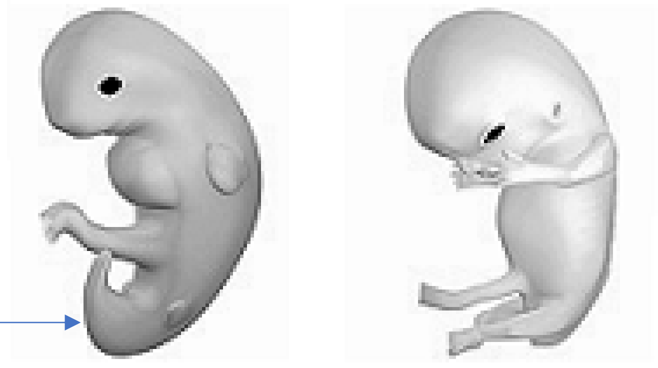
Nature-Totalité

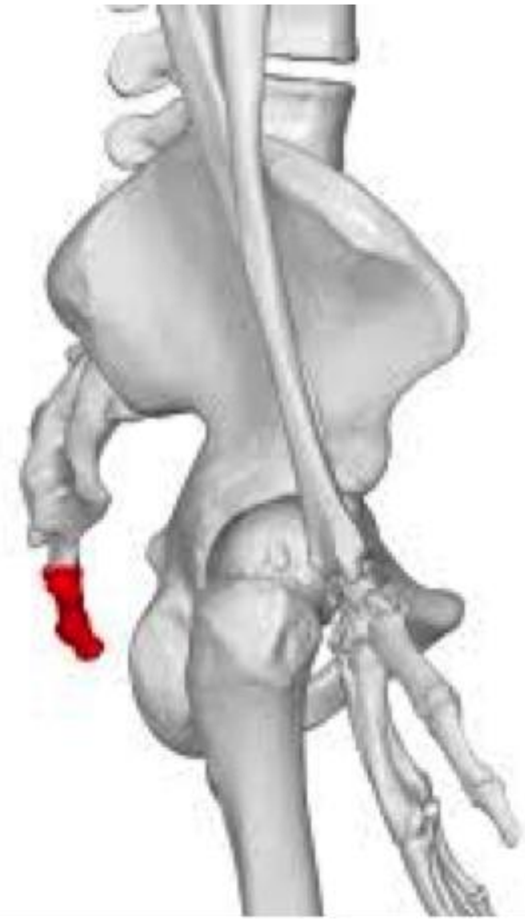
Nature-Altérité (Maris, 2018)

En science, la « Nature » n’est pas une cause :
C’est ce que nous avons le devoir d’expliquer scientifiquement

Par conséquent, la « Nature » ne peut pas être sujet du verbe

Perte d’énergie





Longue queue à la sixième semaine de développement (9 vertèbres caudales, 1/6 de la longueur de l’embryon)

Résorption à partir de la 8e semaine de développement : 5 vertèbres fusionnées

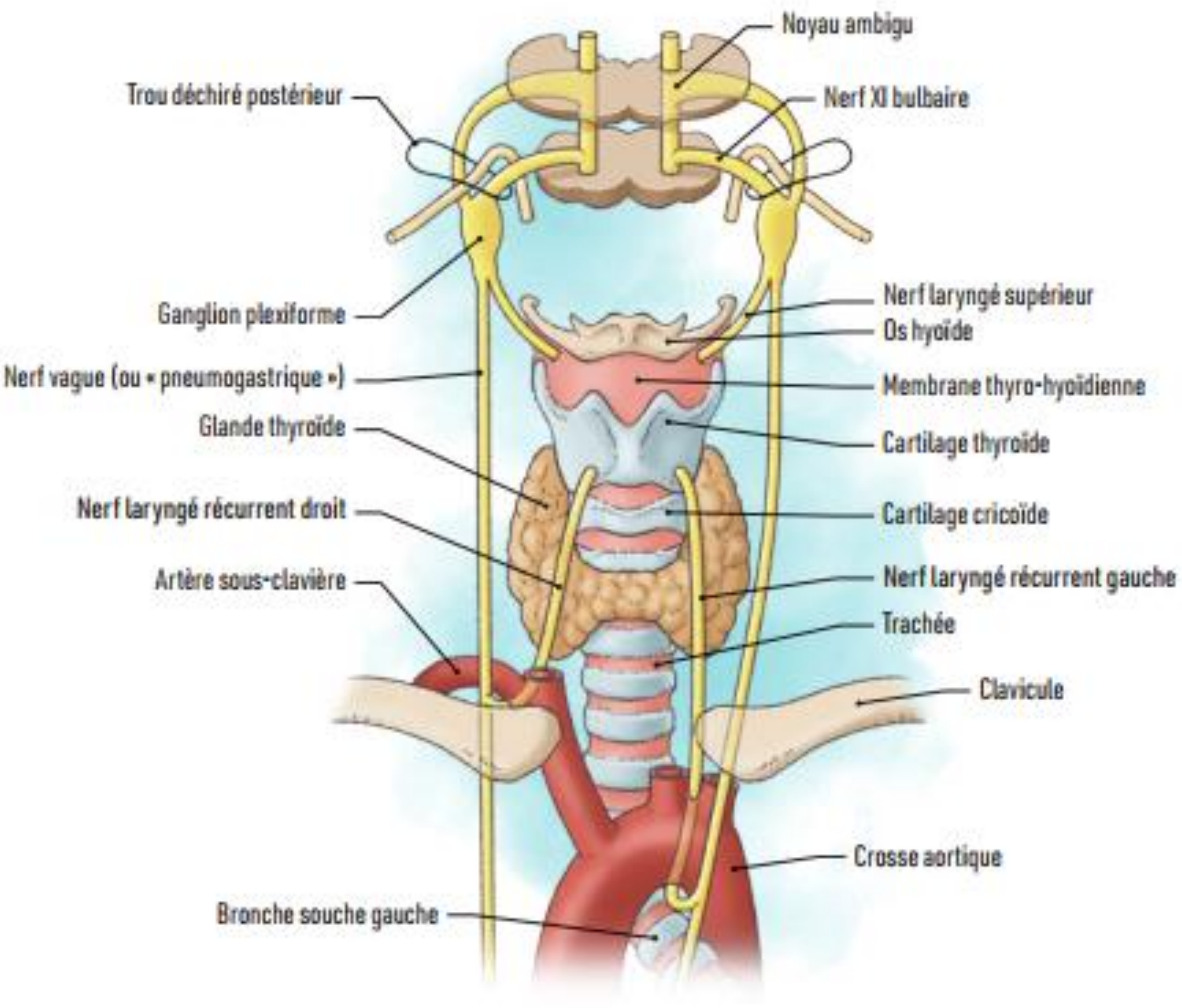
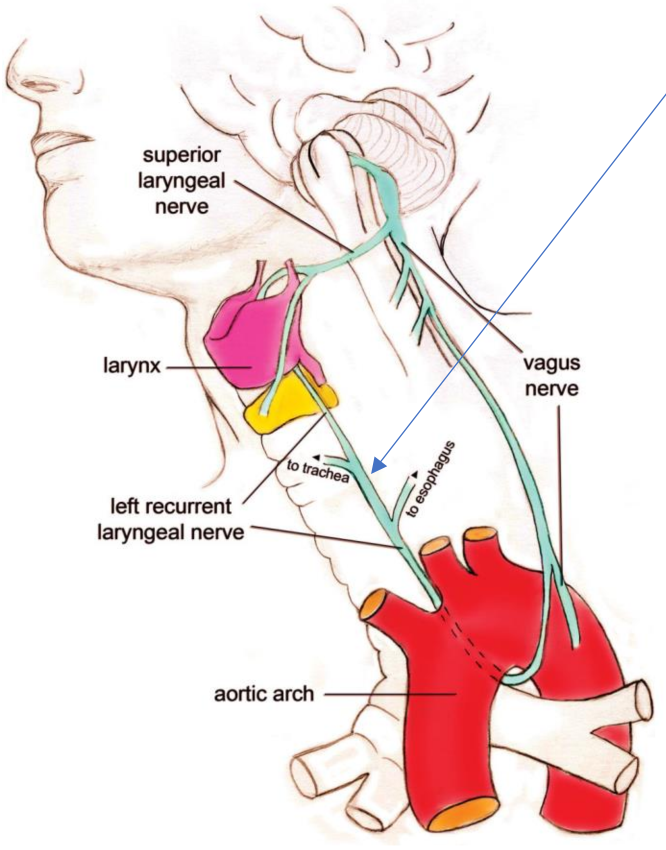
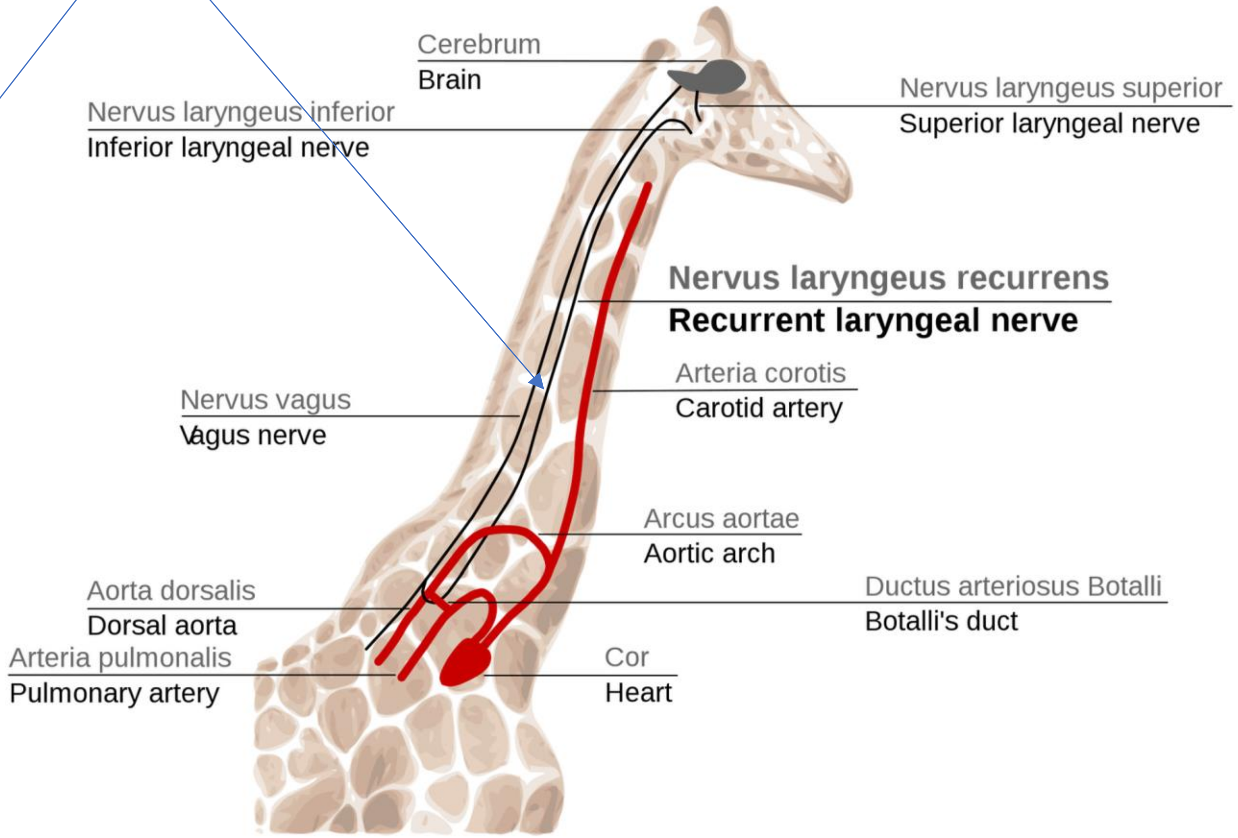


Figure 7. Disposition générale du nerf laryngé, en vue ventrale (la tête est vers le haut, le cœur vers le bas). Le cartilage thyroïde correspond à la bosse que nous avons à l'avant du cou, appelée communément la « glotte ». Sur cette figure, les muscles ne sont pas représentés.

Perte d'énergie

Perte d’énergie





C’est plus compliqué que ça…

- In terms of reproduction, both internal and external constraints can lead to higher energy expenditure than might be inferred from observation of adult populations. Evolutionary processes require considerable amounts of energy—either from the organism’s point of view (number of gametes produced) or from the population’s (number of deaths). However, natural selection seems to ultimately favour physiological systems that minimise energy expenditure.

- En termes de reproduction, des contraintes internes comme externes peuvent conduire à des « dépenses » d’énergie étonnantes en rapport à ce qu’on observe à partir des seules populations adultes. Les processus évolutifs requièrent des quantités considérables d’énergie, autant du point de vie de l’organisme (nombre de gamètes produits) que du point de vue de la population (nombre de morts). Cependant la sélection naturelle semble favoriser les systèmes physiologiques qui minimisent la « dépense » d’énergie.

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Non recyclés depuis 34 millions d'années

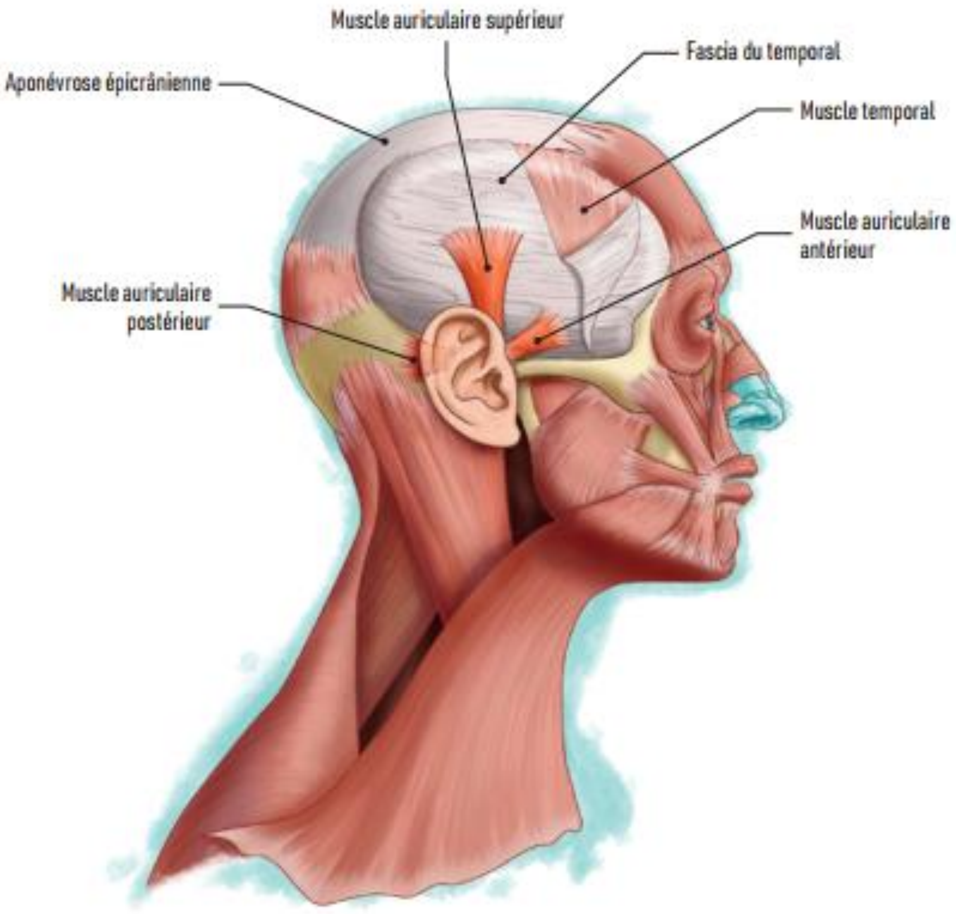


Figure 24. Situation des trois muscles du pavillon de l'oreille chez l'humain en vue latérale droite.

Non recyclés depuis 220 millions d'années

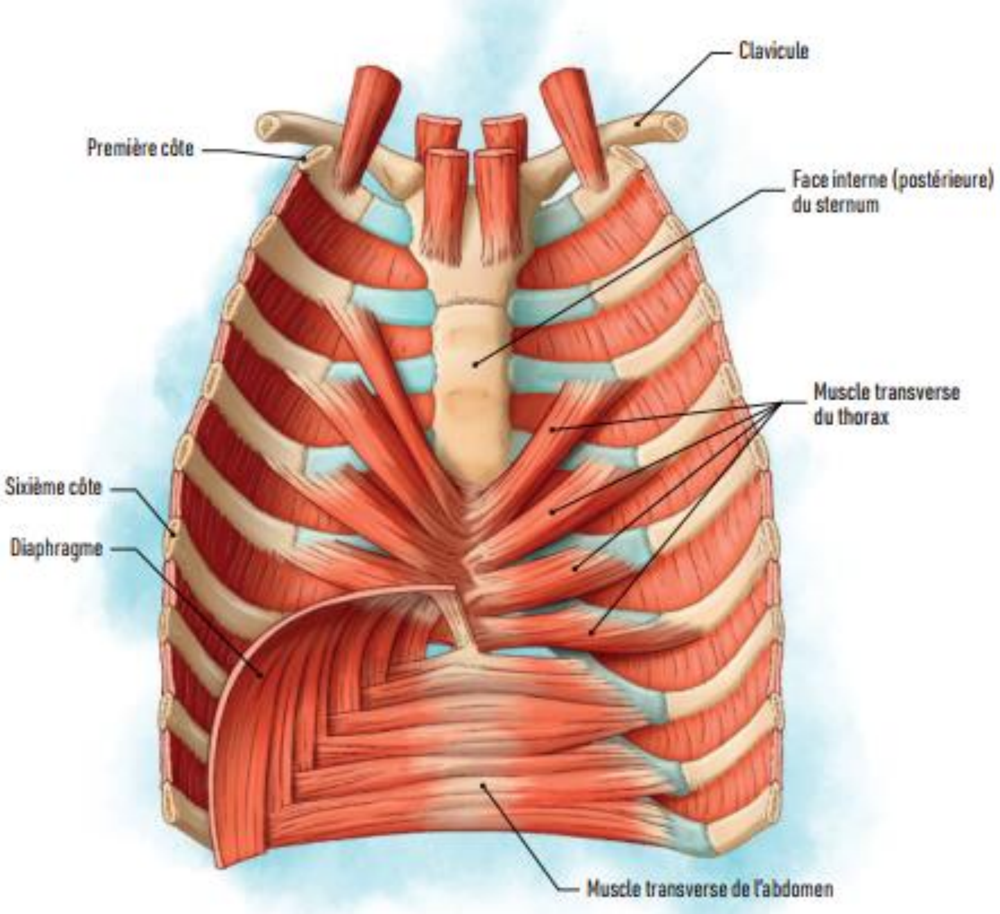


Figure 23. Muscle transverse du thorax chez l'humain, en vue dorsale (l'avant est en haut). Il présente ici quatre faisceaux à droite et cinq faisceaux à gauche, pour montrer la variation qui existe sur ce muscle parmi les humains.

Non recyclé depuis 2 millions d'années

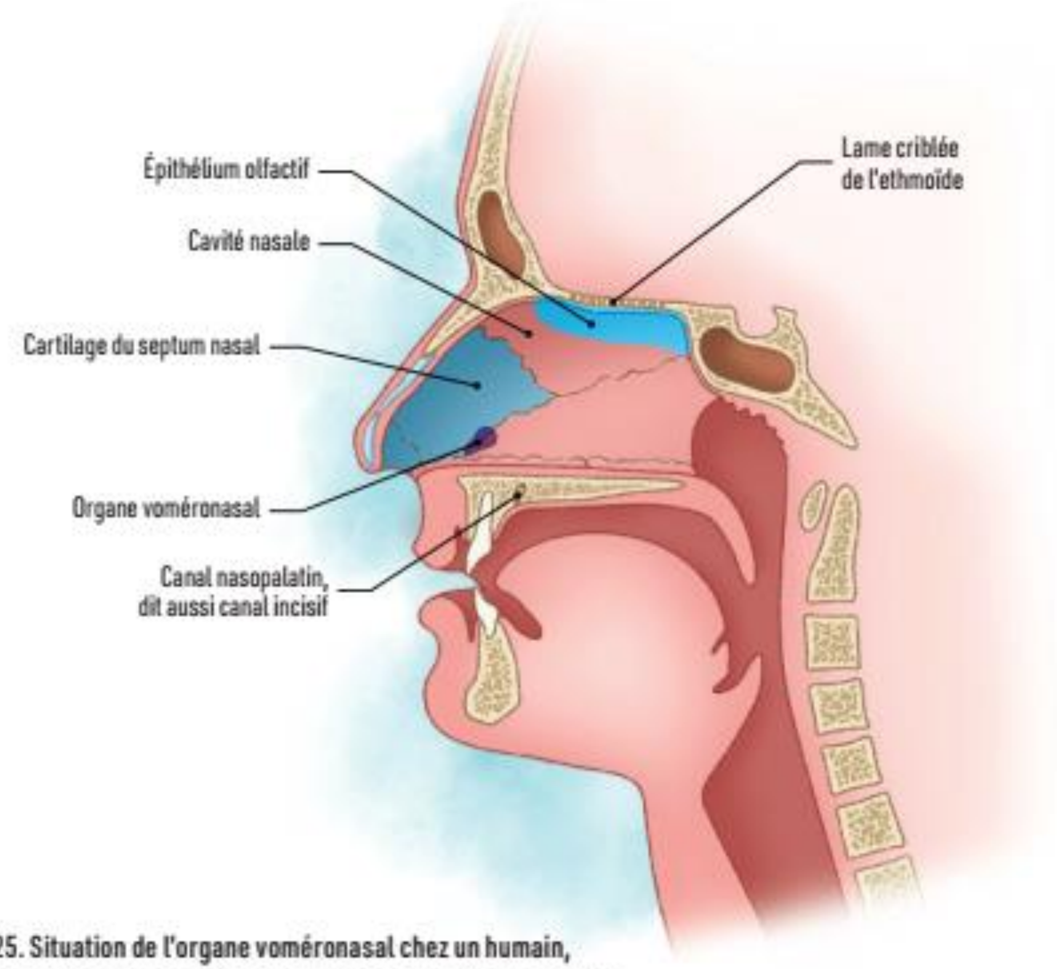


Figure 25. Situation de l'organe voméronasal chez un humain, illustrée par une coupe sagittale de la tête en vue latérale gauche.

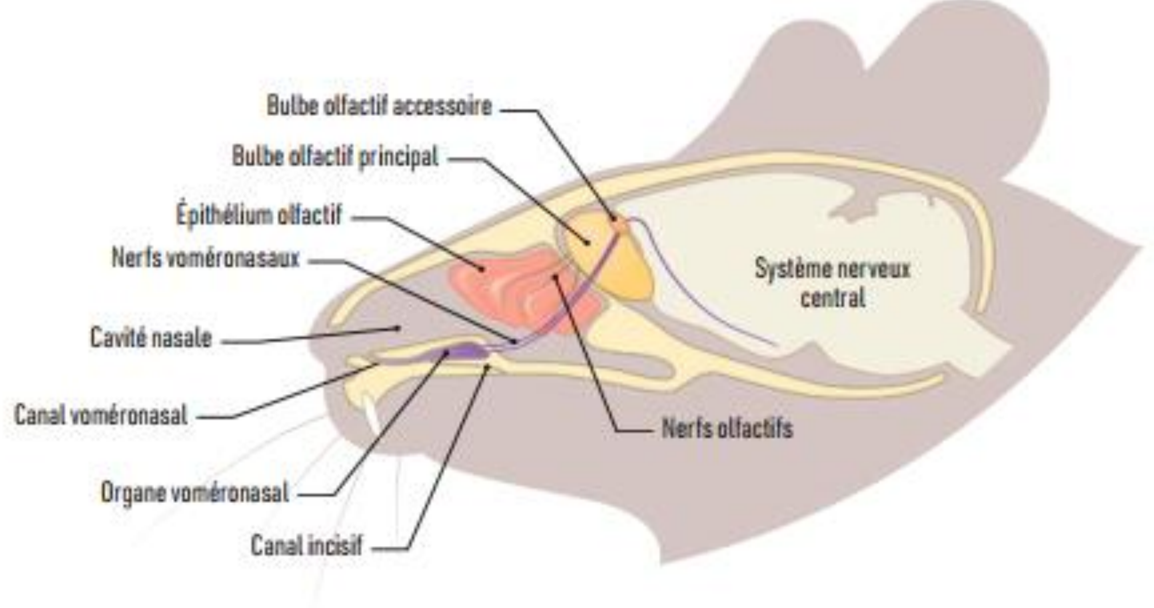


Figure 26. Positions relatives de l'organe voméronasal et de l'épithélium olfactif chez la souris, illustrées par une coupe sagittale de la tête en vue latérale gauche. Tandis que l'épithélium olfactif conduit les signaux nerveux via les nerfs olfactifs vers le bulbe olfactif principal, l'organe voméronasal transmet ses signaux nerveux via les nerfs voméronasaux vers le bulbe olfactif accessoire, puis vers les amygdales cérébrales qui mènent à l'hypothalamus.

Non recyclés depuis 220 millions d'années

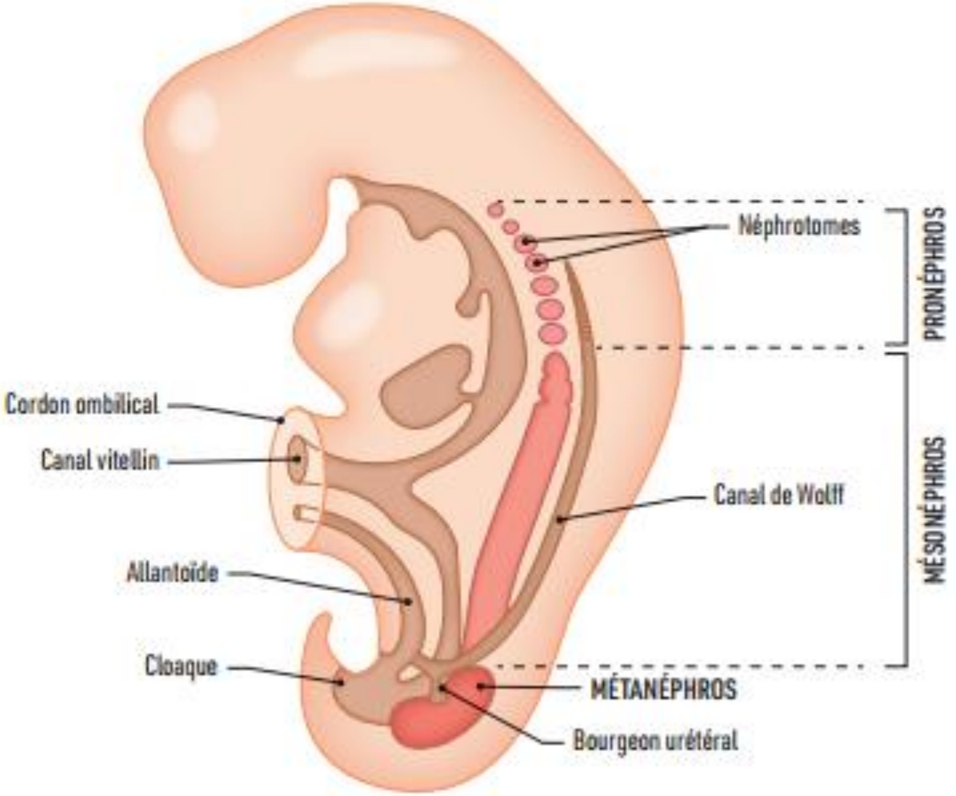


Figure 21. Situation relative des trois appareils néphrotiques chez un embryon humain en vue latérale gauche (avant à gauche). Cette Figure rassemble plusieurs stades entre eux. En effet, le pronéphros et le métanéphros n'existent jamais en même temps.

Variations asymptomatiques depuis 7 millions d'années

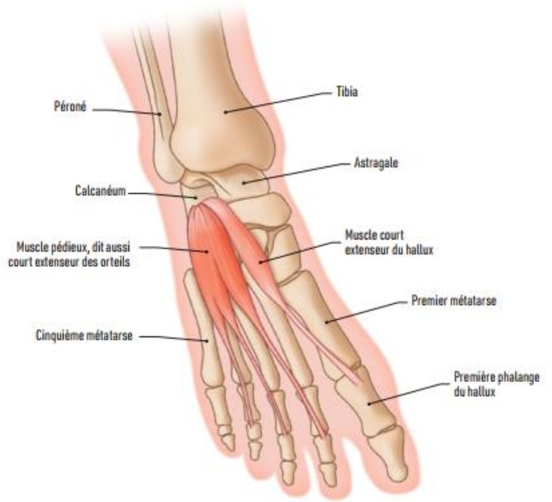


Figure 31. Vue dorsale du pied gauche montrant le muscle pédieux, composé des trois faisceaux courts extenseurs des orteils II, III et IV, et distinct du court extenseur du hallux (I).

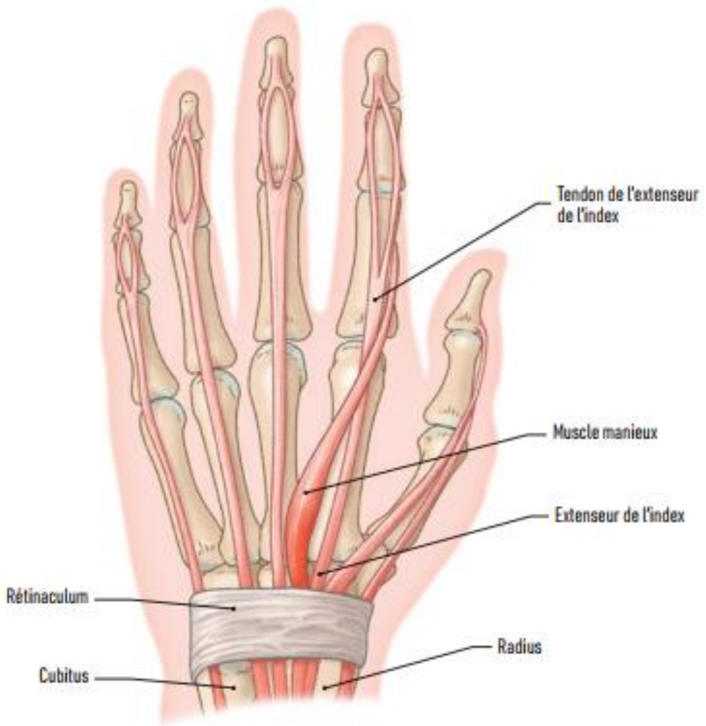


Figure 28. Vue dorsale de la main gauche montrant la disposition la plus fréquente du muscle manieux, s'insérant distalement sur le tendon extenseur de l'index.

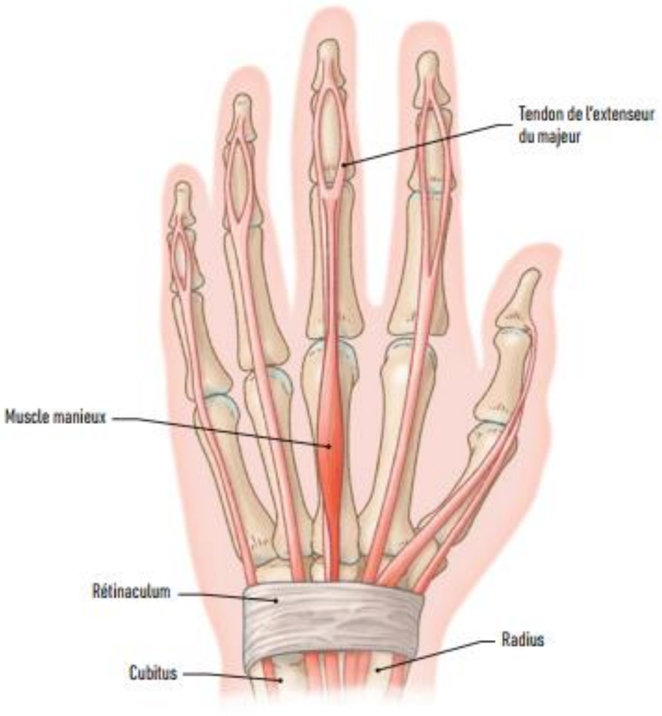


Figure 29. Vue dorsale d'une main gauche montrant la disposition du muscle manieux s'insérant distalement sur le tendon extenseur du majeur.

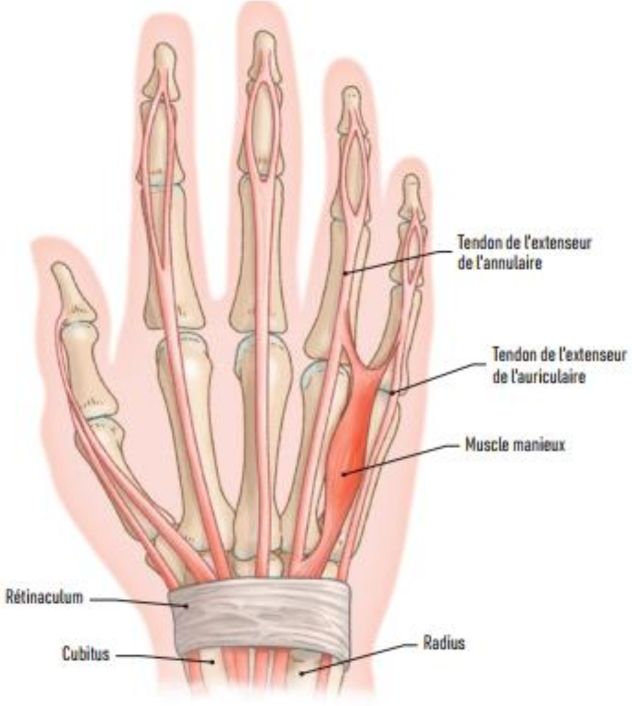


Figure 30. Vue dorsale d'une main droite montrant une disposition rare du muscle manieux, s'insérant distalement sur les tendons extenseurs de l'annulaire et de l'auriculaire.

Variations asymptomatiques depuis 7 millions d'années

Figure 36.
Situation générale du long extenseur du hallux, sur une jambe gauche.

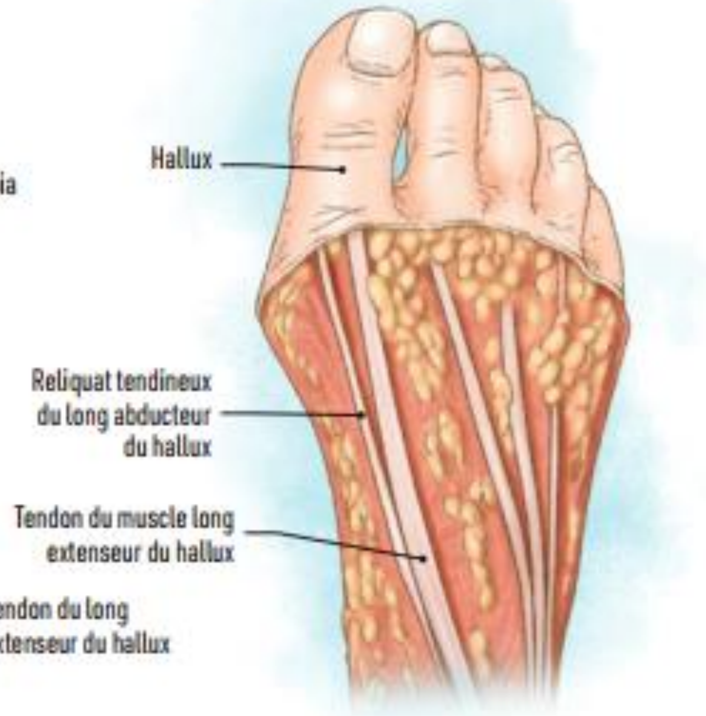


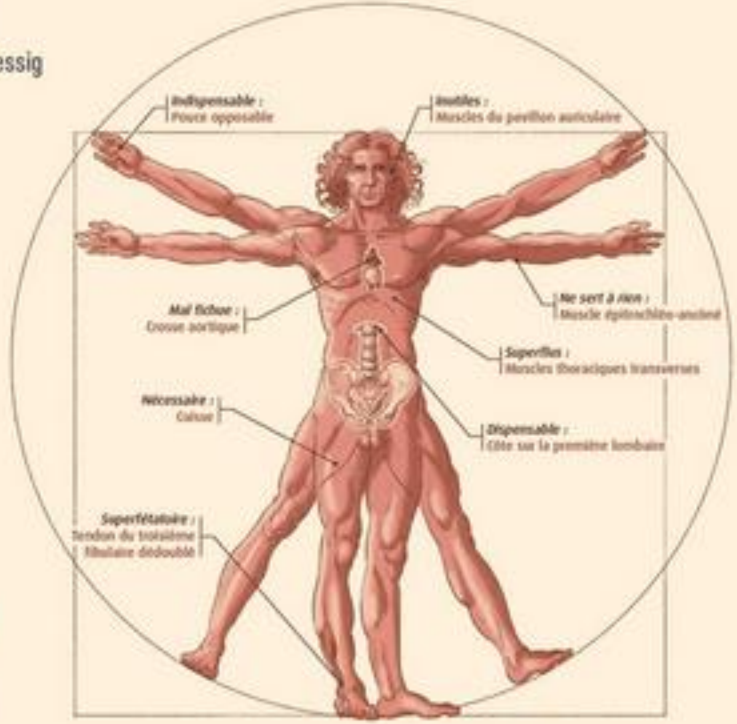
Figure 37. Reliquat tendineux du long abducteur du hallux sur la face dorsale d'un pied droit.

Guillaume Lecointre

PETIT TRAITÉ D'ANATOMIE SUPERFLUE

L'évolution à travers notre corps

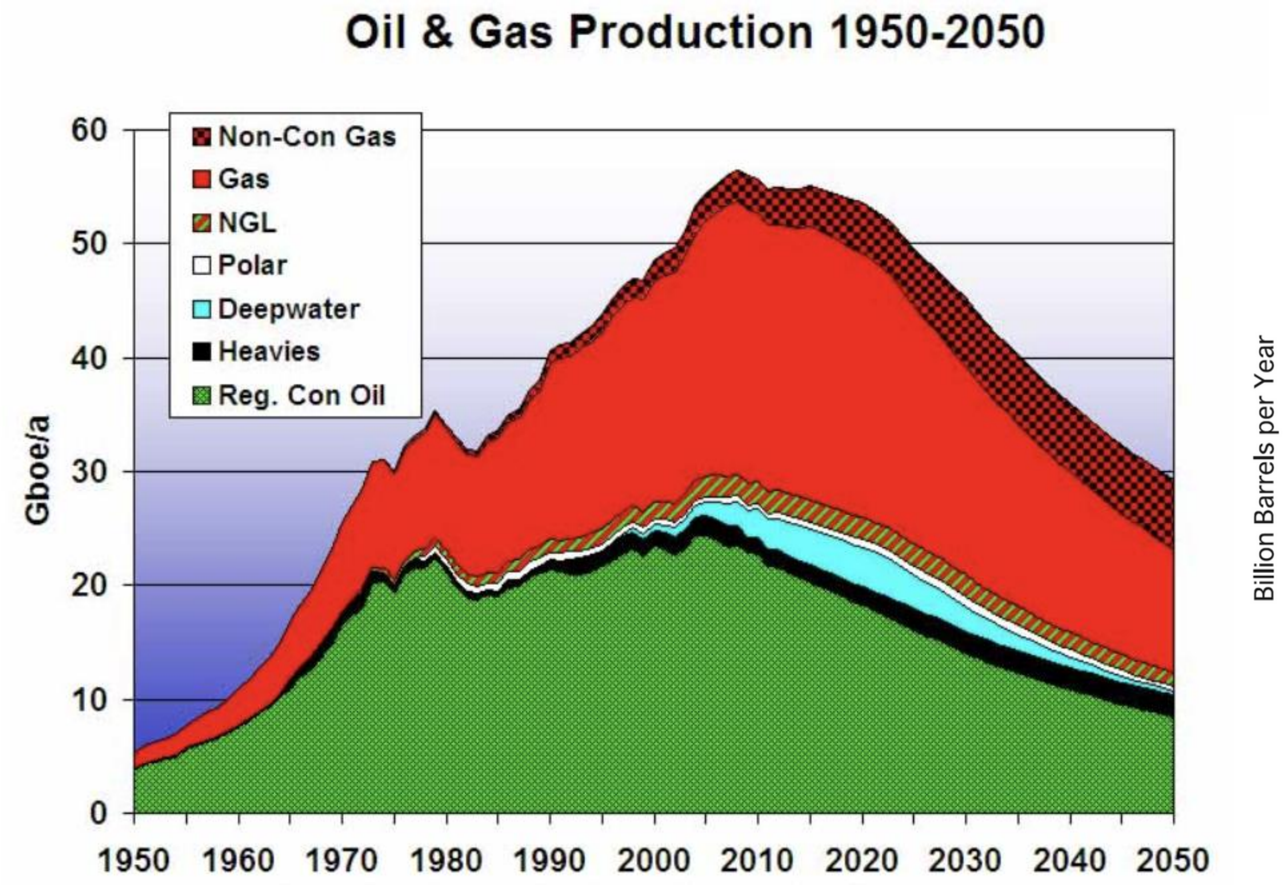
Illustrations
Thomas Haessig



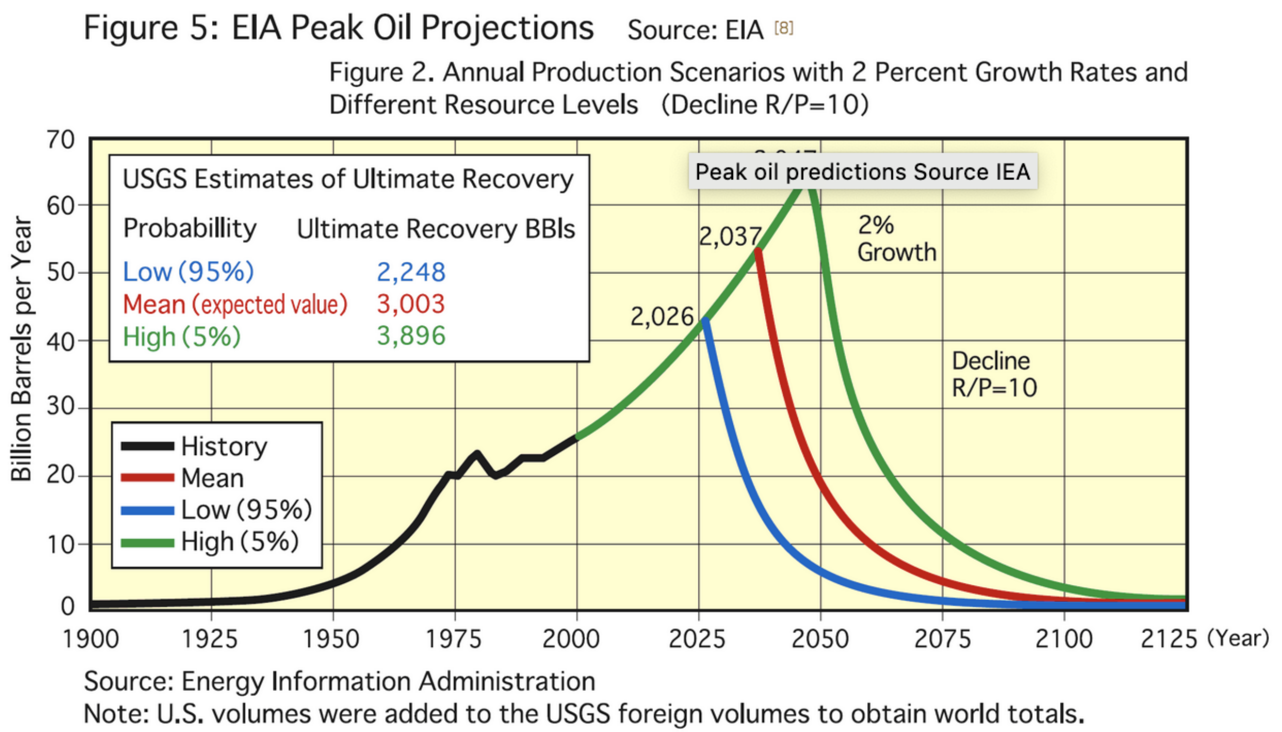
DELACHAUX
ET NIESTLÉ

Les accumulations de bois pourri du Carbonifère n'ont jamais été recyclées depuis 300 M.A. et ont conduit à des volumes considérables de gaz et de pétrole !

Carboniferous rotten wood accumulations that weren't recycled provides us oil and gas…
300 millions years after!



Source: Association for the Study of Peak Oil (ASPO) / Campbell 2011



Source: International Energy Agency (IEA)

C’est plus compliqué que ça…

- The living world has an extraordinary (but not infallible) capacity to recycle organic material. In any given ecosystem, a diversity of organisms reuse, scavenge, or decompose matter into components taken up by other forms of life. However, “recycling” can take millions of years, and some organic materials have never been “recycled” at all.

- Le monde vivant présente une capacité remarquable –mais pas infaillible- de recyclage des matériaux organiques. Dans un écosystème donné, toute une diversité d’organismes réutilisent, décomposent la matière en des composés mobilisés ensuite par d’autres formes vivantes. Cependant, le “recyclage” peut prendre parfois des millions d’années, et certains composés n’ont jamais été “recyclés”.

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Les écosystèmes s’effondrent

Le temps de l’effondrement peut même se simuler…

Article

The projected timing of abrupt ecological disruption from climate change

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Check for updates

Christopher H. Trisos[1,2,3], Cory Merow[4] & Alex L. Pigot[5]✉

As anthropogenic climate change continues the risks to biodiversity will increase over time, with future projections indicating that a potentially catastrophic loss of global biodiversity is on the horizon[1–3]. However, our understanding of when and how abruptly this climate-driven disruption of biodiversity will occur is limited because biodiversity forecasts typically focus on individual snapshots of the future. Here we use annual projections (from 1850 to 2100) of temperature and precipitation across the ranges of more than 30,000 marine and terrestrial species to estimate the timing of their exposure to potentially dangerous climate conditions. We project that future disruption of ecological assemblages as a result of climate change will be abrupt, because within any given ecological assemblage the exposure of most species to climate conditions beyond their realized niche limits occurs almost simultaneously. Under a high-emissions scenario (representative concentration pathway (RCP) 8.5), such abrupt exposure events begin before 2030 in tropical oceans and spread to tropical forests and higher latitudes by 2050. If global warming is kept below 2 °C, less than 2% of assemblages globally are projected to undergo abrupt exposure events of more than 20% of their constituent species; however, the risk accelerates with the magnitude of warming, threatening 15% of assemblages at 4 °C, with similar levels of risk in protected and unprotected areas. These results highlight the impending risk of sudden and severe biodiversity losses from climate change and provide a framework for predicting both when and where these events may occur.

Climate change is projected to become a leading driver of biodiversity loss[1], but it is not clear when during this century ecological assemblages might suffer such losses, and whether the process will be gradual or abrupt. Existing biodiversity forecasts typically lack the temporal perspective needed to answer these questions because they indicate the number and locations of species threatened by climate change for just a snapshot of the future, often around the end of the century[1–3]. These snapshots do not account for the temporally dynamic nature of ecological disruption expected as a result of climate change, often focus at the level of species rather than ecological assemblages, and can seem remote to decision-makers who are concerned with managing more immediate risks[4]. Indeed, many of the most sudden and severe ecological effects of climate change can occur when conditions become unsuitable for several co-occurring species simultaneously, causing catastrophic die-offs and abrupt ‘regime shifts’ in ecological assemblages[5,6].

Forecasting the temporal dynamics of climate-driven disruption of ecological assemblages thus requires quantifying the differences among species in the time at which their climate niche limits may be locally exceeded. Developing advance warnings of the risk of gradual or abrupt ecological disruption is an urgent priority[7–9]. A temporal perspective is also important for adaptation. Reducing emissions and delaying the onset of exposure to dangerous climate conditions—even by a few decades—could buy valuable time for ecological assemblages to adapt[10,11], potentially reducing the magnitude of ecological disruption. However, despite the clear importance of a temporal perspective in understanding and managing the threats of climate change to biodiversity, we lack a general understanding of the time at which species in ecological assemblages will be exposed to climate conditions beyond their niche limits.

The biodiversity climate horizon

To describe the projected timing of the exposure of species to climate conditions beyond their niche, we developed an approach based on species historical climate limits and future climate projections. The range of climate conditions, over both space and time, under which a species has been recorded in the wild demarcates the boundaries of its realized niche[12]. The projected time in the future at which these bounds are exceeded owing to climate change at a site can therefore be thought of as representing a climate horizon, beyond which evidence for the ability of the species to persist in the wild is lacking. Over this horizon lies, at best, a sizeable increase in uncertainty about species survival and, at worst, local extinction[13]. For a given species assemblage, the cumulative percentage of species over time that have been locally exposed to climate conditions beyond their realized niche limits forms

[1]African Climate and Development Initiative, University of Cape Town, Cape Town, South Africa. [2]National Socio-Environmental Synthesis Center (SESYNC), Annapolis, MD, USA. [3]Centre for Statistics in Ecology, the Environment, and Conservation, University of Cape Town, Cape Town, South Africa. [4]Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT, USA. [5]Centre for Biodiversity and Environment Research, Department of Genetics, Evolution and Environment, University College London, London, UK. ✉e-mail: a.pigot@ucl.ac.uk

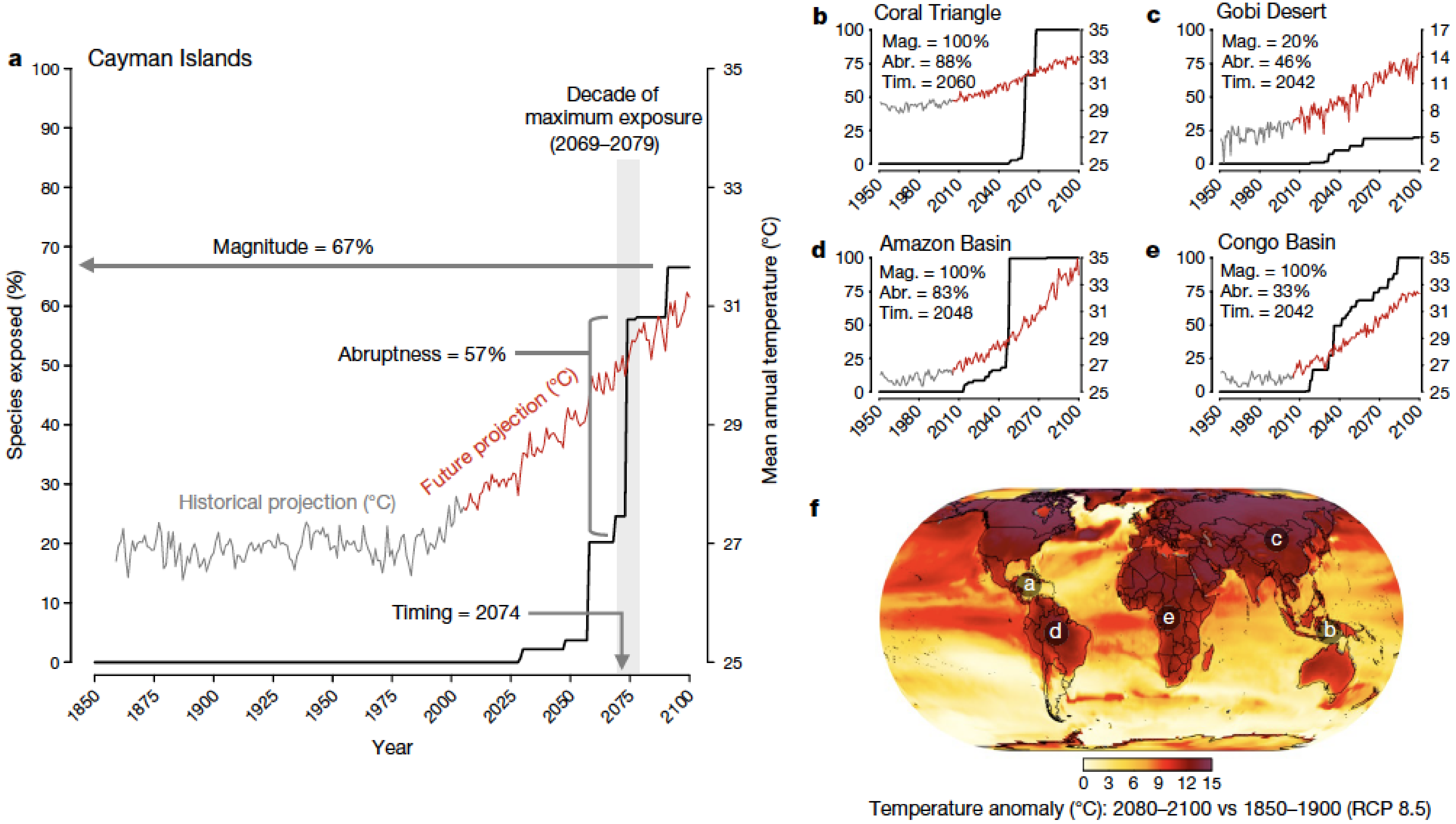

Fig. 1 | Biodiversity climate horizon profiles. a–e, Horizon profiles (solid black lines) indicate the cumulative percentage of species in an assemblage exposed to future temperatures (red lines) beyond their realized thermal niche over time. Iconic ecosystems provide examples of different profile shapes: **a**, Cayman Islands; **b**, Coral Triangle; **c**, Gobi Desert; **d**, Amazon Basin; **e**, Congo Basin. **f**, Map of temperature anomalies that shows the locations of the ecosystems in **a–e**. Horizon profiles and temperature trends are shown for a single run of the Hadley Centre Global Environmental Model (HadGEM2) under a high greenhouse-gas-emissions scenario (RCP 8.5). The profiles differ in terms of timing, magnitude and abruptness. The grey lines show historical temperature projections at a site.

C’est plus compliqué que ça…

- Ecosystems and biological entities are resilient to disturbances only within certain limits. At the ecosystem level, once certain disturbance thresholds are crossed, the “identity” of the ecosystem may be changed irreversibly.

- Les écosystèmes et les entités biologiques sont résilientes aux perturbations dans certaines limites. Au niveau d’un écosystème, une fois certaines limites dépassées, son identité peut s’en trouver irréversiblement modifiée.

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Une femelle de sébaste :
47 millions d'oeufs
Une femelle de poisson-lune :
300 millions d'œufs
Ténia du bœuf : un million d'œufs/jour

Est-ce quelqu'un sait comment on
peut savoir si cette femelle aurait
pu pondre plus d'œufs, et dans quelles
conditions ?

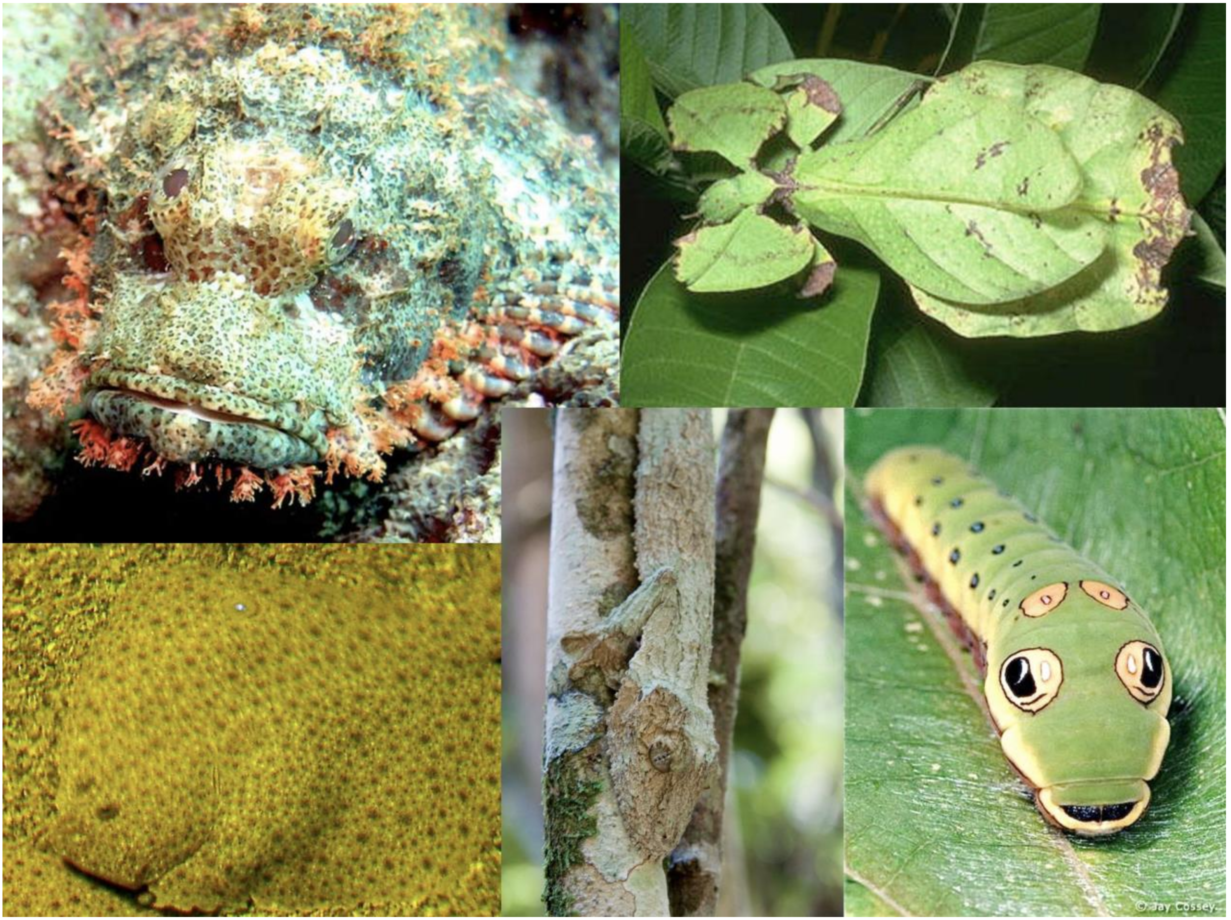
Est-ce qu'une « espèce invasive »
optimise ou bien maximise ?

C’est plus compliqué que ça…

- Living systems are the result of trade-offs, not optimisation. Populations seem to ‘maximise’ reproduction and offspring, which are later filtered by environmental constraints (biotic and abiotic). Apparent optimisations in terms of species’ physical and behavioural traits would be more accurately described as being the ‘best under the circumstances’.

- Les systèmes vivants sont le produit de compromis, et non d’optimisations. Les populations semblent « maximiser » la reproduction et le nombre de descendants, qui sont ensuite filtrés par les contraintes environnementales (biotiques et abiotiques). L’optimisation apparente des traits physiques et comportementaux serait mieux décrites comme les « meilleures compte-tenu des circonstances ».

Compromis entre effets de la sélection naturelle

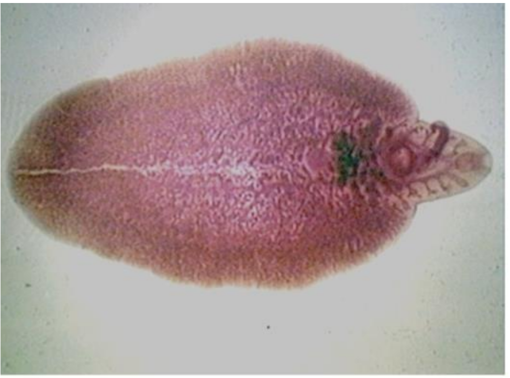


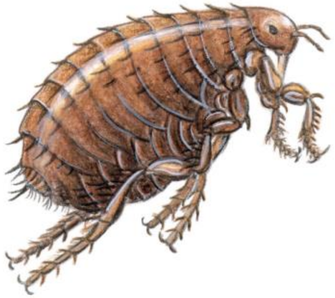
VS

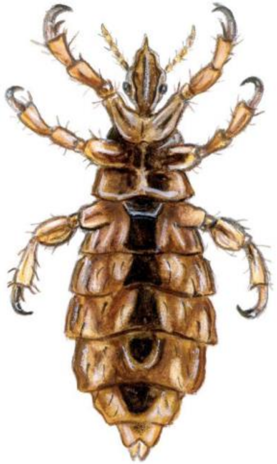
Compromis entre effets de la sélection naturelle

VS

Compromis entre effets de la sélection naturelle







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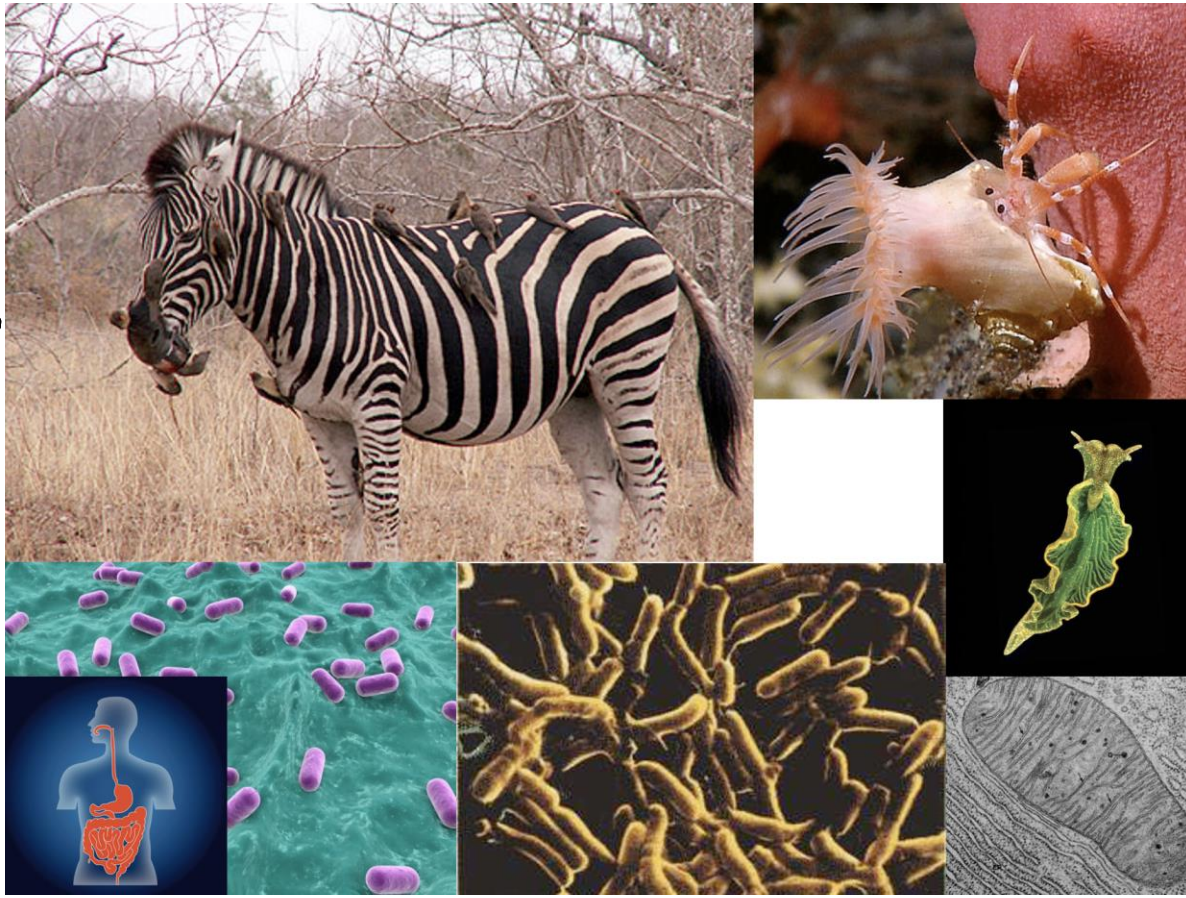

Compromis externes à la sélection naturelle limitant d'adaptation

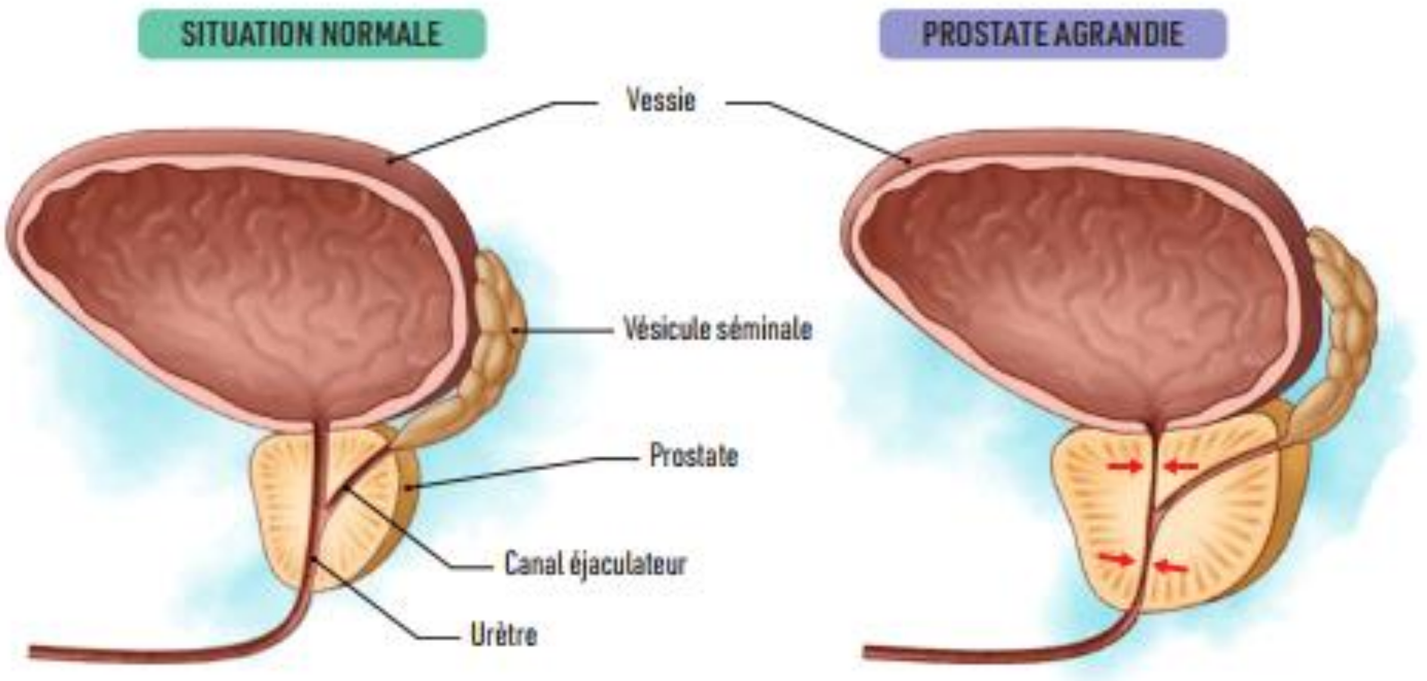

Figure 10. Effet de la croissance de la prostate sur l'urètre, illustrée par une coupe sagittale de prostate en vue latérale gauche. À gauche, situation normale ; à droite, prostate agrandie. L'avant est à gauche, l'arrière à droite. Par souci de simplification, les canaux déférents (canaux des testicules à la prostate) et les uretères (canaux du rein à la vessie) ne sont pas représentés.

Contrainte de construction

Compromis externes à la sélection naturelle limitant d'adaptation

Embryon humain à 6 semaines

Fœtus à 8 semaines

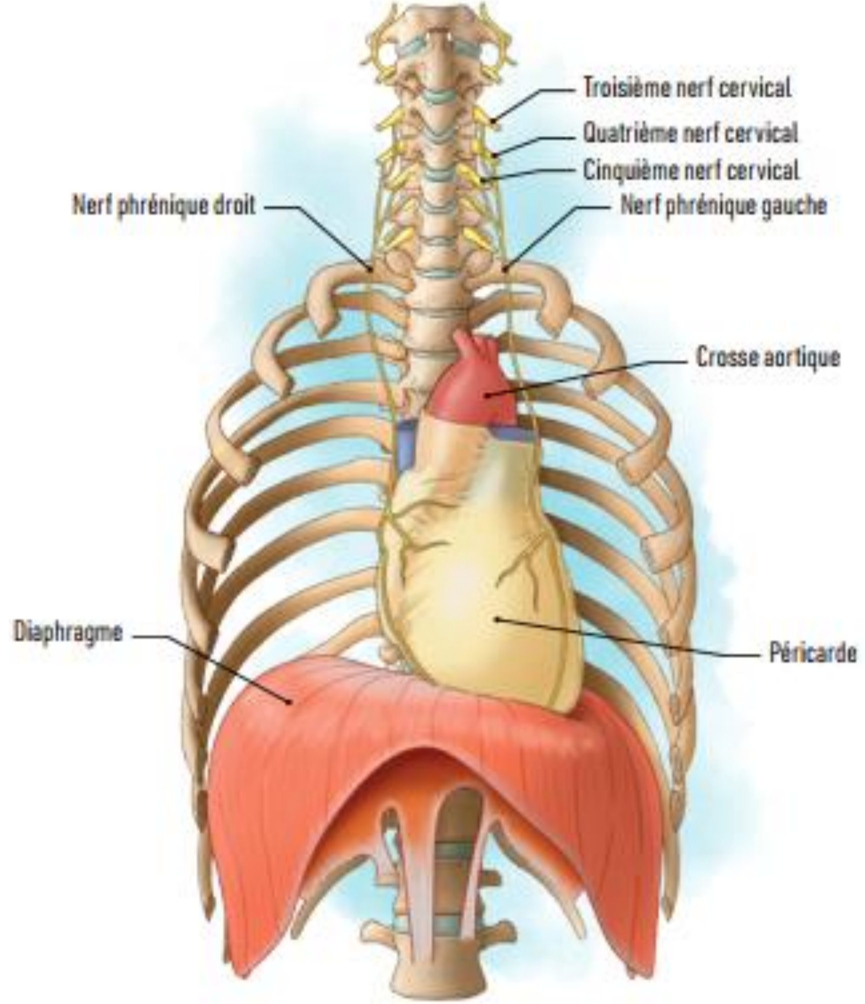

Figure 9. Vue ventrale de la cage thoracique ouverte (les côtes ont été effacées).

Contrainte historique

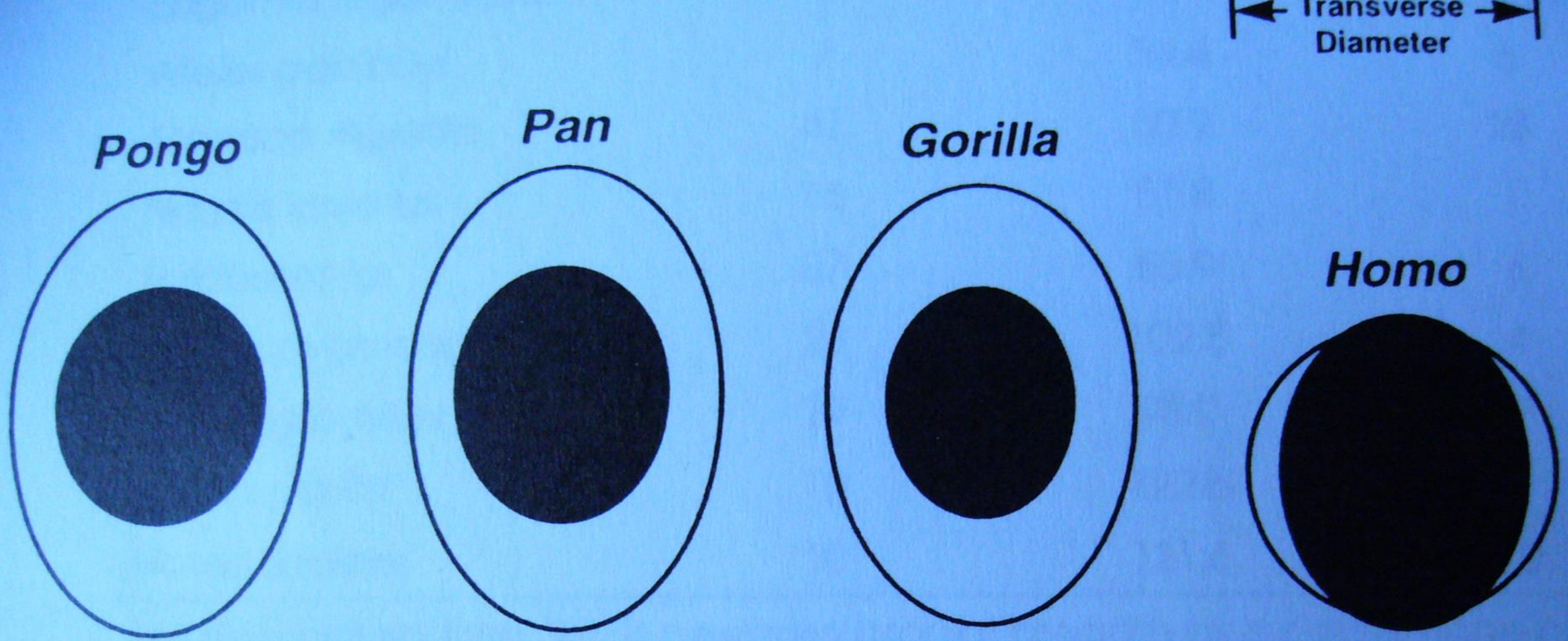

Figure 1. A redrawing of Schultz' classic diagram relating the size of the maternal pelvic inlet and the size of the neonatal head in different primate species. Maternal pelvic and infant cranial outlines are diagrammatic, but scaled so that the transverse diameter of all maternal pelvic inlets are constant and all dimensions are correctly scaled relative to one another. For each species the outlined oval represents the average maternal pelvic inlet, the black oval represents the average infant's cranium. Note that in the monkeys and gibbon, the dimensions of the infant cranium are only slightly smaller than the dimensions of the mother's pelvis. In great apes, the pelvic inlet is relatively spacious. In humans, the infant cranium is actually longer than the anterior-posterior dimension of the pelvic inlet, requiring the head to enter the inlet facing sideways.

on observations that included radio-

Monkeys and apes generally give

Contrainte historique et contrainte de construction

Compromis externes à la sélection naturelle limitant d'adaptation

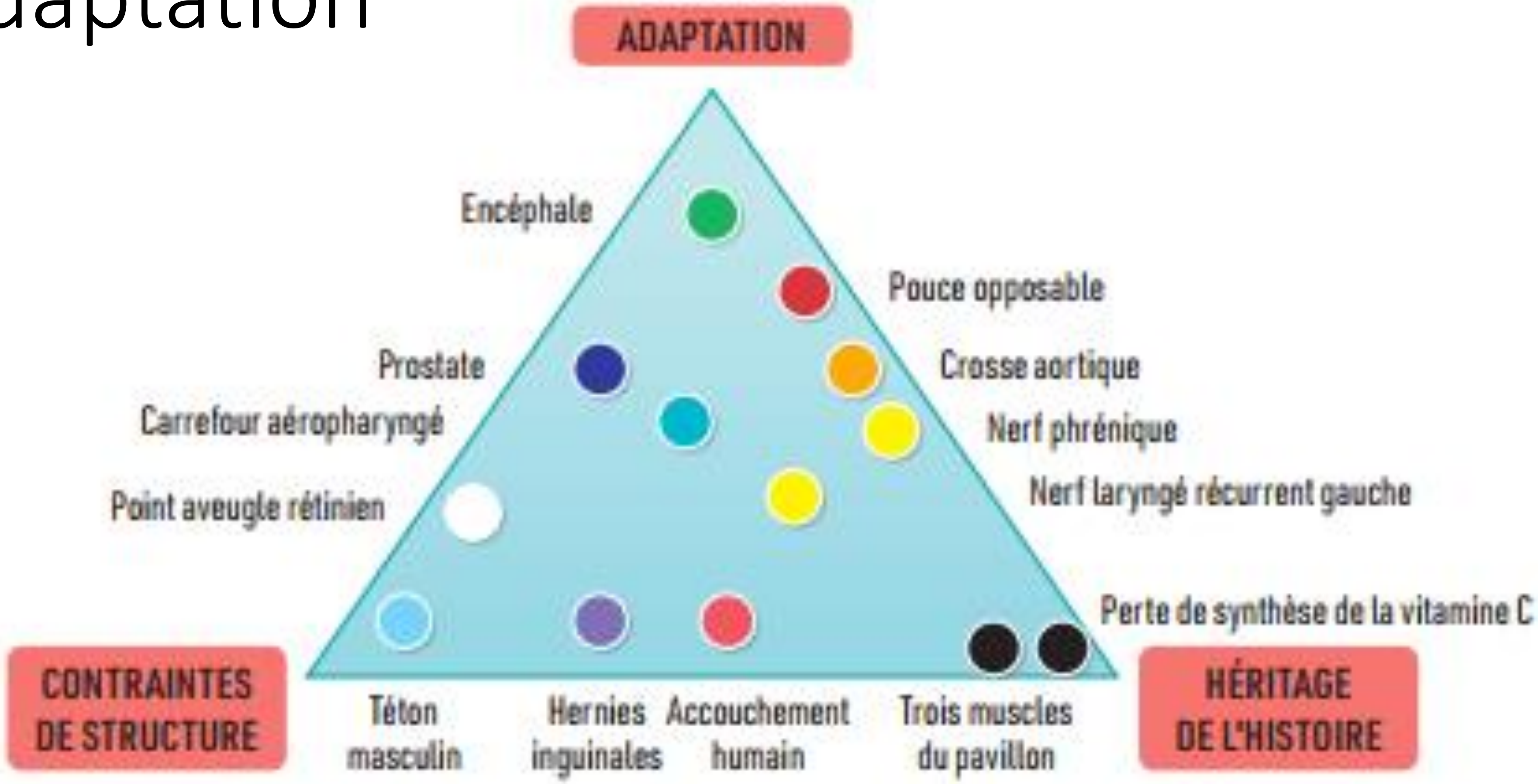

Figure 49. Triangle de Seilacher. Tout organe a trois pôles explicatifs, dans des proportions variées selon les cas. L'emplacement de chaque organe dans le triangle n'est pas le fruit d'une mesure chiffrée, mais d'une compréhension d'ordre conceptuel.

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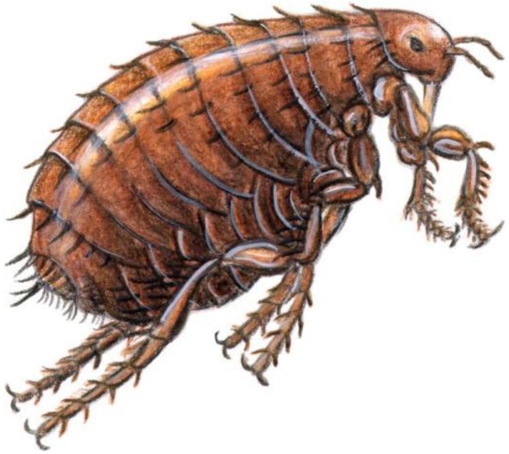
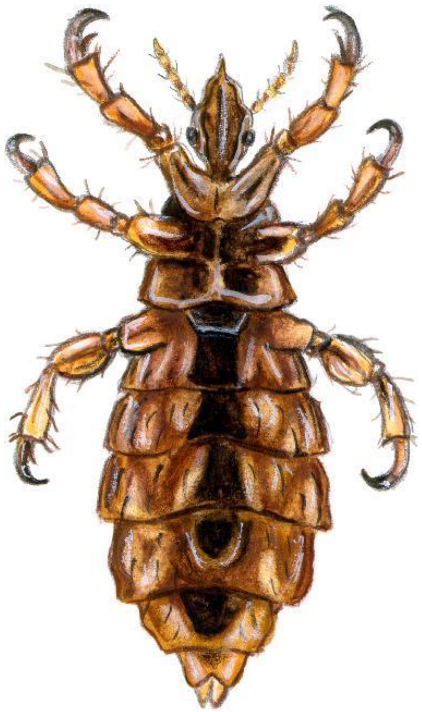
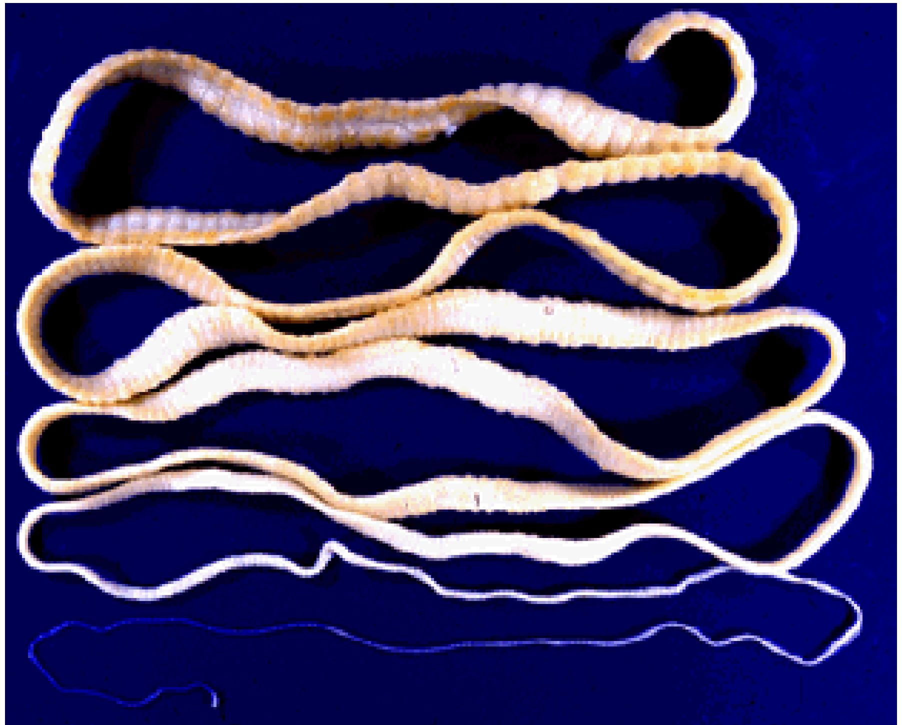
Le parasitisme est généralisé dans tout le vivant…



Première cause de mortalité humaine en zone intertropicale





À l'origine du sexe

C’est plus compliqué que ça…

- Mutually beneficial relationships are found in living systems, yet they are not necessarily more significant than predation and parasitism.

- Les relations à bénéfice mutuel sont constatées entre systèmes vivants, mais elles ne sont pas plus fréquentes et plus significatives que les relations de prédation et de parasitisme.

10 of nature's unifying patterns to consider

Click any of the patterns below for a detailed explanation and examples.

- **Nature uses only the energy it needs and relies on freely available energy.**
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- **Nature is resilient to disturbances.**
- **Nature tends to optimize rather than maximize.**
- **Nature provides mutual benefits.**
- **Nature runs on information.**
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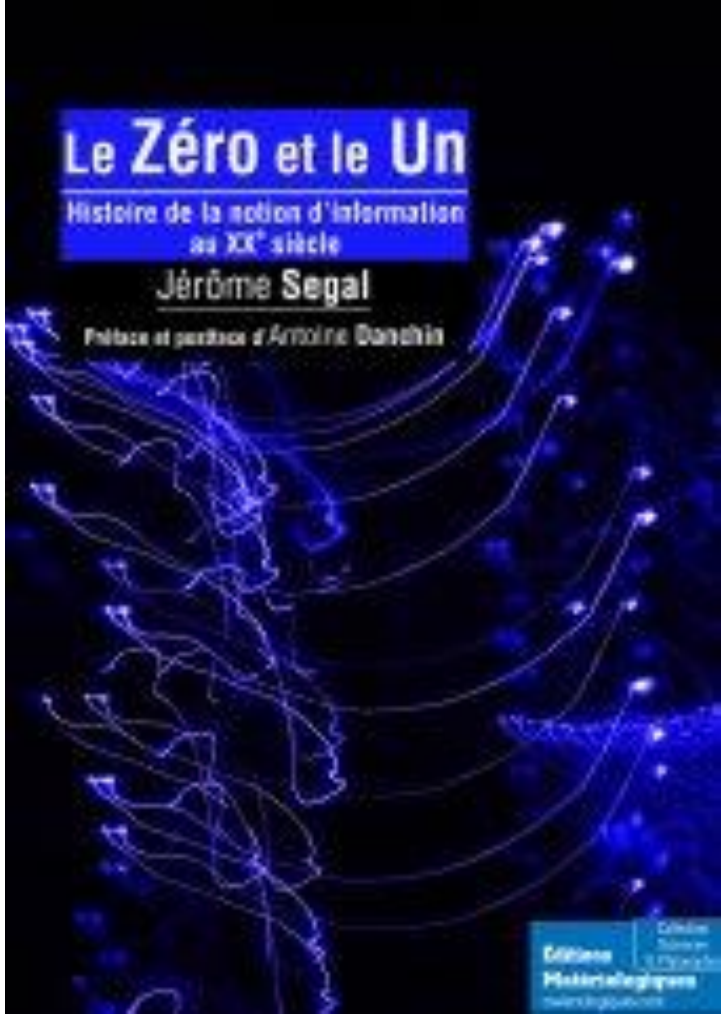
- **Nature uses shape to determine functionality.**

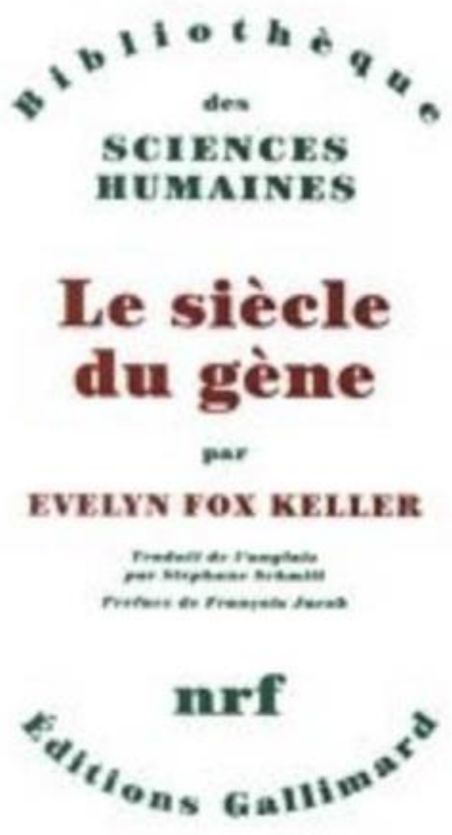
Note: Our intent is not to present this as a definitive and exhaustive list. Rather, it is a work in progress that we hope will be informed and enhanced by the growing community of biomimics who are practicing applying nature's lessons to their designs.

L'information est une notion cybernétique, et non pas biologique !

Annabelle Kremer-Lecointre
Guillaume Lecointre
Démystifier le Vivant
Belin-Éducation



Jérôme Segal
Le Zéro et le Un
Materiologiques.com



Evelyn Fox-Keller
Le siècle du gène
Gallimard

L’information… en sociologie

- Flux d’un émetteur vers un (des) récepteur(s)
- Définie par une propriété d’invariance ! Elle n’a rien de matériel : sa transmission est indépendante de son support.
- Diffuse +/-
- +/- fidèle aux croyances de l’émetteur
- +/- acceptée selon les croyances du récepteur
- Modifie les croyances (l’état) du récepteur

En biologie : le concept d’homologie peut-il sauver l’information ?

- « Donner forme »… Une homologie des processus qui génèrent du semblable
- … jamais de l’identique ! La principale propriété qui définit l’information, l’invariance, s’écroule.
- Le gène passe du statut de « notaire » à celui de « partenaire »

C’est plus compliqué que ça…

- Living systems sense and respond to their internal/external environments and communicate in a multitude of different ways (physical, chemical, and behavioural).

- Les systèmes vivants sentent et répondent à leur environnement et communiquent de multiples façons (physique, chimique, comportementale…).

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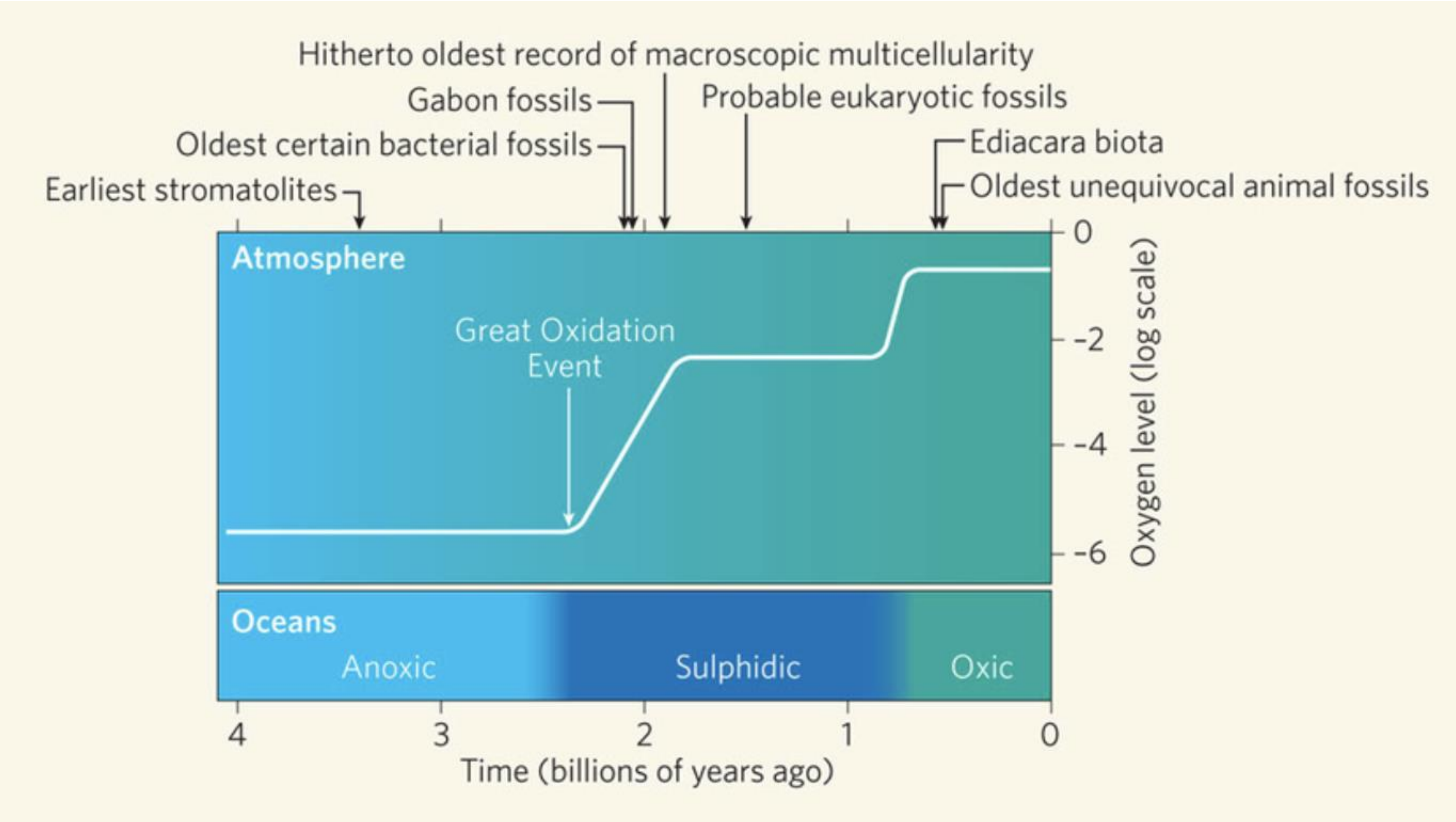
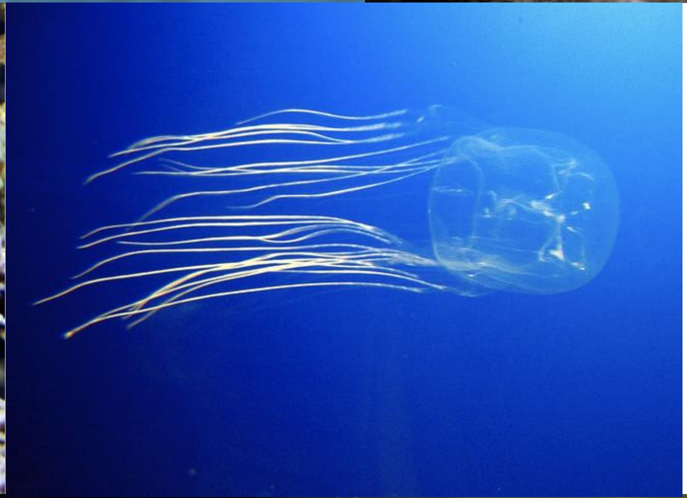
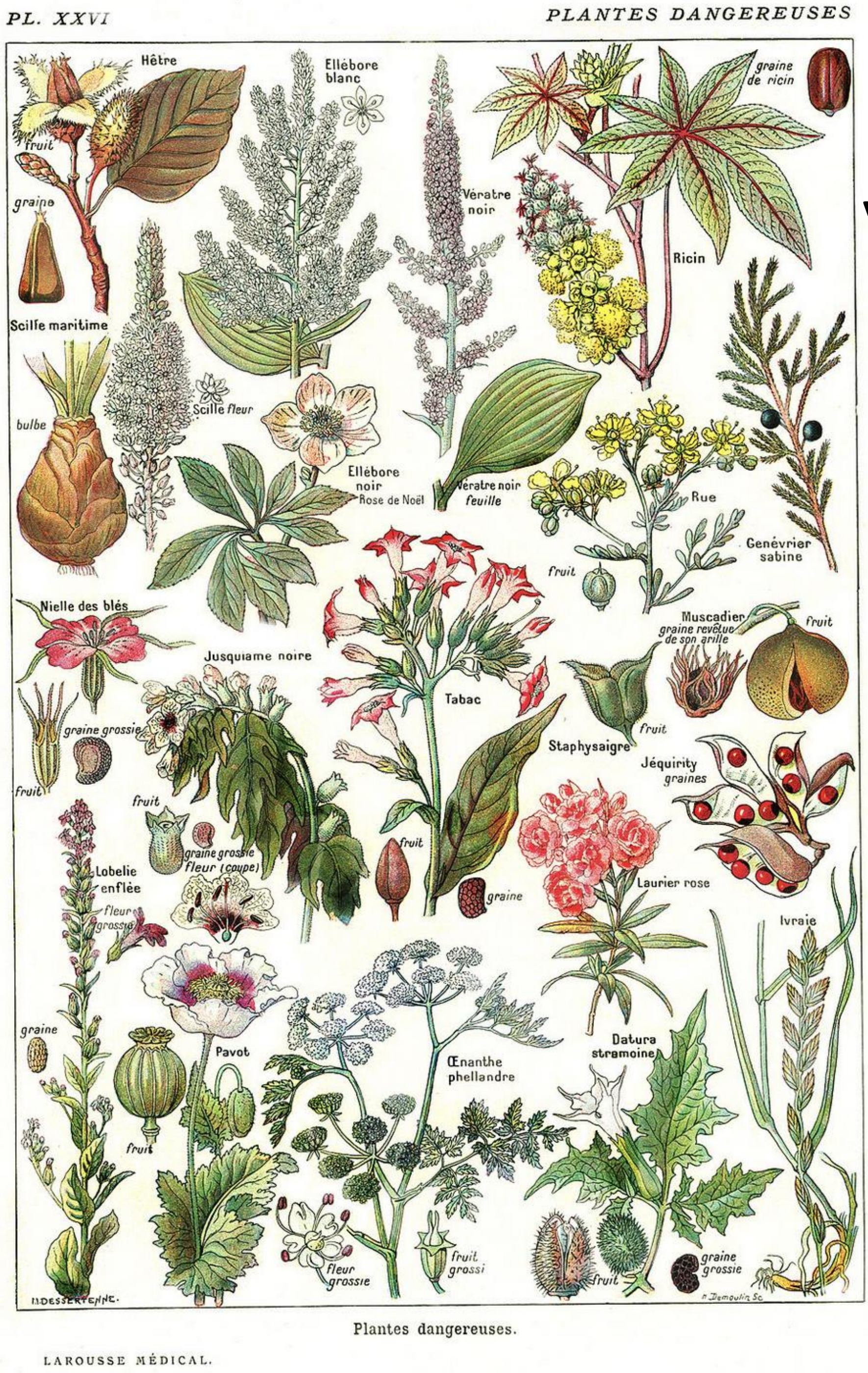


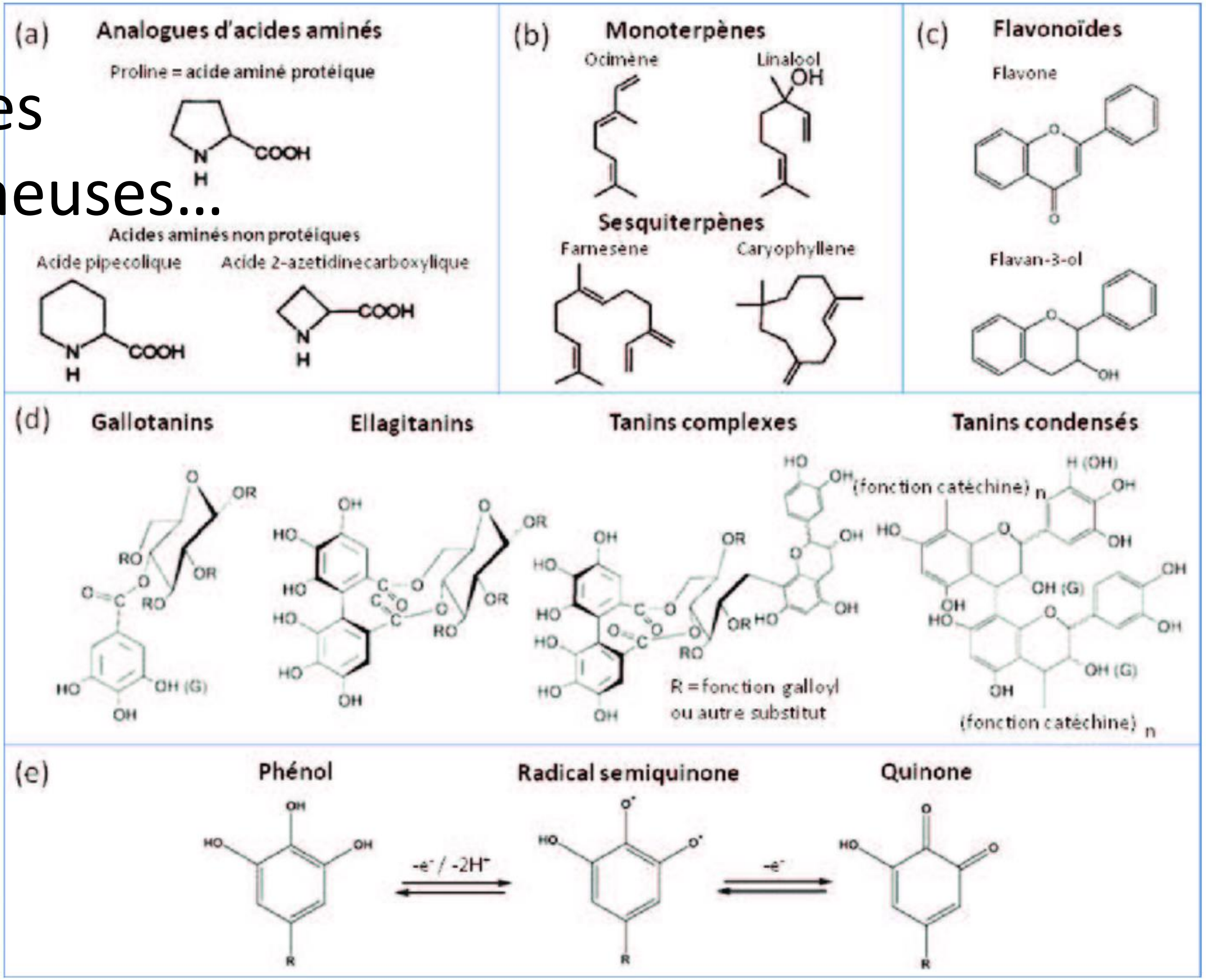
Hitherto oldest record of macroscopic multicellularity
Gabon fossils
Probable eukaryotic fossils
Oldest certain bacterial fossils
Ediacara biota
Earliest stromatolites
Oldest unequivocal animal fossils
Atmosphere
Great Oxidation Event
0
-2
-4
-6
Oxygen level (log scale)
Oceans
Anoxic
Sulphidic
Oxic
4
3
2
1
0
Time (billions of years ago)



Animaux venimeux…

Plantes vénéneuses…





Quelques composés de défense chez les plantes. (a) Analogues d'acides aminés toxiques, exemple de la proline (d'après Bernays et Chapman 1994) (b) Terpénoïdes volatils répulsifs, exemples des mono-et sesquiterpènes (d'après Paré et Tumlinson 1999) (c) Flavonoïdes, exemples des sous-classes flavone et flavan-3-ol (d'après Aron et Kennedy 2008) (d) Classification des tanins, répulsifs et anti-digestifs (d'après Khanbabaee et van Ree 2001). (c) Réaction d'auto-oxydation d'un groupement phénol, produisant des formes plus agressives et un stress oxydant (d'après Barbehenn et Constabel 2011).

C’est plus compliqué que ça…

- Whether the chemicals and materials synthesised within biological systems are “safe” depends on the species in question, their life history stage, their environmental context, and, last but not least, the quantity of the chemical compound in question. Nevertheless, almost all are ultimately biodegradable, given sufficient time and the right environmental conditions.

- Le caractère « sain » des matériaux et composés chimiques synthétisés par les systèmes vivants dépend de l’espèce considérée, de son stade de développement, du moment de sa vie, du contexte environnemental, et plus que tout, de la quantité du composé chimique en question. Néanmoins, presque tous sont biodégradables selon un pas de temps suffisant et des conditions environnementales précises.

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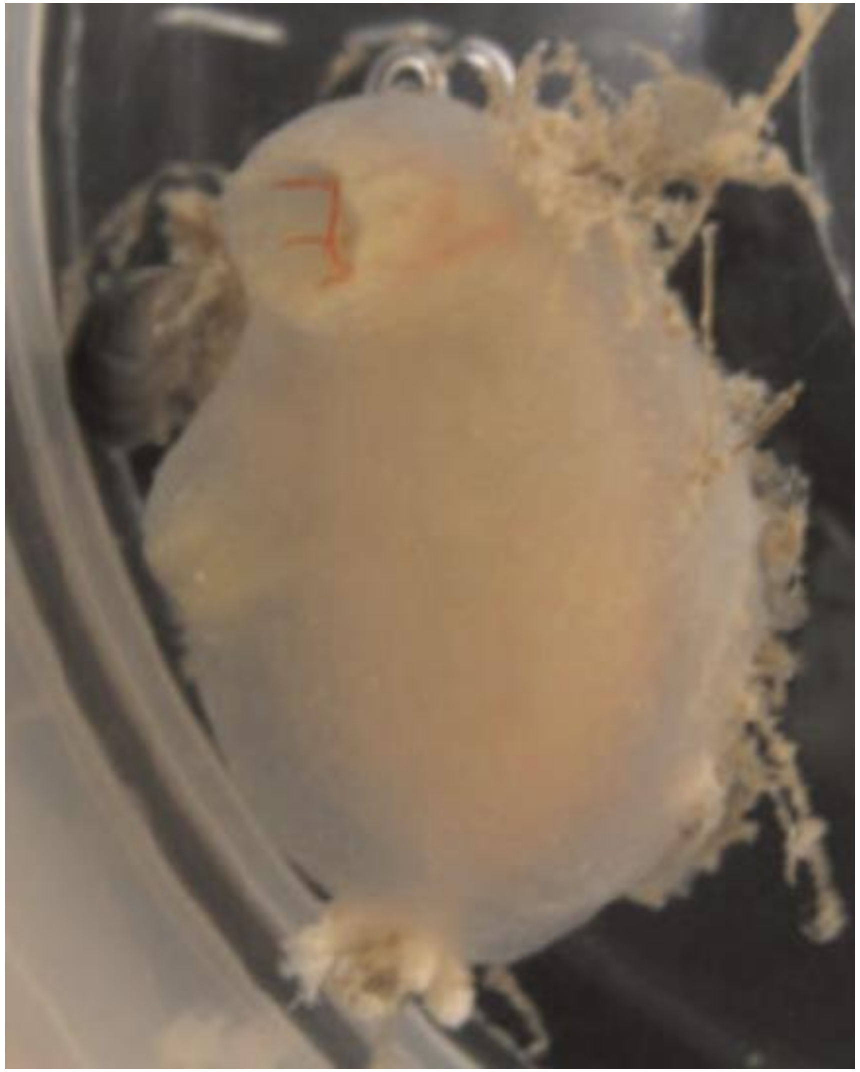
Il s’agit là d’une tautologie, certes, mais…

Le vanadium est un élément rare…



Ascidia gemmata

Vanadocytes

Vanadium 350 mM

Overkill

C’est plus compliqué que ça…

- Most biological materials are inevitably composed of abundant, locally available resources.

- La plupart des matériaux biologiques sont inévitablement composés à partir de ressources abondantes et localement disponibles.

10 of nature's unifying patterns to consider

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C’est plus compliqué que ça…

- Individual organisms are responsive and often able to acclimatise to new environmental conditions. At the population level, organisms continually adapt to their surroundings through natural selection.

- Les organismes individuels sont réactifs et souvent capables de l’acclimater à de nouvelles conditions environnementales. À l’échelle de la population, les organismes s’adaptent à leur environnement à travers la sélection naturelle.

“Chances of survival increase when individuals are good at recognizing local conditions and opportunities and locating and managing available resources. Survival also depends on responding appropriately to information garnered from the local environment. Organisms and ecosystems that are present in a location evolved in direct response to local environmental conditions. Some of those environmental conditions change in a cyclic pattern, such as tides, day and night, seasons, and annual floods or fires. Organisms use those predictable cyclic patterns as an opportunity, evolving to fill a particular niche. Within a particular location, there are micro-environments, such as a low spot that is moister than the surrounding area or an area that experiences more wind than others. These also provide opportunities for organisms to have an advantage over others and thrive. Some environmental conditions change slowly over time as the climate changes or as the organisms and ecosystems influence the local conditions. Being able to respond to these changes, again using them as opportunities, allows organisms and ecosystems to flourish”.

Confusion entre Acclimatation (qui est une propriété Individuelle) et Adaptation (qui est une propriété populationnelle)

- Acclimatation
- Migration
- Adaptation

L'ours brun hiberne

Anser indicus érige ses plumes

L'acclimatation se produit dans le temps physiologique et comportemental, celui de la vie de l'individu

- Acclimatation
- Migration
- Adaptation

Les gnous font des transhumances de 3000 km chaque année

L'oie à tête barrée migre chaque année au-dessus de l'Himmalaya

La migration est saisonnière, ou unidirectionnelle, elle se transmet de génération en génération

- Acclimatation
- Migration
- Adaptation

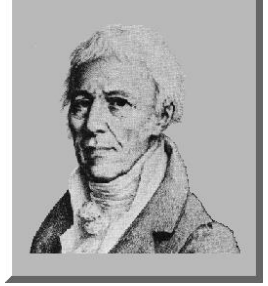
Poisson des glaces (*Chionidraco hamatus*) :
Protéines antigel dans le sang

Anser indicus:
Vole à des altitudes
Entre 8500 et 10,000
Mètres
Muscles hyper-vascularisés
Grands poumons
Hémoglobines spéciales

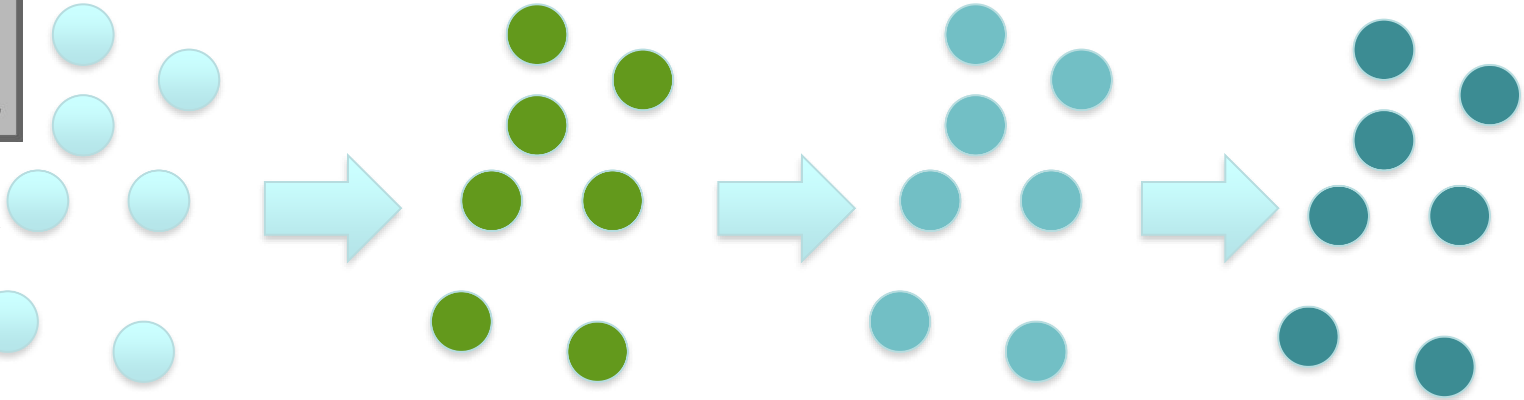
L'adaptation s'effectue à l'échelle des Populations, et se réalise après plusieurs Générations et de nombreux décès

Un seul individu n'y peut rien

Transformation

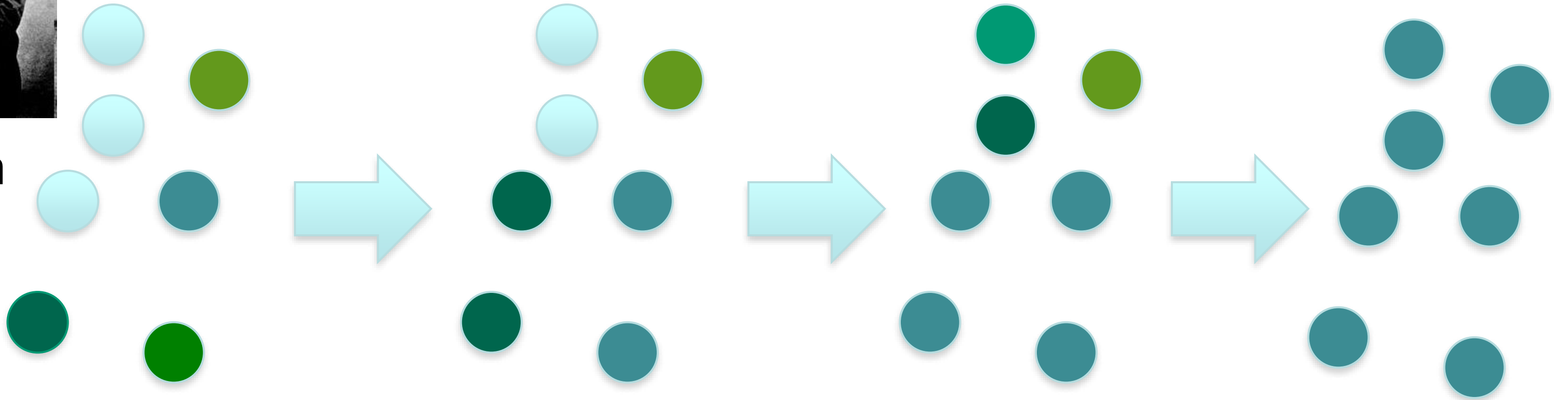


Lamarck
1809



Evolution

Darwin
1859



Adaptation occurs at population scale

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« Le melon a été divisé en tranches par la nature, afin d'être mangé en famille ; la citrouille, étant plus grosse, peut être mangée avec les voisins ».

Etudes de la nature, Jacques-Henri Bernardin de Saint-Pierre (1784)

« Nature uses shape to determine functionality » : Finalisme

- Pour prospectif : finalisme

« C'est étudié pour ! »

« Nature uses shape to determine functionality » : Finalisme

« Nature uses functionality to determine shape » :

Finalité fonctionnelle (pour répospectif)

XVIIIème siècle…

Pierre Louis Moreau de Maupertuis

Quand
la fonction
disparaît,
la forme
aussi…

tétra mexicain (Astyanax mexicanus)

characin aveugle brésilien (Stygichthys typhlops)

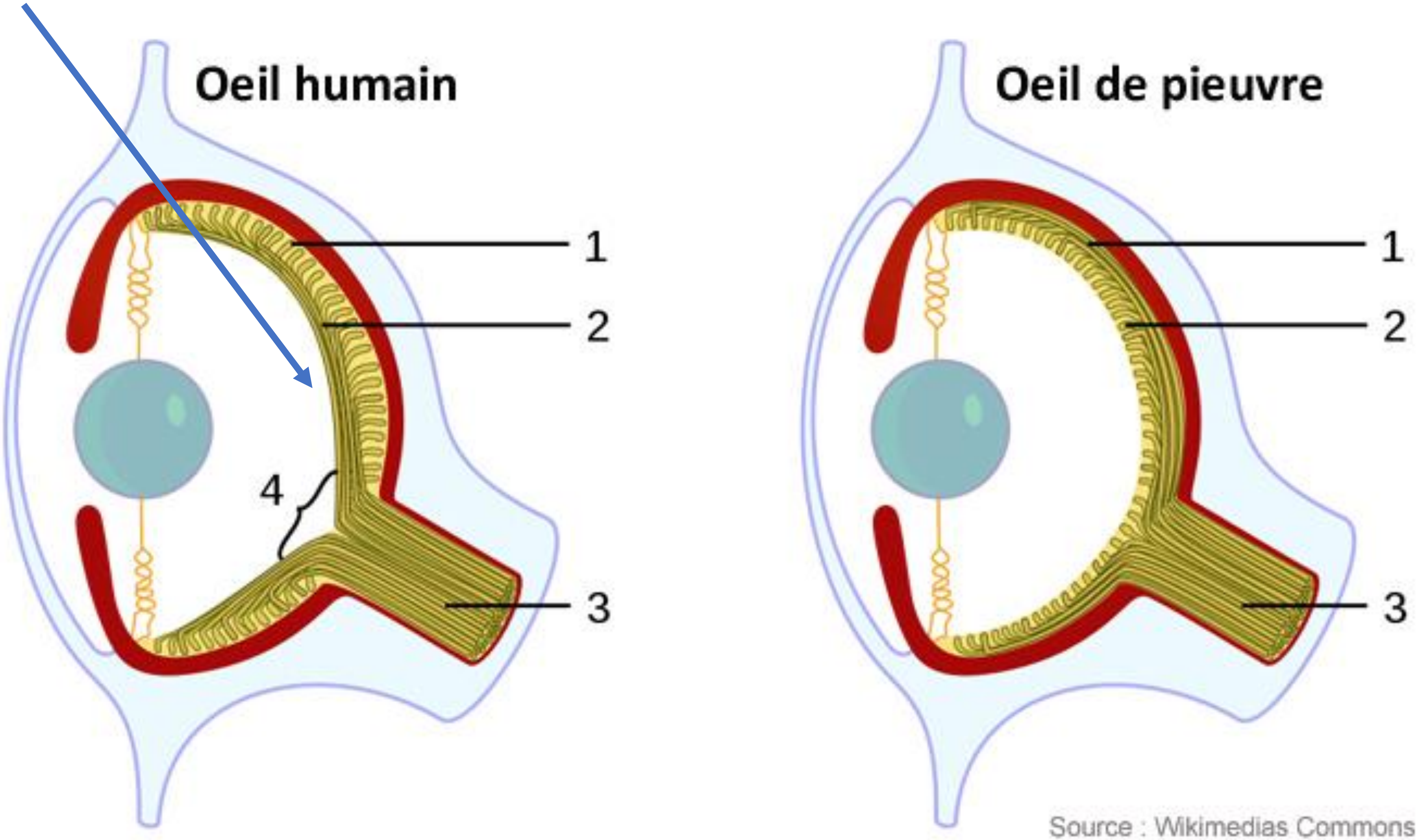
araignée-loup des grottes de Kauai (Adelocosa anops)

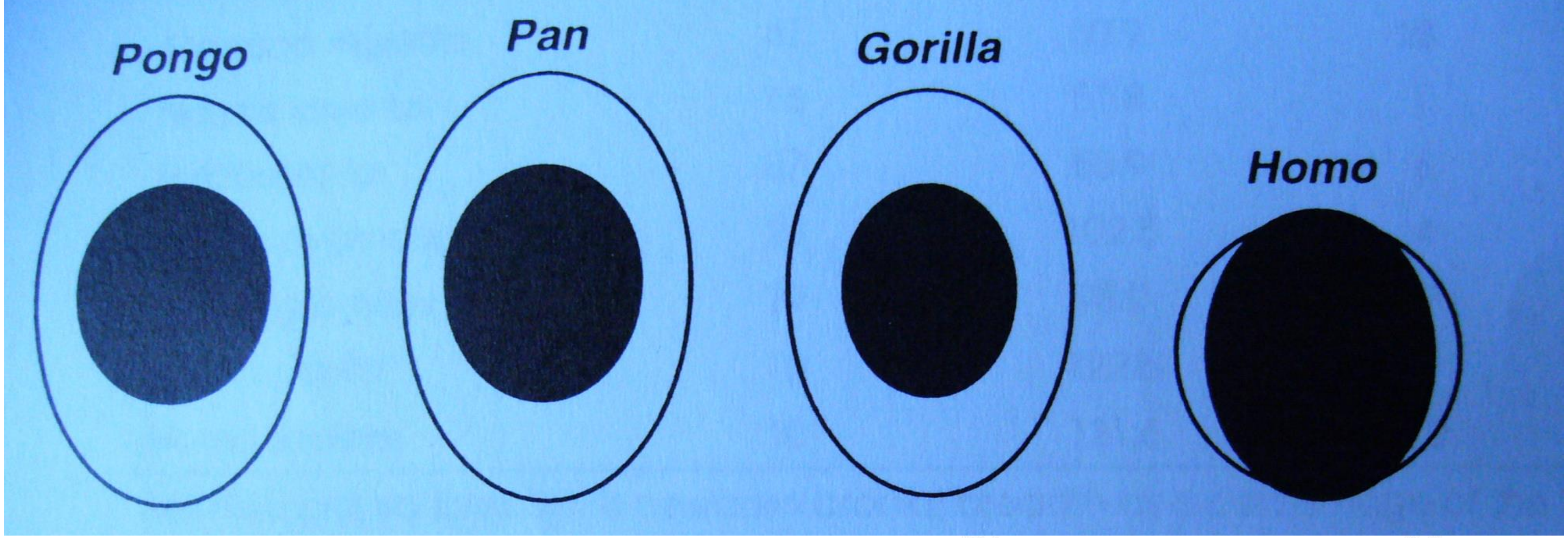
écrevisse américaine des grottes du sud (Orconectes australis)

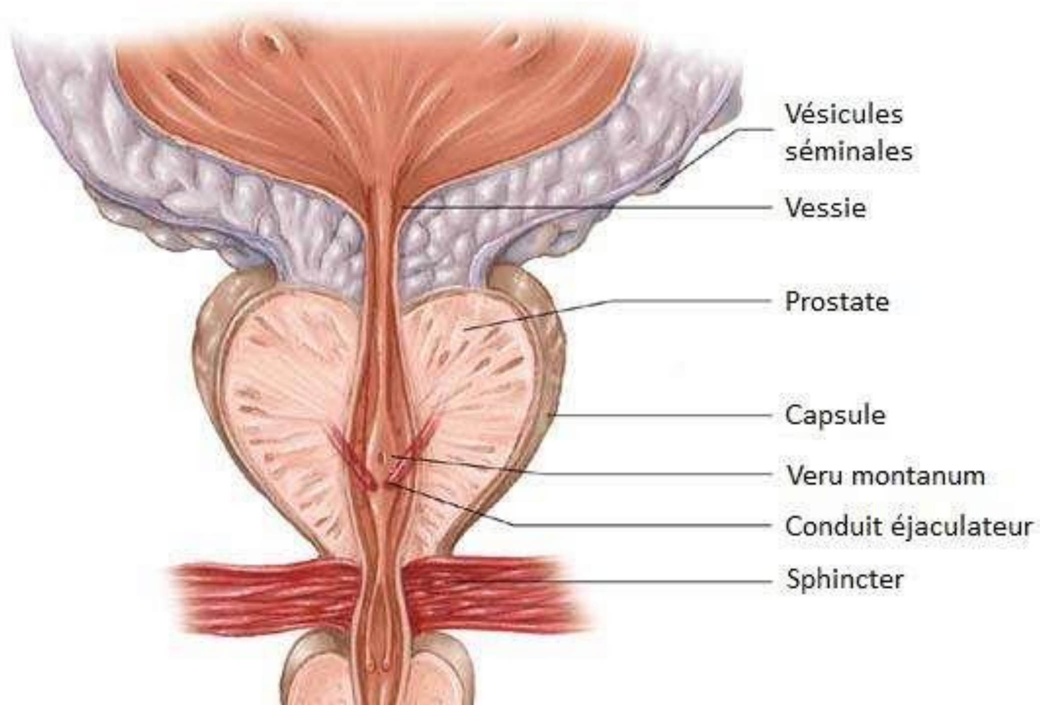
poisson-chat aveugle (Satan eurystomus)

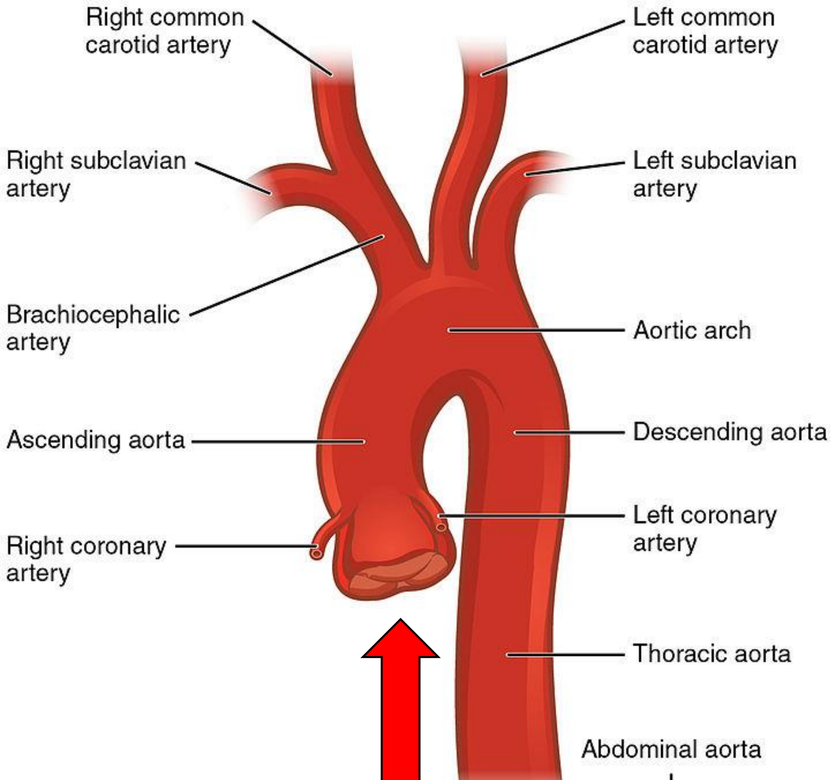

Phymatoniscus propinquus
3 mm (grotte de Clamouse)

« Nature uses shape to determine functionality » ?




Pongo
Pan
Gorilla
Homo


Vésicules séminales
Vessie
Prostate
Capsule
Veru montanum
Conduit éjaculateur
Sphincter


Right common carotid artery
Left common carotid artery
Right subclavian artery
Left subclavian artery
Brachiocephalic artery
Aortic arch
Ascending aorta
Descending aorta
Left coronary artery
Right coronary artery
Thoracic aorta
Abdominal aorta

C’est faux…

- In biological entities, functionality determines form. Structural complexity, rather than chemical composition, is behind the vast array of multi-functional biological materials found in the natural world.

- Pour les entités biologiques, la fonction détermine la forme. La complexité structurale (plutôt que la composition chimique) est sous-jacente à la vaste gamme de matériaux biologiques multi-fonctionnels trouvés dans la nature.

Des principes vraiment biologiques…

- Living organisms are discrete (i.e., bounded), self-organised, self-maintained, thermodynamically open systems that modify their surrounding environment
- Les êtres vivants sont des systèmes circonscrits, auto-organisés, auto-entretenus, thermodynamiquement ouverts
- Living organisms are unique; they vary at random; apparent biological “order” or regularity at the population scale is a consequence, not a cause
- Chaque être vivant est unique, les êtres vivants varient entre eux au hasard, et l’ « ordre » ou les régularités biologiques apparentes à l’échelle de la population sont une conséquence, non une cause
- Living organisms are shaped by their phylogenetic heritage
- Les êtres vivants sont formés par leur héritage phylogénétique
- Living organisms metabolise to grow and achieve homeostasis
- Les êtres vivants croissent et réalisent l’homéostase par leur métabolisme

Des principes vraiment biologiques…

- Living organisms multiply, and all species have the potential to proliferate
- Les êtres vivants se multiplient, et chaque espèce possède un potentiel à la pullulation
- Living organisms transmit through both genetic and non-genetic processes
- Les êtres vivants transmettent à d'autres par des voies génétiques et non génétiques
- Living organisms die, leading to better adaptation and the long-term survival of their lineage
- Les êtres vivants meurent, ce qui a pour conséquence l'adaptation et la survie à long terme de leur lignage
- Living organisms evolve under constraints
- Les êtres vivants évoluent sous contraintes

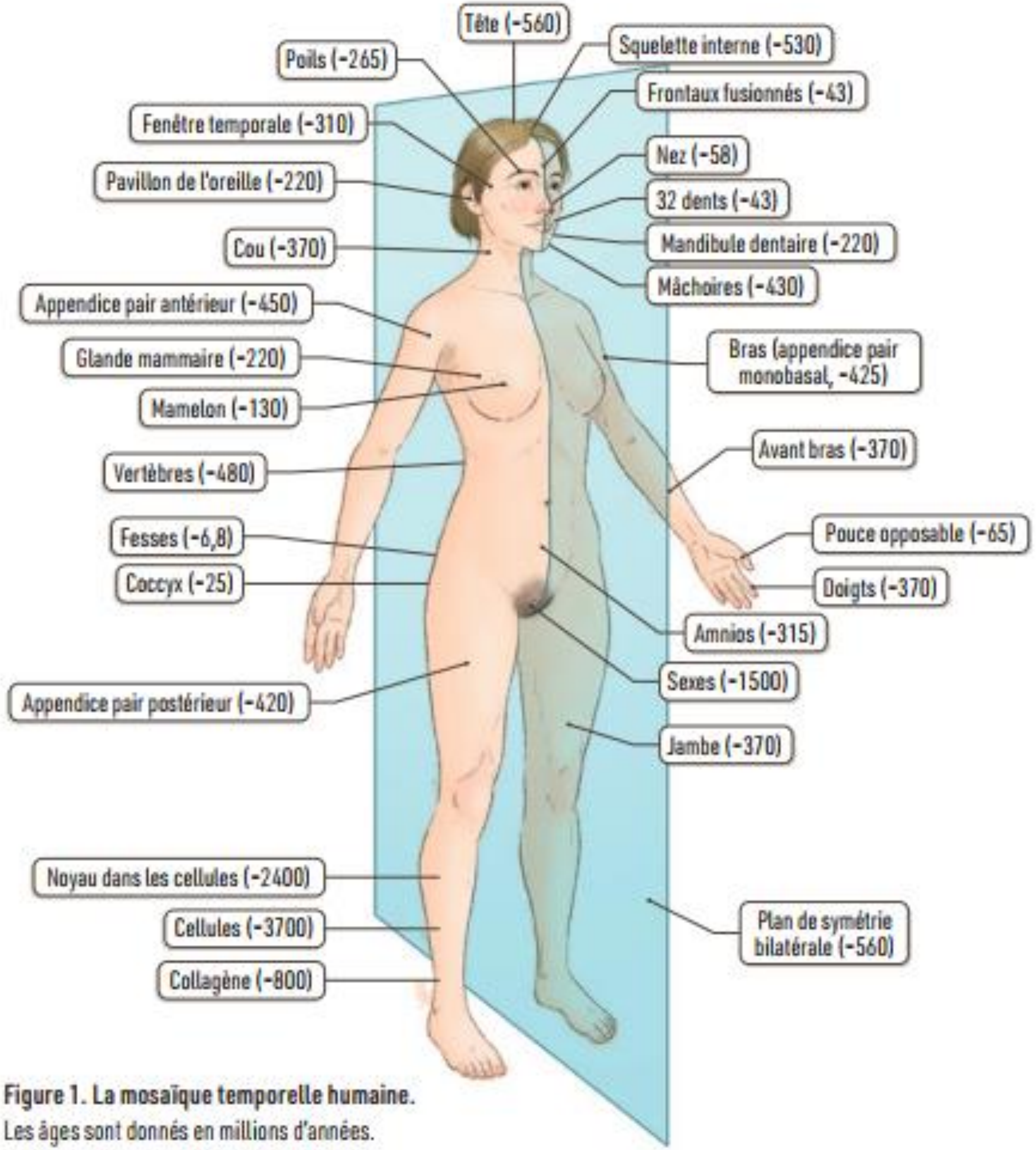


Figure 1. La mosaïque temporelle humaine.
Les âges sont donnés en millions d'années.

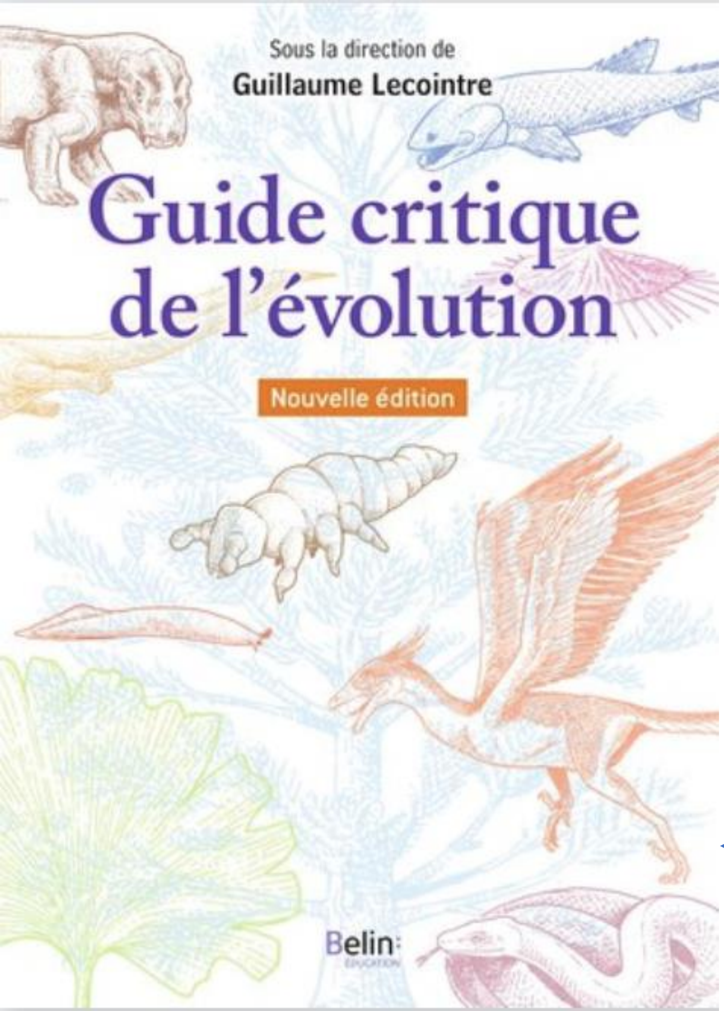
biomimetics

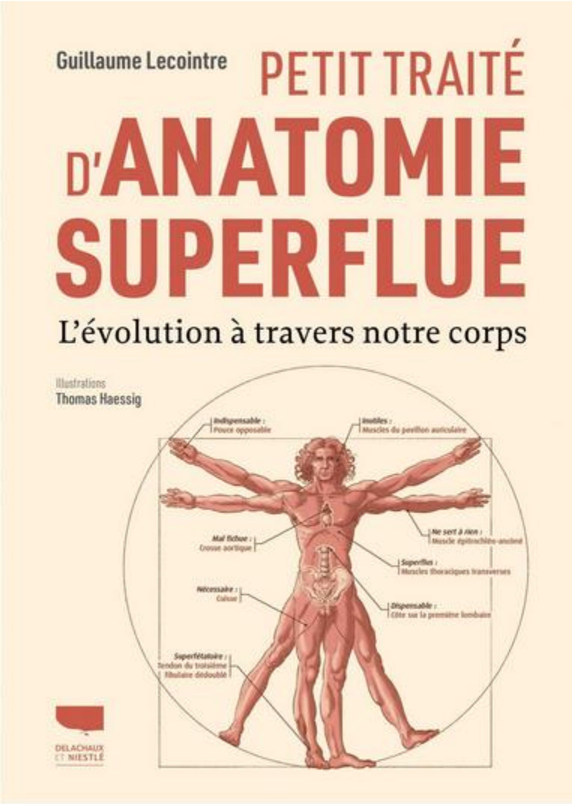
MDPI

Review

Revisiting Nature's "Unifying Patterns": A Biological Appraisal

Guillaume Lecointre [1,*], Annabelle Aish [2], Nadia Améziane [1], Tarik Chekchak [3], Christophe Goupil [4], Philippe Grandcolas [1], Julian F. V. Vincent [5] and Jian-Sheng Sun [6]





2e édition revue et augmentée (704 p.)