Towards a better understanding of adaptation: problem description, partial solutions, and recommendations

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This paper is the product of an international workshop aiming to make progress in our general understanding of adaptation. We met from 5-7 February 2025 in Hannover (Germany), funded by the foundation “Volkswagen Stiftung”. For our group of theoretical and empirical biologists, social scientists, and philosophers of science we set up a program to facilitate communication and collaboration between people with diverse backgrounds and viewpoints. The overall goal that the scientific community should strive for, we think, should be to obtain concrete conceptual, analytical, and experimental tools for researchers to understand and study all the processes of adaptation, and thereby the global phenomenon of adaptation. Our workshop aimed to contribute to this overall goal. For this, we discussed the relative strengths and weaknesses of different approaches, identified areas of consensus, identified areas of disagreement, and resolved (sub)areas of disagreement. Here we briefly report on the progress we have made during the workshop. We lay out the problem, discuss terminology, present a visual framework to think about adaptation, suggest useful approaches for its study, and provide recommendations for practitioners and policymakers.

What is the problem with adaptation?

A basic fact of life is that environments are not constant. Instead, abiotic conditions (e.g., temperature, precipitation, nutrient concentrations) and biotic conditions (e.g., predation risk, food availability, social and demographic population structure) change over time and space. Another basic observation is that not all combinations between environmental conditions and organisms are equally successful. Survival and reproduction depend on an organism's traits and abilities (or 'phenotypes') being well-matched to the environment it is interacting with (Edelaar & Bolnick 2019). This means that organisms – including humans – need to cope with the environmental variation and changes, and need to change too – they need to adapt. The systematic emergence of more successful phenotype-environment associations is known as adaptation, where greater success is understood to mean greater ecological performance and reproductive success. (Unfortunately, the word 'adaptation' is rather ambiguous: see Box 1 for a brief overview.)

Box 1. **What is adaptation?** Adaptation is an ambiguous term (Lewens 2009; Lewontin 1978; Reeve and Sherman 1993), in the sense that it has several different, albeit related, meanings. An adaptation is a characteristic that enhances the survival or reproduction of organisms that bear it, relative to alternative character states (Futuyma & Kirkpatrick 2017). So here the adaptation is a feature of the individual organism. For some people, adaptation can also be a feature of a population, as in 'this population has adapted', or 'there is maladaptation'. Finally, adaptation can be used to refer to the process of becoming adapted over time, a dynamic change (more similar to a verb) rather than a static state (a noun). To summarize, adaptation can be a state of being adapted, the process of becoming adapted, or refer to particular traits whose values provide increased reproductive success.

But what they have in common is that adaptation is evaluated in the context of increasing ecological performance (e.g., nutrient intake rate, or predation avoidance) and ultimately reproductive success. To avoid misunderstanding among these different meanings when writing 'adaptation', we often use alternative wording, for example by talking about the traits themselves, or by describing the process. In other cases the context hopefully avoids confusion.

Other ambiguities exist. One is about the level of biological organization at which adaptations happen and exist. For some people, adaptation only occurs at the population level, via evolution. For others, individual organisms can also adapt, for example via adaptive plasticity and other forms of development. To enable a broader treatment of the topic of adaptation, we follow this inclusive perspective. Another ambiguity is whether an adaptation might come about because of a shift in function (the distinction between adaptation and exaptation; Gould & Vrba 1982), and whether adaptation might be a side effect of selection for other traits (e.g., when a trait that is not under selection evolves because it is genetically correlated with one that is; Futuyma & Kirkpatrick 2017). These ambiguities are less relevant for our treatment here.

Adaptation as a state can come about in various ways, so adaptation as a process has been classified in various ways. Sometimes adaptation is divided into two types. Quoting Haig (2007, p.424): "Adaptation has historically referred to two processes in biology. The first process is the adaptive response of an individual organism to its particular environment (adaptation 1). (...) Such adaptive responses are often considered to be acquired characters (or characters that are induced by the environment). The second process is the change in the heritable properties of organisms over evolutionary time (i.e. generations) that makes organisms more suited to their environments (adaptation 2). Neo-Darwinists believe that phylogenetic adaptation (adaptation 2) occurs by natural selection of random genetic variation and that among the products of natural selection are processes of ontogenetic adaptation (adaptation 1)."

However, adaptation at the individual level does not only happen because of a response of an individual organism to its particular environment (Haig's adaptation 1), it may also just be the consequence of non-responsive (constitutive) development. For example, as a prey organism grows larger, it may no longer be at risk of predation by smaller predators. In addition, this simple binary classification tends to obfuscate that there are two targets for improvement of the phenotype-environment match (Edelaar & Bolnick 2019): the individual organism's phenotype, and its environment (see Figure 1). There are many examples of organisms adaptively making changes to their environment to improve the phenotype-environment match. These include the making of constructions (a change of the local environment), changing the behaviour of other individuals via communication or control (also a change of the local environment), or choosing to move to another environment (Odling-Smee et al. 2003). Recognising these additional dimensions of change, of the individual organism's phenotype or of its environment, has resulted in recognising four fundamental ways to achieve successful trait-environment associations (Edelaar & Bolnick 2019; Trappes et al. 2022; Figure 1):

(1) certain individuals survive and/or reproduce better than others in a given environment because of their characteristics (natural selection - a population-level process),
(2) individuals change their phenotypic traits,
(3) individuals choose the environment (e.g., habitat, food resources, mate, or social group),
(4) individuals construct their local environment.

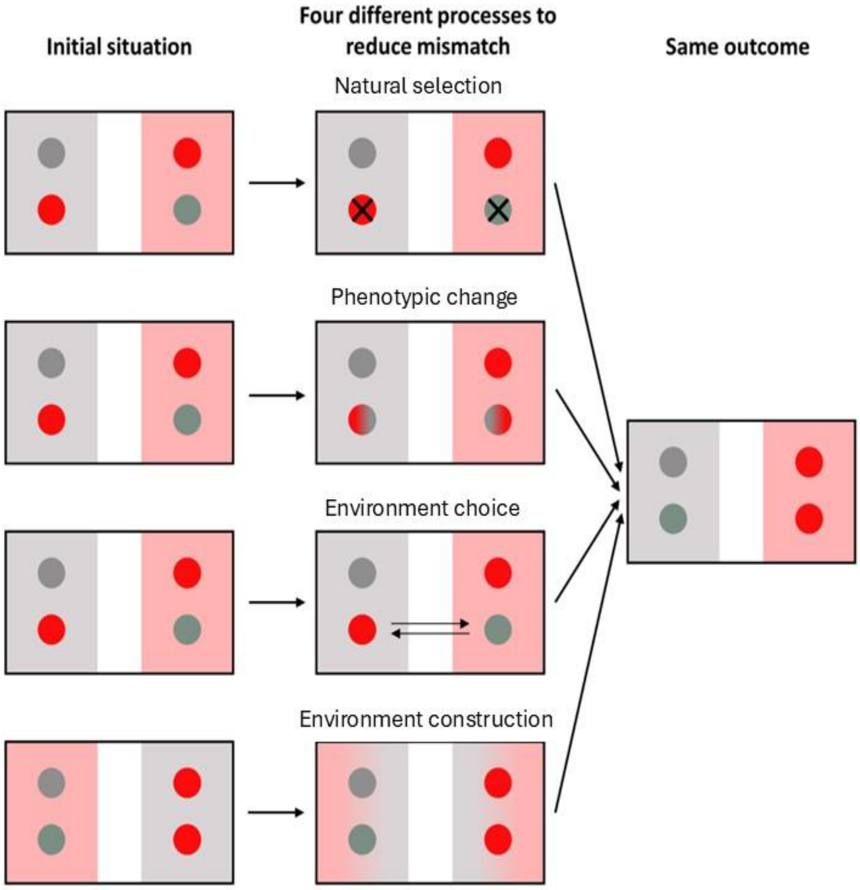

Figure 1. A phenomenological visualization of four possible processes leading to the same observed pattern of improved phenotype-environment match (i.e., leading to adaptation as a state). Each box represents individuals in two different separate environments. Individuals are represented by coloured dots and local environments by coloured backgrounds. When colours match, there is a match between their phenotype and their local environment, resulting in adaptation to that environment. All four processes, namely natural selection (a population-level process), and phenotypic change, environment choice, and environment construction (three individual-level processes), can improve initial individual mismatch and ultimately lead to the same outcome of a matching pattern. These may all occur within a single generation, including natural selection (e.g., via selective mortality). This means that without additional information we do not know which processes contributed to any observed organism-environment match. Thus, without additional information observed patterns cannot be interpreted as due to any specific process. (Original figure by Gabriel Munar-Delgado.)

This expanded classification is broader than Haig's. The first way is essential to Haig's adaptation 2 (evolutionary adaptation of the population across generations), but it also includes within-generation population change via differential survival. The second to fourth ways cover Haig's adaptation 1 (responsive developmental adaptation of the individual, within generations), but it also includes non-responsive (constitutive) change, it also includes (flexible/reversible) change in fully-grown adults, and it also includes change in environmental aspects.

While the concept of adaptation is central to evolutionary biology, the same idea is fundamental in other disciplines. For example, human psychologists try to understand how people developmentally tailor their brains, cognition, and behaviour to harsh and unpredictable environments (Frankenhuis & Gopnik 2023), how the fit between a person's personality and its environment can be improved (Kandler et al. 2024), and economists study the features that allow some companies or organisations to grow where others fail (Child 1997). In all cases we expect to see associations between the traits of organisms (or analogous entities) and the features of their environment.

Obtaining a good understanding of adaptation is therefore of broad importance. It improves our understanding of the variability, functioning, and fitness of individual organisms. This then also impacts the functioning, persistence, and divergence of populations, species, and ecosystems. (Including captive organisms and agricultural species, even if they may have constraints on their abilities to control their environment because of human intervention). As our world is changing more and more (e.g., climate change, economic globalization, societal changes), a greater understanding of how organisms and analogous entities like companies and organizations cope with and control variability is increasingly relevant to predict responses to these changes and to meet societal challenges.

However, obtaining a good understanding of adaptation is not an easy task. As shown in Figure 1, adaptation is a rather complex phenomenon. (i) At its most basic, there is not one process of adaptation, but several. These are not strictly comparable: there is developmental adaptation at the individual level (Haig's adaptation 1) and evolutionary adaptation at the population level (Haig's adaptation 2), and this implies different requirements and different dynamics. For example, evolutionary adaptation at the population level requires heredity of the relevant characters, while developmental adaptation at the individual level may require an active organismal response to the environment. (ii) All four processes result in the same outcome (Figure 1). This means that we have four different solutions to what is essentially the same challenge, that of how to increase organism-environment match. (iii) Whenever different solutions can be applied to the same challenge, then the operation of one solution could reduce the scope for the other potential solutions (a negative effect). For example, a change in the phenotype to match the local environment may remove the need for choice of the environment. Alternatively, one solution could facilitate the other (a positive effect). For example, a change in the phenotype facilitates dispersal and therefore choice of the environment. Another option is that a mixture of solutions, within or between individuals, is favoured (frequency-dependent effects; Araya-Ajoy et al. 2025). (iv) Finally, evolutionary adaptation at the population level includes the evolution of the three individual-level processes of developmental adaptation. Therefore, we expect there to be interactions among the different solutions, in their operation, and in their evolution.

Unfortunately, these four processes of adaptation are largely studied in isolated research programs, even within biology. We are typically not considering all processes at the same time, we tend to isolate the processes, and we tend to pay more attention to some processes than to others (changes to the environment generally receive less attention). This means that some processes are understudied, and the interactions between processes as mentioned above are understudied. For example, researchers studying habitat choice (a form of choice of the environment) or niche construction (a form of construction of the environment) typically ignore phenotypic plasticity (a form of change of the phenotype), and *vice versa*. This isolation can be problematic, because then we ignore that the different organismal solutions to the same challenge may constrain each other or act synergistically (at the moment, and during their evolution). It also means that without additional information we do not know which processes contributed to any observed phenotype-environment match, and thus that observed patterns cannot be interpreted as due to any specific process (Figure 1).

Comprehensive studies investigating all of these processes would benefit from a common and general framework, but such a framework is currently insufficiently developed (Botero et al. 2015; Edelaar et al. 2017; Fokkema et al. 2021; Munar-Delgado et al. 2023; Scheiner 2016; Scheiner et al. 2021, 2022; Gonzalez-Forero 2023, 2024). Moreover, research in other disciplines (e.g., psychology, sociology, economy, and philosophy) developed similar ideas and concepts on adaptation (e.g. Childs 1997; Johnson 2007), but crosstalk between the disciplines is rare (Saltz 2019).

Towards a better understanding of adaptation

Improving terminology and its use

In our workshop we reviewed, compared, and connected existing terminologies. There are, unfortunately, many terms and descriptions that cover at least part of the same biological phenomena, possibly because they have each been developed to describe certain biological phenomena without considering their relation to adaptation as a general phenomenon, and their relation to the many processes that can lead to adaptation. That is, they have been developed in the absence of a common framework. As a result, existing terms in the literature vary in breath and in specificity. As an example of a narrow term, ‘matching habitat choice’ only relates to habitat choice, not to choice of the environment entirely, because that would also cover the choice of a social or sexual partner, or when to be active (temporal choice) (D’Aguillo et al. 2019; Edelaar et al. 2008; Kaiser et al. 2024; Ravigné et al. 2004). Moreover, it is a specific form of habitat choice, one that is driven by an active assessment of local performance by the organism, and thus different from habitat choice due to a genetic preference or a preference developed via imprinting (Edelaar et al. 2008; Ravigné et al. 2004). As an example of a broad term, niche construction covers the change in the local environment for the individual doing the construction, but also the effects for other conspecifics or even heterospecifics. Some people also see habitat choice as a form of niche construction, so-called ‘relocational niche construction’ (Odling-Smee et al. 2003). And in an even broader interpretation, even phenotypic plasticity has been interpreted as a form of niche construction (Sultan 2015).

In the workshop we spent a lot of time reviewing and discussing the terminology, in part because different people have different understandings of the same term and have different preferences. In the end, we concluded that there may not be a single terminology that the entire scientific community needs to use, because some subdisciplines have a tradition of terminology that is unlikely to be replaced by another. However, we do advise authors to provide more information about what they mean when they use specific terms, and to be aware of the connections with other terminology. Some considerations for the three processes of developmental adaptation are as follows.

- **Environment Choice.** It seems better to use the word 'choice' instead of 'selection', to avoid confusion with natural selection. We use the term 'environment' to be as inclusive as possible with respect to what is chosen (a habitat, a niche, a resource, a location, a mate, a social group, etc.). 'Habitat use' is a broader term than ours; use is the outcome of choice, but use still occurs even when there is absence of choice due to the lack of options. Note that choice does not necessarily mean change: perhaps the current option is chosen, and no change is observed (Trappes et al. 2022).
- **Environment Construction.** We use the term 'construction' instead of 'modification' because it has a stronger connotation with adaptation: deterioration is also modification. 'Adjustment' suggests only changing something already existing, whereas construction also includes new elements. We again use the term 'environment' to be as inclusive as possible with respect to what is constructed (something physical, the habitat, the behaviour of other organisms, etc.).
- **Phenotype Change.** This term explicitly refers to a change in the phenotype of the individual, providing a clear contrast to change in the environment via choice or construction. Change of the individual could involve a response (to the environment (Schlichting & Pigliucci 1998), to other individuals as with indirect genetic effects (Baud et al. 2022; Wolf et al. 1998), or to other phenotypic traits as with causally covarying traits (Morrissey 2014)). But it also involves the constitutive, unresponsive ontogeny of traits, since this may still increase adaptation. This means that alternative terms like plasticity, flexibility, conformance, or adjustment are not inclusive enough.

A framework to understand the processes driving adaptation

This discussion of terminology naturally led to a discussion on how the different processes of adaptation operate, how they relate to each other, and how they evolve and influence evolution. This gave rise to the development of a visually intuitive framework to understand the processes driving adaptation (Figure 2). This framework:

- addresses the individual- and population-level mechanisms behind any observed trait-environment association (i.e., identifies the causes of adaptation),
- distinguishes between constitutive (fixed) and responsive (plastic) development,
- considers potential interactions between these mechanisms (in their current operation and in their evolution),

- recognises that organisms are not just passive receivers of environmental effects, but can also be active agents of change,
- acknowledges the complexity of reality – organisms and environments may both evolve over generations, and the different solutions for trait-environment match may interact.

We further present and discuss this framework in a forthcoming separate publication. We hope this framework helps researchers to avoid making implicit (or unrecognised) assumptions about the absence of certain phenomena by simply ignoring them. For example, when faced with an observation as in Figure 1, to only discuss or test for natural selection and phenotypic change.

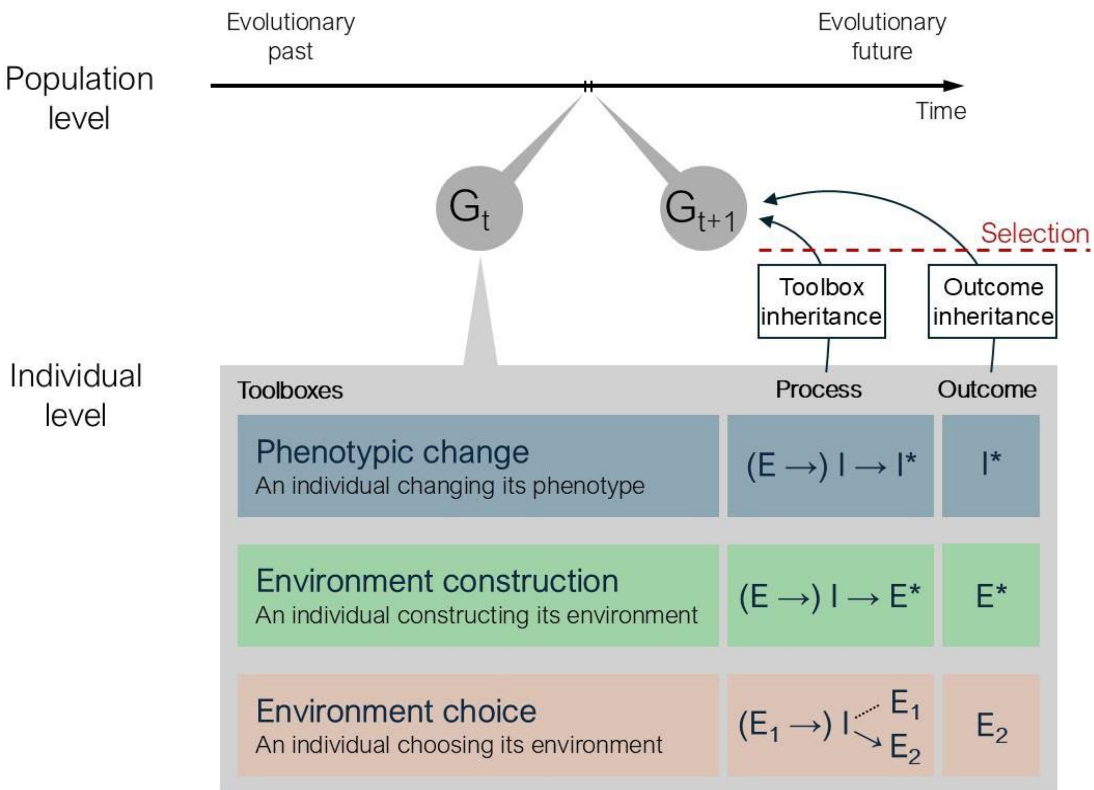

Figure 2. *A schematic framework to understand adaptation and its evolution. Greater adaptation refers here to an improved match between the individual (I) and its environment (E), whose consequence is improved ecological performance and reproductive success. Mechanistically, adaptation occurs at two levels: at the population level and at the individual level. The ability of individuals to adapt (their adaptation 'toolbox') evolves at the population level over time, as captured by the horizontal arrow at the top. From one generation (G_t) to the next (G_{t+1}), individuals can employ different adaptation toolboxes. We recognise three distinct ones (the three differently coloured rows): individuals can engage in phenotype change (giving as outcome I*), individuals can engage in environment construction (giving as outcome E*), and/or individuals can engage in environment choice (here, E_1 versus E_2, and giving as outcome E_2). These three*

different toolboxes might be employed in a constitutive manner (i.e. fixed expression). For example, a plant always develops spines against potential herbivory. Alternatively, the toolbox is employed in a facultative manner (i.e., responsively expressed), here represented by environmental effects on the individuals within parentheses (E →). For example, a plant only develops spines against herbivory if it detects that herbivores are present. When the elements of the toolbox are heritable, and when variation in these elements is associated with variation in reproductive success (indicated as 'Selection'), constitutive and facultative toolboxes can evolve at the population level (indicated as 'toolbox inheritance'). Additionally, in some cases the adaptation outcome is directly (non-genetically) heritable, and can be transmitted to the next generation as a function of its effect on reproductive success ('Selection'). Examples could be epigenetic molecular marks passed on via gametes, behaviours that are copied by offspring, or environments that are inherited by offspring (Agrawal et al. 1999; Anastasiadi et al. 2021; Bonduriansky & Day 2018; Edelaar in press).

Integrating mathematical approaches to adaptation

Addressing a complex topic like adaptation tends to benefit from a mathematical approach, which can provide a precision that language is otherwise lacking, allowing clearer understanding of if, how, and when concepts overlap and diverge. A diverse group of mathematical biologists sat down to discuss different approaches, where the diverse backgrounds and preferences of each became clear. In a forthcoming paper they will present a joint framework, which incorporates all four processes within a single mathematical model, they discuss the correspondence between their approach and existing eco-evolutionary models, and they suggest how this framework might be used to distinguish the effects of each of the four processes of adaptation. There may not be a single best mathematical approach to adaptation, but the group ultimately developed an approach that, interestingly, none of them would have developed individually. Furthermore, they all agreed this approach was better than what they likely would have developed individually. So one lesson is that also in mathematical modelling, collaboration among people with diverse backgrounds pays off. A next step might therefore be greater interaction among theoreticians from different disciplines (e.g., biology, sociology, economics).

Clarifying which features explain and predict the diversity of adaptation

There may be organismal or environmental features that favour the evolution of some processes of adaptation over others. If we can identify these, we are able to give better explanations for how adaptation has evolved in the past, and it may also be relevant to predict how adaptation may play out in the future. This turned out to be a big task, or perhaps one that does not have a single solution because too many contingencies are involved. But a few general observations could be made.

Individual adaptation as a state is often described by the fitness effects of the match between the phenotypical value z and environmental value ϑ:

$$w_{i,X,t} = \alpha \cdot exp\left(-\frac{\left(z_{i,t} - \theta_{i,X,t}\right)^2}{\sigma_{X,t}2}\right)$$

where α is a constant, $z_{i,t}$ is the trait value of individual *i* at time t, $\theta_{i,X,t}$ represents the individual's value of its environment at location *X* at time t, and $\sigma_{X,t}\mathbf{2}$ is the width of the fitness function (a larger value describes weaker selection on mismatch). As can also be seen from this mathematical description, in confirmation of what was said earlier, an individual can achieve a change in its fitness via a change in the phenotype (z) or a change in the environment (θ). Next, the subscripts capture the three different targets identified in Figure 2: a change of its phenotype in time (z_t) (phenotype change), a change of its environment in space (θ_X) (environment choice), or a change of its environment in time (θ_t) (environment construction).

Which of these processes (the toolboxes of Figure 2) will evolve (via evolutionary adaptation at the population level) will be influenced by a number of factors.

- Predictability of the future. Changes of the phenotype or the environment are only adaptive if they increase fitness in the future. This means that such changes are more likely to be adaptive if the future phenotype and/or environment can be predicted with greater reliability.
- Developmental costs. Changing the phenotype takes energy and other resources. Likewise, exploring and choosing another environment, and changing and maintaining the local environment likely takes resources.
- Risk. Change of phenotype or environment may entail risks. Perhaps the future is not as expected, and mismatch is actually increased due to the organismal change. Or the development of a new phenotype or environment includes a transition phase of greater risk of e.g. starvation or predation.
- Time. Information acquisition/processing and subsequent organismal change generally takes time, and during that time it is possible that organismal performance is temporarily reduced. To the extent that all of this takes time, the scale of external temporal variation (e.g. temporal change in the environment) also becomes relevant – change may be so rapid that the organism cannot track it (or tracking it becomes too costly given the short-lived benefit it gives) (Dupont et al. 2024).
- Lost opportunity costs. Activating one process of adaptation now might imply that the benefit of using another process of adaptation in the future is diminished.
- Benefits. These are in principle specified by the fitness function, but some stochasticity is expected, and for environment construction benefits may be taken by or received from other conspecifics.

These insights allow for some further inductions. The evolution of adaptive phenotypic change is more likely if the information received from the environment (the cue) is predictive of the expected environmental state within the proper temporal reaction scale of the organism. Hence, we expect phenotypic change to evolve under positive autocorrelation (red noise) of the environmental temporal variation within a lifetime (or across generations in case of transgenerational transmission). Faster temporal variation within a lifetime is more likely to result in the evolution of reversible phenotypic change.

Adaptive environment choice (either in space or in time) requires local availability of suitable environments within the activity range of the individual organism, and therefore is more likely to evolve when the environments are negatively autocorrelated (blue noise) or uncorrelated (white noise). If within-environment temporal heterogeneity is strong (making any chosen environment unpredictable), then non-informed choice (including diversified bet hedging) is expected to evolve. The same seems true when among-environment variation is positively autocorrelated.

It is not clear under which conditions construction of the environment is expected to evolve. Perhaps it evolves when the other two individual-level processes of adaptation are somehow limited. This might be when environments vary at such a large scale that it is outside the activity range of the individual organism and does not allow for environment choice. Or when environments vary at such a small respectively large temporal scale that it is too fast respectively too slow for the individual organism to track via phenotype change. Or when the range of environmental variation is so large that it extends beyond the range of the phenotypic variation that could match it – in that case, construction of the environment might reduce the environmental variation enough such that match can be achieved again. Construction of the environment may also be more likely to evolve if the costs are shared between different individuals (especially relatives), or when the benefits of a given investment in construction are larger (e.g., when more conspecifics are present that can be influenced by the social phenotype of an individual), or when the constructed environments and their benefits are transmitted to relatives.

Finally, genetic adaptation via natural selection (with outcomes ranging from clines and locally adapted populations to ecological speciation) is more likely for slow environmental change at large spatial scales.

It is clear that the evolution and operation of the different processes of adaptation are not too predictable as they are dependent on the cost-benefit ratio of each process, within the parameter space delimited by constraints. All of these costs, benefits, and limitations depend on characteristics of the environment, but also on characteristics of the organism. This means that past evolutionary trajectories influence future evolutionary trajectories. For example, environment construction favours residency, which may favour phenotype change but disfavour environment choice. Nonetheless, it does seem that to some extent we might be able to understand and predict the relative contributions of the different processes of adaptation by decomposing the spatiotemporal environmental variation into its different wave signals and contrasting these with the organism's life history and spatial neighbourhood.

Generate predictive models

The topic of coaction, coexistence, and coevolution of the different processes of adaptation, and how they might lead to potential correlations at different hierarchical levels, was also explored via simulation modelling, and, more specifically, a discussion on the elements that a quantitative genetic individual-based simulation model might profitably contain. One interesting consideration was that an organism may need to make many changes during its lifetime, and cycles of decision-making could be modelled for this. In every cycle only a single adaptation process is applied, based on the greatest 'liability' for this process. This liability depends on genetic inputs in the form of intercepts of a reaction norm, but also on inputs described by the (equally genetic) slope of the reaction norm. These reaction norms allow the organism to respond to the environmental state (including population density), and its own phenotypic state, and to the phenotype-environment mismatch. Having multiple decision cycles before reproduction allows individuals to dynamically respond to the fast environmental and phenotypic changes, to respond to each other's actions (including transgenerationally transmitted ones), and to display mixtures of processes. The modelling of individuals also allows for differences among individuals to evolve (e.g., different frequencies of distinct strategies).

Simulation models allow for the modelling of complex scenarios and allow for the execution of virtual experiments. For example, after running the models over many generations, we can modify the environmental conditions and observe changes in the genetic parameters (intercept and slope of the reaction norm) underlying the liability of the three actions. We can also observe how the genetic variances responsible for individual differences in their actions are maintained throughout evolution, and whether any positive or negative genetic correlation emerges from their coevolution (i.e., how the different developmental adaptation processes influence each other evolutionarily).

Additional recommendations

Our knowledge of adaptation is already quite considerable. However, as outlined in the introduction, there is also a considerable need for future research, and the facilitation of such research. We end with some recommendations that address these goals.

- We need further development and classification of methods to examine and test the importance of each process of adaptation as an explanation for any observed trait-environment associations. There is likely not a single method that works for all cases, but the exploration for more general methods should be promoted. Descriptive statistical models that still allow for causal inferences would be especially valuable.
- We need more empirical studies that investigate multiple processes of adaptation at the same time. Explanatory power of these studies is likely enhanced when combined with experimental approaches, allowing for causal inferences.
- In studies that investigate adaptation, authors should address explicitly what processes of adaptation they did consider, and which were not considered (or can be ignored), and what this implies. Ideally, they would also mention what limitations exist and what would be needed to study all processes, as a service to readers and potential funders.
- Which processes of adaptation operate likely depends on the spatial scale of environmental variation, and on the temporal scale of environmental and phenotypic variation, all relative to organismal mobility and generation time. These scales therefore need to be quantified or discussed.

- As we obtain more information on which processes of adaptation operate, we should investigate the costs and constraints of the processes.
- Regarding the evolution of the individual processes of adaptation, we need more studies on the heritable variation of these processes, on the strength of natural selection on these, and on the ecological causes behind any natural selection on them.
- We should also investigate the interactions, feedbacks, and trade-offs among the four processes. Can we predict negative or positive interactions among the processes of adaptation with any generality, and how this influences their operation and evolution?
- A more integral approach to adaptation should feature in our teaching, such that a new generation of researchers becomes familiar with the interrelatedness of the different processes of adaptation.
- Adaptation is a transversal topic that is relevant in many fields and disciplines, and more interaction and collaboration between people from these diverse backgrounds is advisable. This may require reflection on different scientific cultures and for sure requires getting familiar with different (usage of) terminology. Such collaboration might be easier if it is focussed on a specific problem, for example a societal need. Collaborative research can benefit from seed money for networking or a discovery phase, not unlike our sponsored workshop.

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