



A Review on Adaptive Responses of Salamanders to Climate Change

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: <https://doi.org/10.56557/upjoz/2024/v45i154250>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://prh.mbimph.com/review-history/3735>

Review Article

Received: 04/05/2024
Accepted: 09/07/2024
Published: 13/07/2024

ABSTRACT

Extinction rates of salamanders are predicted to rise exponentially under rapidly changing environmental conditions. Due to a wide range of anthropogenic activities, the populations of salamanders are highly threatened. The previous published data indicate that salamanders have adapted various plastic responses to acclimatize to the changing environment. These plastic responses help them to buffer the adverse effects of changing environments and also allow them to adapt to new habitats. The objectives of this review paper are to explore the impact of changing climate on salamanders, to elucidate the diverse strategies they employ to mitigate these challenges, and to evaluate the limitations and evolutionary significance of these measures. Additionally, this study will endeavor to forecast whether these adaptive changes are sufficient to address the evolving climate conditions.

Keywords: Salamanders; plasticity; climate change; adaptive strategies.

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Cite as: Ghosh, Rajarshi. 2024. "A Review on Adaptive Responses of Salamanders to Climate Change". UTTAR PRADESH JOURNAL OF ZOOLOGY 45 (15):348-62. <https://doi.org/10.56557/upjoz/2024/v45i154250>.

1. INTRODUCTION

Rapid climate change affects species distribution and is considered one of the major threats to biodiversity and an increased risk to a population of species that fails to adapt to suitable habitats. Extinction rates are predicted to rise with global warming. The most common factors impacting population size in amphibians such as salamanders include habitat loss, global warming and emerging diseases. Increased vulnerability to diseases, changes in body size, decline in population, range contractions are some of the effects of climate change on salamanders [1]. Montane salamander species exhibit a limited range of thermal tolerance. Ever shifting contemporary climatic conditions is a potential danger for persistence of such species. Changing body size is the response seen in many amphibians due to projected climate change scenarios [2]. Such changes affect several biophysical processes that lead to phenotypic alterations affecting their fitness and survival. Warmer temperatures cause more expenditure of energy leading to a decrease in growth. As amphibians are active thermals and constantly need moisture, they tend to be more susceptible to these changes. Differences in foraging behavior, activity patterns, and diets are linked with changes in body size. Animals are capable of remodeling their physiology to make up for the effects of temperature variations. Amphibians experience accelerated energy expenditure in drier and hotter conditions, contributing to population decline [3]. Dynamic environmental conditions result in phenotypic plasticity and adaptive changes at genetic levels which give rise to more adapted and long-lasting phenotypes and have higher fitness in their habitat. Environmentally induced phenotypic variation can also lead to creating conditions that in turn cause adaptive genetic responses leading to natural selection. The efficiency of genetic adaptation depends on the relationship between generation time and the rate of climate change. Metabolic rate and water loss are two fundamental traits controlling an organism's energy balance. Trade-offs between these two traits are an indication of how energetically favorable an acclimatization strategy is [4]. If climate change is relatively slow and unidirectional, short-lived animals may adapt successfully. Though plasticity arises as a non-heritable trait, later these variations are assimilated into the genome and play an influential role in adaptive evolution [5]. Local adaptation is an effective mechanism to resist

the effects of climate change. Local adaptation also results in a change of genomic sequence and is considered as a result of powerful natural selection [6,6a]. This review is centered on the various threats encountered by salamanders as a consequence of environmental changes, as well as their tactics for surmounting these challenges.

2. THREATS DUE TO CLIMATE CHANGE

Organisms of major ecosystems are facing serious trouble due to the ever-changing climatic scenario. Significant shifts in the distribution, migratory period and behavior of organisms have been observed due to global warming. The factors which are the commonest stressors for the long-term population decline of amphibians are not yet finalized [7,8,9,10]. Invasion of foreign species, loss of habitat, emerging diseases [11] and global climate change [12] are a few of the common stressors. Exposure and sensitivity to climate change, resilience to unfavorable conditions, and potential for adaptation control the vulnerability of species to environmental fluctuations but behavioral, physiological, and genetic data is required to predict these vulnerability criteria [13].

A number of species have witnessed a decline according to the study on the amphibian population [14]. Evolutionary climate change escalates fragmentation and loss of habitat. The biggest contribution to the distribution model was made by variables related to precipitation and temperature. Connectivity among populations is highly affected due to climate change and changing landscape [15,16,17,18]. Change in climate results in shift in species distribution and an increase in the risk of extinction of population that fail to adapt or relocate [19,20,21]. The limited dispersal abilities of salamanders make them increasingly vulnerable to climatic change [15,20,22,23,24]. Species adapted to different temperatures showed clear adaptive variation patterns in protein properties. A large-scale change in gene expression during acclimation is involved in the adaptive modification of phenotype.

Overheating and chronic thermal stress may lead to malfunction in cardiac performance that results in inadequate oxygen supply to support aerobic respiration [25]. Negative consequences for the persistence of populations are seen due to climatic change which causes a shift in migration period. Amphibians are ectotherms;

hence the impact of climate change is profound on them. Metabolic processes are regulated by temperature and high expenditure of energy. A decrease in growth rate and less resource allocation is the result of increasing temperature. Projected alterations in the survival, population size, and recruitment of amphibians inhabiting wetland habitats are associated with factors such as snowmelt, precipitation patterns, and the rate of evapotranspiration [26].

Four predictions could be possible regarding the migration of spotted salamander population based on the effect of climate change. i) Higher thermal stress, drying and hydrologic interactions are related to the declining amphibian population [27], ii) It was also predicted that these conditions would lead to uneven sex ratios [28], iii) Due to higher metabolic rates, smaller body size is also predicted [29,30] and iv) Eminent phenological shifts lead to early migration dates [26].

3. BEHAVIOURS IN RESPONSE TO CLIMATE CHANGE

Species living in tropical areas experience more threats due to warm climate than species living at higher latitudes do [31]. As a consequence, many ectotherms including salamanders living in tropical areas have a thermal tolerance of 10-20°C higher than those living in other areas in order to encounter high summer temperatures [32]. Understanding of Global thermal safety margins is important because it helps us to predict species' vulnerabilities to climate change and also gives a clear picture of the contribution

of behavioral avoidance in thermal tolerance [33]. Being terrestrial organism, salamanders have to rely greatly on behavioral adjustments to thrive in the hottest temperatures [34]. Amphibians can tackle thermal extremities by maintaining a wet skin through evaporative cooling [35]. Organisms in great thermal danger try to get access to microrefugia like subterranean habitats to survive in extreme environments [33]. Among amphibians, about 23% of salamanders are known to have a fossorial lifestyle and this is thought to be a safeguard for these organisms against climate change because of the thermally buffered environment of underground [36]. Thus, adaptation to extreme heated conditions can be achieved by this fossorial lifestyle which helps them persist in a physiologically favored environment [37,38].

It has been found that a rise in summer temperature 1-3°C can reduce the body fitness of male breeding salamander by 5-14% [36]. To persist in this changing climate, microhabitat refugia and strict regulation in thermodynamics of behavior are needed [13,37,38,39,40]. These conditions can be satisfied by the fossorial habitat of salamanders and it is very crucial as they have contribution to various ecological functions [41,42]. Recent studies have shown that a rise in temperature can also have a negative effect on the body condition of fossorial salamanders by elevating the metabolism of the organism [36]. Spotted salamanders choose cool and damp burrowed microhabitats which reduce their metabolic rate and thus help to tackle the negative effects of rising temperature [42,43].

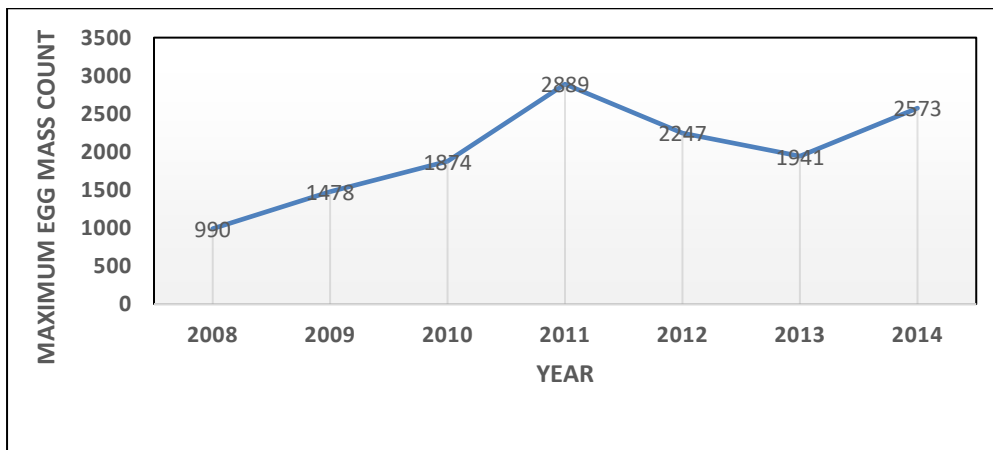


Fig. 1. Egg mass count of spotted salamander (*Ambystoma maculatum*) at Bat Lake in western Algonquin Provincial Park situated at the low latitude boreal wetland region of Ontario, Canada [36]

Change in climate and environmental cues such as temperatures, precipitation and Vapour Pressure Deficit (VPD) creates an impact on the growth rate, energy budget, migrational behaviors and annual breeding time of salamanders [26,44,45,46]. Response of amphibians due to climate change is hard to predict because of its idiosyncratic nature [47,48,49]. Measurement of egg mass count at the peak of breeding season is a way to detect reproductive output of a population as shown in Fig. 1, but any significant autocorrelation was failed to detect in yearly egg-mass abundance [36].

Multiple authors suggested that higher thermal stress and increased risk of desiccation might lead to a diminished number of adult individuals returning after migration [27,50,51,52]. When the condition of migration is not optimal, females generally have a lesser migration probability than males and this would cause a skewed sex ratio where the number of male salamanders is higher [28]. The advancement in migration timing in warm winters supported the theory that prolonged summers would lead to early migration [1]. Previously it was proposed that alterations in migration timing result in the asynchronous arrival of male and female individuals [53].

4. CLIMATIC RESPONSE TO BODY SIZE

In accordance with fundamental ecological and metabolic principles, numerous species are already exhibiting smaller sizes as a response to climate change, and this trend is expected to persist into the future. Natural selection influences the linking of body size as an integrative trait to the fitness of an individual and is highly heritable [54]. The complex relationships in ectotherms between body size variation and climate could be explained by evolutionary forces such as selection for tolerance to desiccation, or resistance to starvation [55,56,57]. Fossil records from the Paleocene-Eocene Thermal Maximum (PETM) warming phase showed a reduction in the body size of organism by 50- 75%. During PETM, an average of 3-4° C temperature rise and 40% decreased precipitation was found, so this provides insight into similarities with current global warming scenes and how the rapid nature of that could be responsible for the change in body size of organisms in the present day [58].

Changes in the environment affect several biophysical processes that lead to phenotypic

alterations that influence fitness and survival. Metabolic rates are directly related to temperature for ectotherms. They limit their growth in order to ensure fitness and to maintain basic physiology as overall energy must be divided between such physiological activities. The developmental rate is increased, leading to smaller ectotherms, because the growth rate often does not match up to the high developmental rate caused by increasing temperatures [59]. Ectotherms respond to these high temperatures through faster development, greater metabolism and decreasing body sizes as suggested by recent studies. Amphibians are particularly susceptible to these changes because of their constant need for moisture and their ectothermic physiology. All these changes such as phenotypic shifts, breeding phenology and reduction in body size point towards lowered survivorship [29].

Plethodontid salamanders, ectothermic and lacking lungs, inhabit the globally significant hotspot of the southern Appalachian Mountains. Temperature and precipitation strongly govern their ecology. Range shifts, change in migration timing and alteration in body size are the three most frequently noted ecological response to climate change in ectothermal organisms. Research conducted on Appalachian *Plethodon* salamanders aimed to forecast whether body size constituted a significant response to shifting climate conditions, with investigations conducted into shifts in their mean body size. An 8% decrease in adult size was noted for all 15 species of *Plethodon* species across a 55-year study period [44]. Over time, significant body size variation for seven species of salamanders was found. A significant decrease in body size was exhibited by six of those species. It was concluded that changes in body size had strong environmental associations after correlating changing body size with attributes such as elevation, latitude, average species size and climate change. The most significant reduction in size occurred in southern latitudes; particularly in areas undergoing pronounced drying and warming. This phenomenon was a little better explained by variation in latitude than by temperature change and precipitation [44]. A strong relationship between a reduction in body size mediated through metabolism increase and latitude was found. Regions with more warmth and those which were drier saw the most body size change. Within a population, a decrease in mean body size or small species proportion increase could explain shifting mean body size

hypotheses. Although in this study no evidence regarding the shift in small species proportion was found. The study supported the population-body size hypothesis that was explained by the increase in juvenile proportion, decrease in minimal adult body size of an individual [60].

5. INTRODUCTION TO PHENOTYPIC AND PHYSIOLOGICAL PLASTICITY

The high rate of climate change due to human activities has threatened many species of animals. These environmental stresses can surely be established by measurable phenotypes [61,62,63,64]. To buffer these environmental changes, organisms have come up with a tool called phenotypic plasticity. It is a genotypical phenomenon in which organisms produce different phenotypical responses or alternate forms of a particular phenotype in response to environmental challenges.

Phenotypic plasticity is considered as the organism's ubiquitous aspect [65]. The chance of survival in an extreme environment is increased by plastic attributes [66]. Rising temperature leads to the destruction of three-dimensional structures of proteins and thus disturbs the enzymatic activity of organisms. The body size of an organism has a serious impact on its thermal tolerance, individuals with smaller body size will have a greater tolerance to heat [25]. Physiological plasticity enables organisms to adapt to rising global temperatures by reducing sensitivity to temperature in vital activities and enhancing physical tolerance [67]. Previous studies suggested that climate change and environmental challenges would surpass the capability of amphibians to tolerate these changes [68]. Despite being one of the most vulnerable classes of animals, amphibians exhibit a high level of plasticity [68,69]. These plastic traits generally involve tolerance to high temperature and regulation in the timing of metamorphosis. Among amphibians, salamanders exhibit a great deal of plasticity to acclimate to a changing climate. Their plastic traits mainly involve strategies to resist global warming and rising vapour pressure deficit. Plasticity involves behavioral avoidance and physiological acclimatization. Without these traits, 63% of the current geographical area could not favor the salamander population [4].

Dispersal is a common practice seen in animals that is induced by unfavorable environmental conditions in a particular habitat. Plasticity

decreases reliance on dispersal and thus saves energy expenditure of an organism as dispersal is a highly energetically unfavorable process [70]. A twofold increase in positive energy balance can be achieved in the core of salamander's range by plasticity which is mainly accomplished by the adjustment of three parameters – skin resistance to water loss (r_i), body size, and behavioral avoidance [4]. Despite of the wonderful capabilities of plasticity, there is a threshold to which the change can be tolerated after those environmental challenges might increase the cost of plasticity [68]. An individual's fitness describes whether a phenotypical trait is neutral, adaptive or maladaptive [5]. A reaction norm is a variation of a particular trait across various environmental conditions [71]. Plasticity can be shown by an alteration in the reaction norm between the derived population and the ancestral population [72,73]. The effectiveness of plasticity in adaptation relies entirely on the environment in which it manifests [5]. Plastic responses consistently aim to align an organism's performance closer to its optimum, with greater shifts towards this ideal resulting in increased benefits for the organism [74]. This benefit, however, hinges entirely on the energetics of plasticity, gauged by the balance between gas exchange and water loss [4].

6. RESISTANCE TO EXTINCTION

In order to compensate for the effects of varying temperatures, animals remodel their physiology or acclimatize themselves to confer resistance to climate change [67]. It has been suggested that phenotypic plasticity is first established in a population, which is later assimilated genetically speeding up the adaptive evolutionary process. Plasticity allows broader tolerance in genotypes to varying environmental conditions in order to maintain greater fitness levels, although the adaptive evolutionary aspect of plasticity depends on the environment upon which it shows its expression [5]. The freshwater ectotherms of thermally stable, cool environments are found to be less sensitive to variation in temperature compared to those species in variable and warm temperatures. According to climate change predictions, it is expected that metabolic rates will increase substantially in ectotherms of freshwater and terrestrial habitats despite having potential for thermal acclimation. Global warming is supposedly accelerating extinction rates with every increasing degree. This physiological plasticity is capable of buffering the effects of

global climate change to a certain extent by decreasing the thermal sensitivity and minimizing exposure to such temperatures [67].

Behavioral avoidance is also responsible for such adaptation which masks the harmful effects of climate change and provides resistance to extinction [13,75,76]. The black outline in Fig. 2 delineates the range limits for the *P. jordani* species complex. As warming progresses over time, estimates of energy balance (ranging from green to red) and extinction risk (grayscale)

illustrate that acclimatization and avoidance behavior can mitigate extinction within the core of the global hotspot of salamander diversity (Fig. 2). Green regions indicate predicted sufficient energy for reproduction, while orange regions signify negative energy balance and grayscale regions denote areas of extinction. The panels on the left do not incorporate acclimatization, while those in the middle include acclimatization, and the panels on the right incorporate both acclimatization and avoidance behavior.

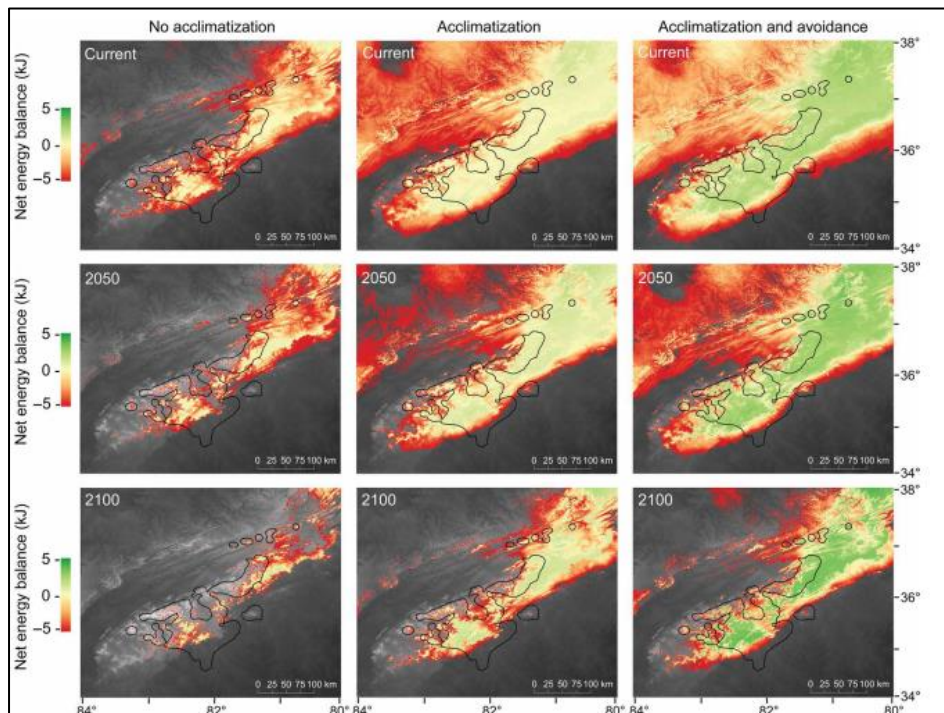


Fig. 2. Acclimatization and avoidance behavior contribute to a reduction in extinction risk within the core of the salamander diversity hotspot [76]

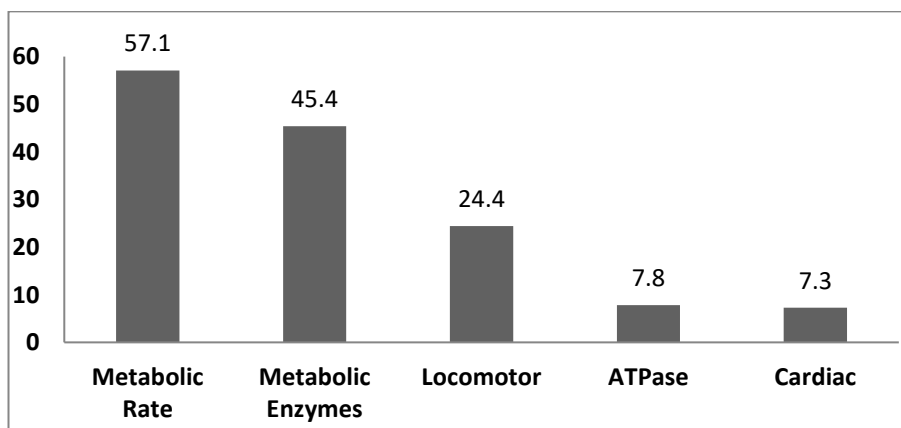


Fig. 3. The most commonly measured physiological traits that are affected as a result of climate change [4]

Mechanistic Species Distribution Models (SDM's) are process-based models that consider how the environment constrains physiological performance at a given geographical location and help identify areas to be prioritized for conservation and are also useful for studying the ecological effects of plasticity on amphibian species. SDMs calculate the suitability of habitat by connecting functional features with the biophysical environment of species to get to know about its fundamental niche. They foretell the distribution of suitability of habitat through space and time by studying the energy balance. Amphibians exhibit a high percentage of physiological plasticity despite of being one of the most vulnerable organisms. The high physiological plasticity of salamanders is a result of their evolutionary history, diverse habitats, metamorphic life cycle and sensitivity to environmental changes. These adaptations are critical for their survival in fluctuating and sometimes challenging environments, despite their vulnerability to human impacts and other threats. Seven species of salamander within the *Plethodon* species complex were tested for plasticity in metabolism rates, behavioral adaptations to resist the effects of unfavorable temperatures, to address the gap in knowledge about the relationship between energy balance and plasticity. The magnitude and constant pattern of acclimation in field and laboratory studies showed a high potential for skin resistance (almost 68% under experimental conditions) to water loss in order to reduce the ecological impact of increasing vapour pressure deficit; thus, it was concluded that salamanders showed high physiological acclimatization capabilities. Physiological acclimatization and behavioral avoidance were integrated into a simulation-based SDM to foretell the risk of extinction of salamander diversity hotspots worldwide [4]. Fig. 3 illustrates the impact of climate change on physiological traits, with the most affected traits listed in descending order: metabolic rate, metabolic enzyme activity, locomotory abilities, ATPase function and cardiac performance [4].

In the current climate conditions, it is crucial to prioritize avoidance behaviors that facilitate reproductive energetics and acclimatization in preparation for further increases in temperature. Juveniles experience greater stress under warming conditions. Although climate warming does affect populations but plasticity has maintained energy balance in the core of the hotspot of salamander diversity. Physiological

acclimatization and behavioral avoidance have the potential to decrease the extinction threat under climate change scenarios. Global warming disproportionately threatens the younger salamander population and thus reduction in body size is seen as a universal response because of the growing energetics cost that decreases available energy for growth and development [30]. Factors such as disease vulnerability, overexploitation, climatic factors and conversion in habitat have led to a decline in amphibian populations including that of salamanders. Plasticity up to some extent does buffer the effects of these multiple factors. The effectiveness can be enhanced by taking into consideration the physiological mechanisms leading to population decline [10]. The efficiency of genetic adaptation depends on the alignment between the rate of climate change and the generation time. In cases where climate change is gradual and consistently directional, short-lived animals may have the capacity to adapt through directional selection.

7. COSTS AND TRADE-OFFS ASSOCIATED WITH PLASTICITY AND ACCLIMATIZATION

The costs of plasticity refer to any decrease in fitness observed in a plastic individual compared to a non-plastic individual with identical trait values. A high cost of plasticity is observed because plastic traits are not imprinted in the genome and are only expressed due to changing environment; hence can lead to a reduction in fitness [77,78,79]. Organisms increase their fitness by becoming more resilient to changing climate; this has been accomplished by the capability of regulating homeostasis [5,75]. Trade-offs have been defined as a reduction in a physiological trait due to an increase in energy expenditure of another related trait [80]. It has been noted that acclimatization alone can provide a reproductive ground of 67.2%, but when a trade-off is incorporated, this percentage decreases to 44.9% (Fig. 4). Due to this reduction, salamanders have to pay a cost related to fitness during acclimatization. In salamanders, positive energy balance increases from 28.8 % to 53.1 % due to plasticity but the trade-off reduces it to 44.5 % [81].

An individual's capability of surviving in a challenging environment and its energy expenditure are dependent on the rate of water loss and metabolism [82,83]. As salamanders respire through their moist skin surface,

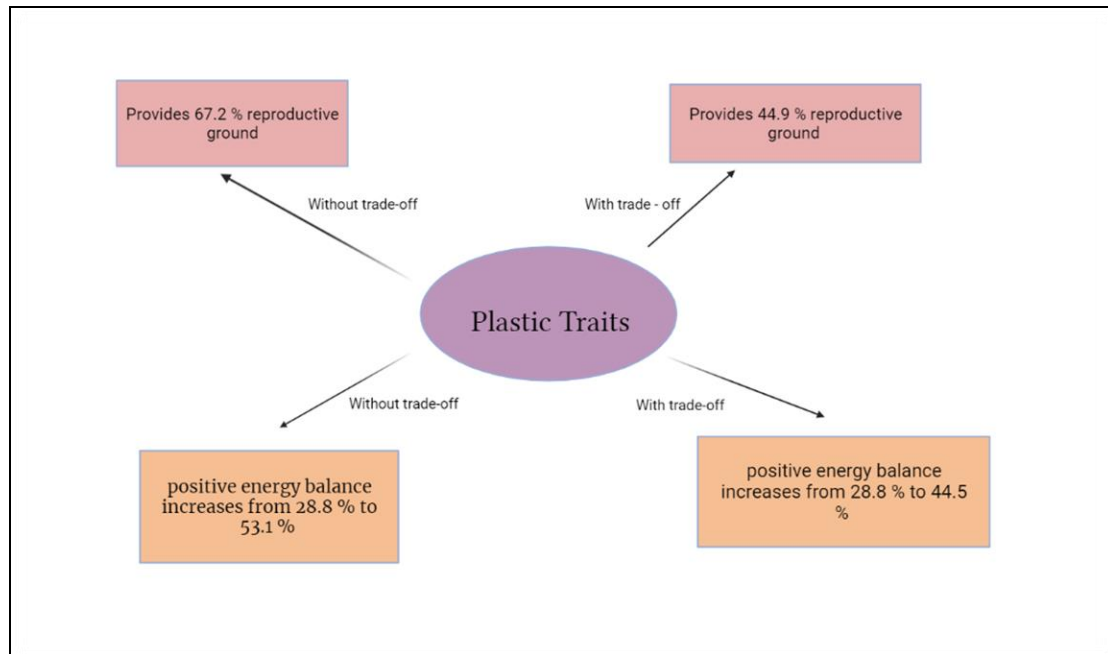


Fig. 4. Change in reproductive ground and positive energy balance due to incorporation of Trade-offs [81]

experiments have been performed on lung less salamanders to evaluate the trade-off between volume of oxygen consumption (VO_2) and skin resistance to water loss (r_i). Results indicated that a reduction in the flux of oxygen is directly proportional to a decrease in the flux of water and this change is possible due to some underlying relationships between these two traits [4]. Reduction in water flux, finding stable microclimate and diminishment of crucial physiological processes are observed during dormancy [84].

8. EFFECT ON GENETIC EXPRESSION

The study analysis revealed that constitutive expression of the ALOXE3 gene correlated with a phenotype characterized by high trans-epidermal water loss. The genes which can control vasoconstriction and blood vessel development were linked with the high plasticity of phenotype. Salamanders seemed to adapt to resist skin desiccation and reduce water loss without relying on constant expression of ALOXE3. They achieved this by restricting blood flow to the skin's vascular system, which proved to be an effective strategy [85]. They not only regulate pathways involved in vasoconstriction but also demonstrated control over hemostasis, angiogenesis, and vasculogenesis pathways, which is normally restricted to the embryos and capillary formed *de novo* from hematopoietic

stem cells [86]. Through continuous expression of embryonic developmental pathways, salamanders possess the ability to regenerate various types of tissues [87,88]. They utilize this capability to regulate dermal capillary growth, thereby adjusting skin water loss in response to changing environmental conditions. The hypothesis suggests that exposure to warming temperatures triggers vascular regression in the skin's capillary beds through sustained vasoconstriction. This process leads to hemostasis and ultimately programmed cell death of the capillary beds over time [89].

Expression of the gene ALOXE3 is linked with the production of fatty acid in epidermal tissue ceramides and is negatively associated with resistance to skin desiccation plasticity. Maintenance of lipid compositions is important in resisting water loss from the skin in amphibians including salamanders as they are the structural units of integument that prevent skin desiccation. Under conditions of climate warming, genotypes that exhibit better performance under high temperatures are naturally selected. This selection occurs as elevated body temperatures due to climate change lead to reduced fitness and performance in organisms less suited to higher temperatures [90,91,92,93,94,95]. Overall fitness will remain relatively constant if the response to selection aligns with changes in body temperature [62,90,95,96,97,98].

Persistence is facilitated by genetic exchange between genetically differentiated populations [99,100]. Variations in the frequencies of aspartate and alanine aminotransferase allozymes reflect vertical position and temperature stress, evidenced by allele variations along a temperature gradient [101,102]. The structural and functional properties of proteins give information about the adaptive variation patterns of species at different temperatures as they are highly temperature sensitive [103].

Ectotherms' responses to rising temperatures are influenced by three types of DNA lesions. The first type involves partial or complete loss of protein-coding genes from the genome, leading to reduced complexity of the proteome. The second type includes disruptions in open reading frames in protein-encoding DNA, resulting in the generation of pseudogenes and corresponding protein loss in the proteome. The third type of mutation affects gene regulatory regions, possibly due to DNA loss or sequential mutations, which impairs the ability to regulate gene expression under thermal stress. This impairment can hinder the organisms' ability to properly modify their phenotype during acclimatization [25].

9. EVOLUTIONARY SIGNIFICANCE OF PLASTICITY

In stressful environments, strong directional selection poses a significant challenge. This challenge is overcome by genetic variations in response to environmental stress [104,105]. Plasticity reveals hidden phenotypic or genotypic variations that were unexpressed under previous environmental conditions [104,106,107]. Under specific environmental conditions, the majority of individuals in a population exhibit similar patterns of plastic responses [5]. In certain individuals, exposure to a selective and stressful environment can result in a mixture of two types of traits: traits that exhibit no response to the stimuli of novel environments, and traits that demonstrate adaptive or non-adaptive plasticity [66], which is known as 'mosaics of traits' [5]. Historically, the selection of non-heritable phenotypic variations was often disregarded because they were considered unimportant in terms of evolution [74,108,109]. Variations induced by the environment have been considered a factor that delays adaptive evolution because they can shield the genotype from selection pressures [15,110,111]. Later, a

new perspective emerged proposing that environmentally induced phenotypic variation can lead to adaptive responses, even when these responses are not directly controlled by genetic changes [65].

Plasticity, initially non-heritable, can become assimilated into the genome and subsequently expressed without the original environmental cue [112,113]. This process can facilitate adaptive evolution through plastic responses [65]. In new environments, the proximity of a plastic response to the optimum regulates the rate of adaptation [114]. Extreme phenotypes are subject to directional selection, enhancing the population's potential for adaptation [5]. Local adaptation is also an effective mechanism for acquiring fitness in a changing climate by salamanders [6]. Local adaptation, unlike phenotypic plasticity, produces alterations in the genomic sequence of the organism. As a result, it can produce phenotypes that are long-lasting and lead to better fitness than phenotypic plasticity [115,116]. Larvae of salamanders originating from ponds can more readily adapt to streams compared to larvae originating from streams adapting to ponds. This concludes that the pond habitat is showing divergent selection and this larva would be maintained as more potential sexual mates [117]. Therefore, when variations in DNA sequences are incorporated into the genome through local adaptations and plasticity, it facilitates adaptive evolution.

10. CONCLUSIONS

As the Earth's climate undergoes drastic changes due to anthropogenic activities, there is a rapid extinction crisis affecting numerous species. Among vulnerable groups like amphibians, salamanders have shown remarkable adaptive measures in response to these changes. Our review highlights that salamanders exhibit a wide range of adaptive responses, primarily through plasticity, an epigenetic phenomenon that does not alter DNA sequences directly. However, over generations, the application of plastic responses has been observed to induce changes in salamander DNA sequences, thereby facilitating adaptive evolution. Nevertheless, there are limits to plasticity due to associated costs and trade-offs. While plasticity can help mitigate the adverse effects of climate change to a certain extent without altering an organism's annual energy balance, there is a critical need to recognize and respect these limits. Failure to do so risks not

only the extinction of salamanders but also threatens the survival of other species. It is imperative that we adopt responsible practices and policies to safeguard biodiversity and the natural world. Our collective actions today will determine the future coexistence of all species on Earth.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Prof. Dipak K. Som, Head of the Department of Zoology, Maulana Azad College, Kolkata for his constant support during the preparation of this review article.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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