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Editorial

Special Issue: "Fluctuating Asymmetry as a Measure of Stress: Influence of Natural and Anthropogenic Factors"

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1. Introduction

The main cause of stress, according to Selye [1], is the deviation of any vital parameter of the internal or external environment of the body from the optimal level, which disturbs its homeostasis. On the one hand, the state of stress is potentially dangerous because the effects of extreme stressors and/or long exposure lead to exhaustion and death of the body; as a result, this can lead to a population decrease. On the other hand, there is undoubtedly an important evolutionary consequence of moderately stressful effects when stress becomes a survival mechanism since it stimulates the search for adaptive reactions. The ability to maintain the homeostasis of development in changing environmental conditions determines the ecological plasticity of species, i.e., their resistance to the stressful effects of a wide range of factors.

Fluctuating asymmetry (FA) is one of the most convenient indicators of developmental stability (DS). It represents minor non-directional and non-hereditary deviations from perfect bilateral symmetry [2]. Previous research shows that FA levels are minimal under normal conditions but increase under various stressful influences [3,4]. Due to this fact, FA values can be used as a universal indicator of total stressful impact [5–7].

The analysis of the causes of FA variation in natural populations is of interest for insight into the mechanisms of adaptation of species to the pessimal zone and for predicting possible reactions to the combined effect of adverse factors of different origins [8].

Earlier, we published a Special Issue of *Symmetry*, "Fluctuating Asymmetry as a Measure of Stress" (2020), containing articles devoted to FA variability in trees, insects, and small mammals under the effect of stress-inducing, primarily anthropogenic factors, and we continue this discussion in this Special Issue titled "Fluctuating Asymmetry as a Measure of Stress: Influence of Natural and Anthropogenic Factors". This Special Issue includes four original articles that focus on the FA in woody plants [8], algae [9], terrestrial vertebrates [10,11], and one communication [12]. To assess the FA value, the authors used different approaches, i.e., calculation of meristic features [11], measurement of plastic features [8], and methods of geometric morphometry [9,10].

2. Contributions

The article by Shadrina et al. [8] is devoted to the analysis of the impact of different external and internal factors on the DS of woody plants. The influence of climatic factors, biotopic conditions, latitude, altitude, and the age of trees on the natural populations of the silver birch (*Betula pendula* Roth) was analyzed. The material consisted of 13,000 leaves of silver birch from 11 regions of north-eastern Siberia. The influence of 23 climatic factors and six integrated coefficients characterizing the general suitability of the climate, as well as summer, winter, spring, and autumn, was analyzed. The DS of woody plants and,

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consequently, the level of the FA of the lamina in natural biotopes can vary in a wide range. The authors concluded that climatic factors, mainly conditions in the warm season, have a significant impact on woody plants. In addition, the influence of age, biotope, and light conditions was noted. An increased FA level in the silver birch is characteristic of senile plants, and young shoots develop from the radical buds of old plants. An increased FA level in senile plants and young shoots from radical buds at the final stages of their ontogeny is presumably associated with a general decrease in vitality with age. There was intraindividual variability in FA manifestations of the leaf in some cases; the FA value in large and small laminae is higher than in the middle size, as a rule. These intraindividual differences reflect the development of the organ but are not indicative of disturbances in the DS of the individual. For *Betula pendula*, an increase in FA was registered on the ecological periphery of its range, i.e., on the edge of the forest belt in the north and in the mountains. The data obtained demonstrate the high influence of natural stress-inducing factors on DS in plants [8].

Woodard and Neustupa [9] consider the manifestations of bilateral asymmetry in the alga *Eunotia bilunaris* (Eunotiales, Bacillariophyceae). Pennate diatoms typically have teratogenic deformations of their siliceous frustules due to the effects of environmental stress, but, unfortunately, the quantitative assessment of these deformations has rarely been applied [9]. Consequently, Woodard and Neustupa aimed to illustrate the geometric morphometric analysis of symmetry as a tool for assessing the severity of teratogenic deformations. *Eunotia bilunaris* as an object of study is very suitable for these purposes because it has bilaterally symmetric frustules with dorso-ventral differentiation; at the same time, it is known that this species aberrations have frequently been reported. To assess the asymmetry, they used generalized Procrustes analysis (GPA). Due to the peculiarities of *Eunotia bilunaris*, asymmetry cannot be decomposed into directional and fluctuating components; therefore, the general bilateral asymmetry is discussed in this article. The deformations primarily affected the ventral part of the frustules, and the regions of the ventral outline near the central part of the valves were the most prone to asymmetric deformations [9]. In addition, morphometric analysis has also shown that the overall rate of these deformations increases significantly with decreasing cell size. However, in all cases, the Procrustes-based decomposition of the shape asymmetry could represent a well-applicable framework for scoring the severity of diatom frustule teratology in relation to different types of environmental stress, such as metal contamination, acidification, eutrophication, or increased radioactivity [9].

The article by Castilheiro et al. [10] is devoted to an assessment of the impact of habitat fragmentation on small mammals' DS. The mandibles of two species of Rodentia (*Proechimys longicaudatus* and *Necromys lasiurus*) and two species of Didelphimorphia (*Marmosa demerarae* and *Monodelphis glirina*), trapped in 17 forest fragments ranging from 5 to 900 hectares, were used for analysis. Moreover, 131 specimens of Rodentia and 173 specimens of Didelphimorphia—a total of 304 adult individuals—were analyzed. Measurements of FA were obtained from digital images of the left and right mandibles with twelve landmarks on either. To obtain estimates of FA, all configurations of landmarks were superimposed using a full Procrustes fit and projected onto the shape tangent space. Castilheiro et al. did not find differences in the manifestation of FA between Rodentia and Didelphimorphia species, and they concluded that for these species, ecological characteristics and biological traits have a greater effect on FA than their phylogeny [10]. Besides, FA means (values) did not differ significantly between sexes in all species. The authors note that the two largest species, *P. longicaudatus* and *M. demerarae*, exhibited significantly higher levels of FA in mandibular shape in small forest fragments (5–26 ha) in comparison to large ones (189–900 ha). For small mammal communities, fragments of more than 200 ha should be the focus of conservation efforts, as both resilient and more sensitive species would benefit from their more preserved biotic and abiotic conditions. Conversely, fragments less than 25 ha seem to lead to a significant increase in stress during development. Edge length negatively affected *M. demerarae*, the only arboreal species, reinforcing its strongest dependence on core forest habitats. According to the authors, these facts suggest that in these species, environmental stress caused by the reduced habitat area significantly affected the mandible's embryonic development [10].

One of the important conclusions of Castilheiro et al. is that measuring FA has proven to be an effective biomonitoring tool for conservation biology, including critically endangered species. Such approaches can potentially constitute sensitive bioindicators to be used in the conservation and management of disturbed populations.

The research by Zakharov et al. [11] is devoted to the variation of 13 meristic characteristics of pholidosis in the sand lizard, *Lacerta agilis*. Moroever, 805 specimens from 32 natural populations in Eastern Europe (Russia) and 180 individuals that were obtained as a result of experimental incubation under different temperature conditions were studied.

The total phenotypic variability was assessed by the variation of the sum of the number of scales on the left and right sides of the body, while the measure of DS, providing insight into the degree of FA or developmental variability, was assessed by the variation of the difference in the parameter values on the left and on the right [11]. Experimental incubation of eggs at different temperatures demonstrates that the minimal level of both kinds of variability corresponds to a certain temperature, which can be characterized as the optimal one, increasing both with an increase and with a decrease in the temperature in that regime. The data demonstrate the crucial role of the temperature effect for the phenotypic variation in question. An increase in the level of developmental variability to the north and to the south from the center part of the species range, in the absence of an obvious trend in geographic variation of the level of total phenotypic variability, seems to suggest an increased role of developmental variability in the observed phenotypic diversity at the periphery of the species range. Zakharov et al. [11] emphasize the importance of the population phenogenetic approach for studying DS in natural populations and obtaining information on the reasons for phenotypic diversity within a species range.

The communication by Zakharov and Trofimov [12] is devoted to general reasoning about the relationship between stress, developmental noise, and biological system conditions. Zakharov and Trofimov consider developmental noise as one of the main sources of intrapopulation phenotypic diversity. The most common measure of developmental noise is the value of FA; it allows for the estimation of the developing system condition, but it is not the only way. The authors cite the references of other researchers proving that the developmental noise may also be assessed by the efficiency of photosynthesis (i.e., by the ratio of the variable fluorescence to the maximum), by cytogenetic homeostasis (i.e., by the frequency of cells with micronuclei), by immune status (i.e., by the value of the integrated index of deviation from the conditional norm for some parameters of the immune system), etc. Zakharov and Trofimov discuss previously published articles concerning FA assessment in different species, their own and those of other authors, and suggest that developmental noise can be used to assess the condition of not only an organism but also a population, community, or ecosystem. The authors suggest that there may be a connection between FA at the level of the organism and higher levels of organization in living matter.

3. Conclusions

In this Special Issue we published the results of the studies in different fields of biology [8–11], and using the example of four different systematic groups, we can assess the stressful effect of various environmental factors on the DS and, as a result, on the values of FA. We can see that DS may be disrupted as a result of the impact of many natural factors and anthropogenic transformations—climate, light conditions, pH of the environment, pollution with heavy metals, and fragmentation of habitats [8–11]. At the same time, the influence of environmental conditions on the FA value of species occupying similar ecological niches manifests itself in a similar way, regardless of their phylogeny [10]. Therefore, FA evaluation may be used as an effective biomonitoring tool for environmental health assessment, as an indicator of biological system conditions, and in conservation biology to assess acceptable limits for the transformation of natural ecosystems and the conservation of critically endangered species [8,10,12].

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References

1. Selye, H. *The Stress of Life*, 4th ed.; McGraw-Hill Book Co.: New York, NY, USA, 1956; 324p.
2. Van Valen, L. Study of fluctuating asymmetry. *Evolution* **1962**, *16*, 125–146. [CrossRef]
3. Palmer, R.A.; Strobeck, C. Fluctuating assymmetry: A measurement, analysis, patterns. *Annu. Rev. Ecol. Syst.* **1986**, *17*, 391–421. [CrossRef]
4. Parsons, P.A. Fluctuating asymmetry: An epigenetic measure of stress. *Biol. Rev.* **1990**, *65*, 131–145. [CrossRef] [PubMed]
5. Leary, R.F.; Allendorf, F.W. Fluctuating asymmetry as an indicator stress: Chance use in protect nature. *Acta Zool. Fenica* **1989**, *4*, 214–217.
6. Parsons, P.A. Fluctuating asymmetry: A biological monitor of environmental and genomic stress. *Heredity* **1992**, *68*, 361–364. [CrossRef] [PubMed]
7. Freeman, D.C.; Graham, J.H.; Emlen, J.M. Developmental stability in plants: Symmetries, stress and epigenesis. *Genetica* **1993**, *89*, 97–119. [CrossRef]
8. Shadrina, E.; Soldatova, V.; Turmukhametova, N. Fluctuating Asymmetry as a Measure of Stress in Natural Populations of Woody Plants: Influence of Ecological and Geographical Factors on Developmental Stability. *Symmetry* **2023**, *15*, 700. [CrossRef]
9. Woodard, K.; Neustupa, J. Geometric Morphometrics of Bilateral Asymmetry in Eunotia bilunaris (Eunotiales, Bacillariophyceae) as a Tool for the Quantitative Assessment of Teratogenic Deviations in Frustule Shapes. *Symmetry* **2022**, *14*, 42. [CrossRef]
10. Castilheiro, W.F.F.; Muñoz-Muñoz, F.; Ventura, J.; dos Santos-Filho, M.; Mathias, M.d.L.; Gabriel, S.I. Differential Impact of Forest Fragmentation on Fluctuating Asymmetry in South Amazonian Small Mammals. *Symmetry* **2022**, *14*, 981. [CrossRef]
11. Zakharov, V.M.; Zhdanova, N.P.; Trofimov, I.E. Phenotypic Variation in a Species Range: Another Look (Developmental Stability Study of the Meristic Variation in the Sand Lizard Lacerta agilis). *Symmetry* **2022**, *14*, 2426. [CrossRef]
12. Zakharov, V.M.; Trofimov, I.E. Developmental Noise and Biological System Condition: Prolegomena. *Symmetry* **2022**, *14*, 2380. [CrossRef]