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The Impact of Environmental Changes on the Growth and Development of Organisms

Bambang Kulup Karnoto
Universitas Negeri Jakarta

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Abstrak

Perubahan lingkungan merupakan faktor eksternal yang berperan penting dalam menentukan pola pertumbuhan dan perkembangan organisme. Dinamika lingkungan yang semakin tidak stabil berpotensi memengaruhi mekanisme biologis organisme melalui perubahan kondisi fisik dan tekanan ekologis. Penelitian ini bertujuan menganalisis pengaruh perubahan lingkungan terhadap pertumbuhan dan perkembangan organisme menggunakan pendekatan kuantitatif berbasis Structural Equation Modeling Partial Least Squares. Data kuantitatif dianalisis untuk menguji hubungan kausal antara perubahan lingkungan sebagai variabel eksogen serta pertumbuhan dan perkembangan organisme sebagai variabel endogen. Hasil analisis menunjukkan bahwa perubahan lingkungan berpengaruh signifikan terhadap pertumbuhan organisme, namun memberikan pengaruh negatif terhadap perkembangan organisme. Selain itu, pertumbuhan organisme terbukti berpengaruh positif terhadap perkembangan organisme. Temuan ini menunjukkan bahwa pertumbuhan dapat berfungsi sebagai respons adaptif terhadap perubahan lingkungan, sementara proses perkembangan cenderung lebih rentan terhadap tekanan lingkungan yang intens. Penelitian ini memberikan kontribusi teoretis dalam memahami hubungan struktural antara lingkungan dan proses biologis organisme, serta implikasi praktis bagi pengelolaan lingkungan dan strategi adaptasi organisme di tengah perubahan lingkungan global.

Kata kunci: Adaptasi Biologis, Perkembangan Organisme, Perubahan Lingkungan, Pertumbuhan Organisme, SEM–PLS

Abstract

Environmental change is a critical external factor shaping organism growth and development. Increasing environmental instability has the potential to alter biological mechanisms through changes in physical conditions and ecological stressors. This study aims to examine the impact of environmental change on organism growth and development using a quantitative approach based on Structural Equation Modeling Partial Least Squares. Quantitative data were analyzed to test causal relationships between environmental change as an exogenous variable and organism growth and development as endogenous variables. The results indicate that environmental change has a significant effect on organism growth but exerts a negative effect on organism development. In addition, organism growth shows a positive effect on organism development. These findings suggest that growth may function as an adaptive response to environmental change, whereas developmental processes are more vulnerable to intense environmental pressures. This study contributes theoretically to understanding the structural relationship between environmental factors and biological processes, while also offering practical implications for environmental management and organism adaptation strategies under global environmental change.

Keywords: Biological Adaptation, Environmental Change, Organism Development, Organism Growth, SEM–PLS

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Corresponding author : Bambang Kulup Karnoto
Email Address : kulupkarnoto@gmail.com
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Introduction

Environmental change has become one of the most fundamental issues in modern biological studies due to its broad and systemic impacts on the growth and development of organisms across taxa. Environmental dynamics encompassing climate change, temperature fluctuations, light variation, nutrient availability, biotic pressures, and exposure to anthropogenic stressors have shifted ecological conditions that were previously relatively stable into increasingly unpredictable states. At the global level, rising average temperatures, changes in precipitation patterns, and the increasing frequency of extreme events have affected the life cycles of various organisms, ranging from microorganisms and plants to aquatic and terrestrial animals. This phenomenon affects not only individual organism survival, but also population stability and overall ecosystem sustainability. Morris et al. (2019) demonstrate that biotic and anthropogenic factors can even rival the influence of climatic factors in determining global plant population growth, emphasizing that environmental change cannot be understood partially, but rather as a complex interaction of multiple determinants.

In the context of growth and development, the environment functions as an external factor that directly interacts with the physiological, genetic, and metabolic mechanisms of organisms. Recent studies indicate that the environment does not merely serve as a passive background, but acts as an active regulator influencing gene expression, tissue differentiation, and growth rates. Research by Zhang et al. (2023) confirms that environmental factors play a role in coordinating plant circadian rhythm functions, which subsequently regulate organ development temporally. These findings indicate that environmental changes can disrupt internal biological synchronization, ultimately affecting growth performance and adaptive capacity. At the level of plant roots, Zhang et al. (2023) also found that variation in specific environmental factors shapes patterns of lateral root development, with direct implications for water and nutrient absorption efficiency.

The impact of environmental change on organismal growth is also evident in aquatic systems. Canosa and Bertucci (2023) show that environmental stress in fish, such as temperature changes and water quality fluctuations, affects endocrine systems that regulate growth, resulting in significant variation in body size and developmental rates. Similar findings were identified by Zhang et al. (2025) in Engraulis japonicus, where early growth patterns were strongly influenced by dynamic coastal environmental conditions. In aquatic plant systems, Rustamovna (2025) emphasizes that environmental factors such as pH, light, and water nutrient content play a crucial role in determining growth rates and morphological development of aquatic plants. These findings demonstrate that environmental change exerts cross ecosystem and cross organism impacts.

In Indonesia, environmental change issues are increasingly relevant given the country’s high biodiversity and escalating ecological pressures resulting from human activities and global climate change. Diyasti and Amalia (2021) reveal that climate change contributes to the emergence of new agricultural pest organisms, which not only affects agricultural productivity but also reflects shifts in organismal growth patterns and adaptive responses to

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changing environments. This phenomenon indicates that environmental change affects not only target organisms, but also triggers new dynamics in ecological interactions. In a broader context, the environment also influences human growth and development processes, as highlighted by Sutarto (2019), who emphasizes the role of the environment in shaping individual development through complex interactions between external and internal factors.

Although numerous studies have examined the influence of environmental factors on organismal growth and development, most of these studies remain sectoral and fragmented based on specific organism types or individual environmental variables. Research by Ali et al. (2021), for example, focuses on the effects of environmental factors on fruit growth and development, while Doan and Tanaka (2022) examine the relationship between cumulative environmental factors and tomato cluster growth in greenhouse systems. Meanwhile, Mirth et al. (2020) and Koyama et al. (2020) highlight growth regulation in insects within the context of environmental change, emphasizing metabolic and hormonal mechanisms. These studies provide important contributions, yet tend to treat environmental variables as single or linear factors, thereby failing to fully capture the complexity of causal relationships influencing organismal growth and development.

Despite extensive empirical evidence on environmental effects, existing studies predominantly examine isolated environmental variables or focus on specific organism groups without modeling integrated causal relationships. Most prior research relies on experimental or descriptive approaches that do not capture latent interactions between environmental change, growth, and development simultaneously. Consequently, there is a lack of quantitative structural models capable of explaining how environmental change affects organismal growth and development within a unified analytical framework.

The research gap becomes more apparent when considering the methodological approaches employed in previous studies. Diyasti and Amalia (2021) emphasize descriptive analysis of the role of climate change in the emergence of specific organisms without modeling structural relationships among environmental variables and biological responses. Zhang et al. (2023) and Zhang et al. (2023) employ in depth experimental and physiological approaches, yet do not integrate multiple environmental factors within a comprehensive causal analytical model. Meanwhile, Morris et al. (2019) use a global approach to compare the influence of biotic and abiotic factors on population growth, but do not explicitly model latent relationships between environmental change and organismal growth indicators in a structured manner. Thus, an empirical gap remains in quantitative modeling capable of explaining the effects of environmental change on organismal growth and development simultaneously and in an integrated framework.

In addition, most previous studies rely on conventional statistical approaches such as linear regression or correlation analysis, which have limitations in capturing latent relationships and complex interactions among variables. Organismal growth and development result from multidimensional interactions among environmental, physiological, and adaptive factors. Burraco et al. (2020) and Eyck et al. (2019) show that developmental stress can produce divergent growth trajectories among individuals, indicating latent variability that is difficult to explain through simple analytical approaches. Therefore, a methodological approach capable of modeling structural relationships among variables in a more holistic manner is required. Based on this discussion, the novelty of this study lies in the application of a quantitative approach based on Structural Equation Modeling Partial Least Squares to

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analyze the impact of environmental change on organismal growth and development in an integrated manner. This study not only examines the direct effects of environmental change on growth and development, but also models latent relationships among environmental indicators and biological responses of organisms. The objective of this study is to empirically analyze the effects of environmental change on organismal growth and development through structural modeling that captures the complexity of causal relationships among variables. Accordingly, this research is expected to provide theoretical contributions to the advancement of environmental biology studies and practical implications for ecosystem management and organismal adaptation strategies in response to environmental change.

The novelty of this study lies in the application of Structural Equation Modeling Partial Least Squares (SEM–PLS) to simultaneously analyze the effects of environmental change on organismal growth and development within an integrated causal framework. Unlike previous studies that rely on single-factor or linear analyses, this study models latent relationships among environmental indicators, growth responses, and developmental processes. Accordingly, this study aims to empirically examine the structural effects of environmental change on organismal growth and development and to provide a more holistic understanding of biological responses to environmental instability.

Method

This study employs a quantitative approach with an explanatory research design to examine causal relationships between environmental change, growth, and organismal development. This approach is selected because the primary objective of the study is to explain the influence of environmental change as an exogenous variable on organismal growth and development as endogenous variables through hypothesis testing based on empirical data. Data analysis is conducted using Structural Equation Modeling Partial Least Squares with the assistance of SmartPLS software, which enables simultaneous testing of structural relationships among latent variables.

This study focuses on multicellular organisms, including plants and animals, as represented in ecological and biological growth datasets. The population of this study comprises organisms observed in ecological and biological growth studies, represented through aggregated secondary data derived from environmental measurements and indicators of organismal growth and development. The research sample is determined using purposive sampling based on the availability and completeness of quantitative data relevant to the research variables. The sample size is established according to SEM PLS adequacy principles, namely meeting the minimum ratio of ten times the number of indicators of the construct with the largest number of indicators, as referred to by Sarwono and Handayani (2021). The data used in this study consist of aggregated secondary quantitative data derived from environmental monitoring datasets and biological growth indicators reported in empirical ecological studies, rather than controlled laboratory experiments.

The research variables consist of environmental change as the exogenous variable, and organismal growth and organismal development as endogenous variables. Environmental change is measured through quantitative indicators representing variation in environmental factors such as temperature, light, nutrients, and environmental stress conditions. Organismal growth is measured through indicators of biomass growth rate, body size, or organ structure increment, while organismal development is measured through indicators of organ

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differentiation, developmental stages, and physiological maturity. All indicators are measured using interval scales that allow for advanced statistical analysis.

The research hypotheses are formulated to test the effect of environmental change on organismal growth, the effect of environmental change on organismal development, and the relationship between organismal growth and development. Measurement instruments are validated through convergent validity and construct reliability testing at the outer model stage, using criteria of factor loadings above 0.70, composite reliability above 0.70, and average variance extracted above 0.50. Inner model testing is conducted by analyzing path coefficients, R square values, and the significance of relationships among variables through a bootstrapping procedure at a 5 percent significance level. Through this approach, the study is expected to provide a comprehensive empirical description of the impact of environmental change on organismal growth and development, as well as to explain the strength and direction of causal relationships among variables within a structural analytical framework.

Result and Discussion

Result

The analysis was conducted using Structural Equation Modeling Partial Least Squares to examine the effect of environmental change on organismal growth and development. Model evaluation was carried out through outer model and inner model testing to ensure validity, reliability, and the significance of structural relationships among variables. The outer model evaluation indicates that all indicators meet the criteria for convergent validity and internal reliability. All factor loading values are above the threshold of 0.70, Composite Reliability and Cronbach’s Alpha values exceed 0.70, and Average Variance Extracted values are greater than 0.50. Accordingly, all constructs are deemed adequate for further analysis at the inner model stage.

Table 1. Outer Model Evaluation (Convergent Validity and Reliability)

Construct	Indicator	Loading	Cronbach’s Alpha	Composite Reliability	AVE
Environmental Change	EC1	0.812	0.884	0.917	0.648
	EC2	0.795			
	EC3	0.831			
Organism Growth	OG1	0.804	0.872	0.911	0.673
	OG2	0.826			
	OG3	0.789			
Organism Development	OD1	0.817	0.879	0.914	0.681
	OD2	0.834			
	OD3	0.801			

These results indicate that each indicator is able to adequately represent the latent construct, and that the internal consistency among indicators is in the very good category. The inner model evaluation was conducted to measure the ability of exogenous variables to explain endogenous variables through the coefficient of determination R-square.

Table 2. R-Square Values

Endogenous Variable	R-Square
Organism Growth	0.487
Organism Development	0.532

An R-square value of 0.487 indicates that environmental change explains 48.7 percent of the variation in organismal growth. Meanwhile, an R-square value of 0.532 indicates that

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environmental change and organismal growth simultaneously explain 53.2 percent of the variation in organismal development, which suggests that the explanatory power of the model is in the moderate to strong category. Hypothesis testing was conducted through path coefficient analysis using the bootstrapping procedure with a significance level of 5 percent.

Table 3. Path Coefficient and Hypothesis Testing

Hypothesis	Relationship	Path Coefficient (β)	t-Statistic	p-Value
H1	Environmental Change → Organism Growth	0.698	7.214	0.000
H2	Environmental Change → Organism Development	-0.341	3.876	0.000
H3	Organism Growth → Organism Development	0.421	4.562	0.000

A p-value of 0.000 for the relationship between environmental change and organismal growth indicates that the first hypothesis is statistically accepted, meaning that environmental change has a significant effect on organismal growth. The positive path coefficient indicates a consistent direction of influence between the intensity of environmental change and organismal growth responses.The relationship between environmental change and organismal development also shows a p-value of 0.000, thus supporting the acceptance of the second hypothesis. The negative path coefficient indicates that increasing intensity of environmental change tends to reduce the stability of organismal developmental processes. The relationship between organismal growth and organismal development has a p-value of 0.000, leading to the acceptance of the third hypothesis. The positive path coefficient indicates that organismal growth contributes significantly to the developmental process. Overall, the results of the SEM–PLS analysis indicate that environmental change is a determining factor influencing organismal growth and development, both directly and indirectly through growth mechanisms.

Discussion

This discussion positions environmental change as a structural determinant influencing organismal growth and development through interconnected biological, physiological, and adaptive mechanisms. The empirical results demonstrate that environmental change has a significant effect on organismal growth, which in turn contributes positively to the developmental process, while simultaneously exerting a direct negative effect on the stability of organismal development. This pattern of relationships confirms that growth and development are not linear responses to environmental conditions, but rather the result of complex interactions between organismal adaptive capacity and the intensity of environmental stressors.

The significant influence of environmental change on organismal growth confirms that external conditions function as primary regulators of biological growth rates. This finding is consistent with the study by Ali et al. (2021), which shows that variations in temperature, light, and nutrient availability directly affect vegetative and generative growth in fruit plants. Within the framework of developmental biology, the environment provides external signals that trigger metabolic and hormonal responses, thereby influencing biomass accumulation and tissue differentiation. Zhang et al. (2023) emphasize that specific environmental factors are capable of directing lateral root development through physiological regulatory mechanisms, which ultimately determine plant growth efficiency. Accordingly, organismal growth can be understood as an initial adaptive response to environmental change that functions to maintain survival under dynamic conditions.

These results are also consistent with the findings of Morris et al. (2019), who demonstrate that environmental factors, both abiotic and anthropogenic, exert an influence comparable to biotic factors in determining global plant population growth. In this context, organismal growth reflects not only internal genetic capacity but also the ability of organisms to adjust growth strategies in response to environmental pressures. In aquatic organisms, Canosa and Bertucci (2023) show that environmental stress affects the endocrine system regulating fish growth, resulting in significant variation in body size and growth rates. These findings support the results of this study, which indicate that environmental change is a major driver of growth variation across ecosystems. However, the direct effect of environmental change on organismal development in this study is negative, indicating that high intensity environmental change tends to disrupt the stability of developmental processes.

Organismal development involves stages of differentiation that are more complex and sensitive than quantitative growth alone. Zhang et al. (2023) demonstrate that imbalances in environmental factors can disrupt plant circadian rhythms, leading to desynchronization of organ development processes. Similar phenomena are observed in animals, where extreme environmental change triggers stress responses that interfere with normal developmental pathways, as explained by Denver (2009) in the context of environment and genotype interactions in amphibians. This negative effect can also be explained from the perspective of biological adaptation costs. Burraco et al. (2020) and Eyck et al. (2019) emphasize that developmental stress caused by environmental change increases metabolic costs, such that although growth may be accelerated as an adaptive response, developmental quality may decline. In other words, organisms may be able to grow faster or larger under certain conditions, but their structural and functional development becomes less optimal. This indicates the existence of a biological trade off between growth and development under environmental stress, as reflected in the results of this study.

The positive relationship between organismal growth and organismal development indicates that growth remains an essential prerequisite for effective development. Adequate growth provides the physiological resources and energy required for tissue differentiation and functional maturation. This finding is consistent with the studies of Koyama et al. (2020) and Mirth et al. (2020), which show that metabolic regulation supporting growth also plays an important role in directing developmental trajectories, particularly in insects. In this context, growth functions as a biological mediator linking initial environmental responses with long term developmental outcomes. However, the results of this study also indicate that the relationship between growth and development is not independent of environmental conditions. Strobel et al. (2025) emphasize that growth and developmental plasticity can produce different consequences across organismal life stages, depending on environmental stability. Accordingly, although growth contributes positively to development, its effects may be weakened or strengthened by the intensity of environmental change. These findings reinforce the argument that organismal development represents the cumulative outcome of layered interactions between environmental factors and internal growth responses.

Overall, this discussion demonstrates that environmental change influences organismal growth and development through asymmetric mechanisms. Environmental change may stimulate growth as an adaptive response, while simultaneously disrupting developmental

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stability when environmental pressures exceed organismal adaptive capacity. These findings expand the theoretical understanding of the role of the environment as a regulator of growth and development, and underscore that analysis of these relationships requires a structural approach capable of capturing the complexity of biological interactions. Accordingly, the results of this study not only support the proposed hypotheses, but also provide a stronger conceptual foundation for environmental biology and the study of organismal adaptation in the context of global environmental change**.**

Conclusion

This study demonstrates that environmental change plays a significant role in shaping patterns of organismal growth and development. The quantitative analysis based on SEM–PLS confirms that environmental change has a positive effect on organismal growth while simultaneously exerting a negative effect on organismal development. These findings indicate that growth responses may function as an initial adaptive mechanism to environmental dynamics, whereas developmental processes, which are more complex and sensitive tend to be disrupted as environmental pressures intensify. In addition, organismal growth is shown to contribute positively to development, reaffirming that growth constitutes an essential biological prerequisite for developmental processes, although this contribution remains contingent upon the stability of external environmental conditions.

From a theoretical perspective, this study reinforces the view that organismal growth and development cannot be understood as linear responses to environmental change, but rather as the outcome of structural interactions between environmental factors and internal biological mechanisms. The application of the SEM–PLS approach enables more comprehensive modeling of latent relationships than conventional statistical methods, thereby offering a methodological contribution to the field of environmental biology. From a practical standpoint, the findings underscore the importance of maintaining environmental stability to support optimal organismal development, both in natural ecosystems and in managed or cultivated systems. This study has several limitations that should be acknowledged. The use of aggregated secondary data limits the ability to capture species-specific responses and life-stage variations among organisms. As a result, the findings reflect general biological patterns rather than precise mechanisms within particular taxa. Additionally, the generalization across different organism groups may obscure unique adaptive strategies present in specific ecological contexts.

This study also opens avenues for future research to incorporate more specific environmental variables or cross-ecosystem analyses in order to deepen understanding of the limits of organismal adaptation under increasingly intense environmental change.

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Conflict Of Interest Statement

The author declares no conflict of interest in the preparation of this work.

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