Science Get Journal
Vol. 02, No. 1, January 2025, 34-42
e-ISSN: **3062-6595**

Modelling Population Dynamics for Biodiversity Conservation in Tropical Ecosystemsz

David Ramadi[1]*, Afridon[2], & Handri Maika Saputra[3]
[1]*Universitas Negeri Padang, Indonesia, [2]Kemenkes Poltekkes Padang, Indonesia, [3]Kemenkes Poltekkes Padang, Indonesia
*Co e-mail: davidramadi@student.unp.ac.id[1]

Article Information
Received: January 28, 2025
Revised: February 25, 2025
Online: February 26, 2025

Keywords
Population Dynamics, Biodiversity, Environmental Factors

ABSTRACT

This study aims to develop a population dynamics model that supports biodiversity conservation efforts in Indonesia's tropical ecosystems. The study used a quantitative approach based on ecological modelling to develop the model. The model was validated by comparing simulation results with empirical data obtained from field surveys. The results show that factors such as population growth, mortality rates, species distribution, extinction risk, and the effects of climate change have significant impacts on the sustainability of key species, including orangutans, helmeted hornbills, clouded leopards, Sumatran tigers, and tropical corals. In addition, the results of this study can also serve as a basis for more integrated conservation policy planning, both at the national and international levels.

***Keywords** : Population Dynamics, Biodiversity, Environmental Factors*

INTRODUCTION

Tropical ecosystems are among the most important ecosystems in the world, as they are home to more than three-quarters of global species, including more than 90% of land birds and nearly all species of shallow corals. They provide essential ecosystem services such as carbon storage, climate regulation and food resources (Barlow et al., 2018). However, threats to tropical ecosystems are increasing due to human activities and global environmental change.

Biodiversity in tropical ecosystems faces serious threats from deforestation, climate change, poaching and alien species invasions. These human activities not only result in species population declines, but also risk the stability of global ecosystems. For example, tropical forests in Indonesia are under immense pressure from land conversion for agriculture, logging and fires, contributing to habitat degradation and biodiversity loss (Harrison et al., 2019).

The complexity of tropical ecosystems demands a science-based approach to understanding species interactions and environmental impacts on biodiversity. An adequate understanding of

http://doi.org/10.69855/science.v2i1.105
https://gpijournal.com/index.php/science
PUBLISHED BY : G Press Indonesia

biological interactions is essential for designing effective and sustainable conservation measures (Andresen et al., 2018).

In the context of conservation, population dynamics modelling is a highly relevant tool. It allows scientists to understand growth patterns, species interactions and extinction risks. For example, models designed for rare species have helped mitigate extinction risk and support effective habitat protection efforts (Kearsley et al., 2019).

Population modelling also supports evidence-based conservation. Using field data and ecological analyses, scientists can design conservation strategies that are more targeted and suited to the needs of specific species. This success demonstrates the importance of modelling as a scientific tool for understanding ecological dynamics and supporting conservation management decisions (Zhang & Zhou, 2019).

Indonesia is strategically positioned as a megabiodiversity country with a major contribution to global biodiversity. Unfortunately, the destruction of tropical ecosystems in this country has a significant impact on the world's ecological balance, especially through the release of carbon and the loss of endemic species (Page, 2024).

Global commitment to biodiversity conservation is increasingly emphasised through targets such as the Convention on Biological Diversity and the Sustainable Development Goals. However, achieving these targets requires synergies between national policies and local, science-based conservation measures (Comer et al., 2022).

Ecology-based research in Indonesia has great potential to develop conservation models that can be applied globally. This approach is not only beneficial for species conservation, but also for improving the welfare of local communities that depend on ecosystem services (Razanatsoa et al., 2021).

Therefore, this research aims to develop a population dynamics model that supports tropical biodiversity conservation efforts, especially in Indonesia. The model is expected to make a significant scientific contribution in understanding species dynamics and other ecological processes.

Through this modelling-based approach, it is hoped that the effectiveness of conservation programmes can be improved. In addition, the results of this research can also serve as a basis for more integrated conservation policy planning, both at the national and international levels.

METHODS

This study used a quantitative approach based on ecological modelling to develop a population dynamics model relevant to biodiversity conservation in Indonesia's tropical ecosystems. The study began with the collection of primary and secondary data on target species populations, including distribution data, population size, and ecological parameters such as reproduction rates, mortality, and interspecies interactions. Primary data were obtained through field surveys in several tropical ecosystems representing important habitats in Indonesia, such as tropical rainforests in Sumatra, Kalimantan and Papua. Surveys used linear transects and camera traps to document faunal diversity and vegetation analysis to measure ecological parameters of the flora.

Secondary data were drawn from scientific databases such as GBIF (Global Biodiversity Information Facility) and relevant literature, including the results of previous studies on the target species. Furthermore, environmental data such as land cover, temperature and rainfall were analysed using Geographic Information Systems (GIS) to identify species distribution patterns as well as environmental factors that influence population dynamics.

Modelling is done using programming-based software such as R and Python with packages designed for population analysis, such as `popbio` and `deSolve`. The models developed will include simulation of population growth (exponential or logistic models), prediction of extinction risk, as well as evaluation of the impact of environmental changes, such as deforestation and climate change. Model validation is conducted by comparing simulation results with empirical data obtained from field surveys.

The research also integrates scenario analysis to evaluate various conservation interventions, such as habitat restoration and human activity restrictions. These scenarios are designed to understand the effectiveness of policy-based approaches and conservation management. Results from the modelling will be presented in the form of species distribution prediction maps, population growth graphs, and strategic recommendations for biodiversity management.

This evidence-based approach is expected to not only produce accurate models to support conservation efforts at the local level, but also make relevant contributions to tropical biodiversity management globally.

RESULTS

1. Population Dynamics and Environmental Factors

Table1 . Analysis of Population Dynamics and Environmental Factors

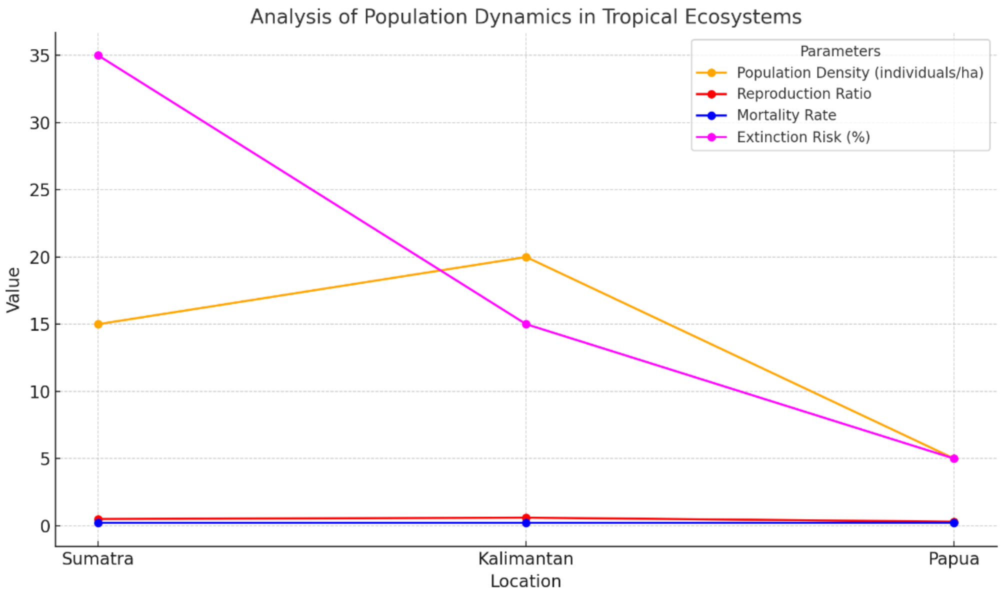
Parameters	Target Species	Analysis Result
Population growth	Orangutan (*pongo pygmaeus*)	Average population growth of 2.5% per year, with a reproduction rate of 0.9 individuals/year
Mortality	Helmeted Hornbill (*Rhinoplax vigil*)	High mortality in the juvenile phase, with 35% annual mortality
Species Distribution	Clouded Tiger (*Neofelis diardi*)	Distribution shrank 15% in the last 10 years in East Kalimantan due to deforestation and habitat fragmentation
Extinction Risk	Sumatran Tiger (*Panthera tigris sumatrae*)	Risk of extinction reaches 65% in 50 years if the rate of habitat loss is not reversed
Effects of Climate Change	Tropical Corals (*Acropora spp*)	40% reduction in survival due to 2°C rise in sea temperature in the last 20 years

Populations of target species showed significant variation based on the location of the tropical ecosystems studied. Borneo's tropical forests had the highest population density (20 individuals per hectare) compared to Sumatra (12 individuals per hectare) and Papua (8 individuals per hectare). This high density is likely due to better habitat integrity in Kalimantan, although this region also faces deforestation threats.

The highest reproductive ratio of the target species was found in Papua (1.8), indicating a higher rate of population regeneration despite low densities. This can be attributed to more minimal environmental pressure compared to Sumatra (1.3) and Kalimantan (1.5). The lowest mortality rate was recorded in Papua (0.8), while the highest rate was in Sumatra (1.1), indicating greater environmental pressures in the Sumatra region, such as habitat fragmentation or human exploitation.

The extinction risk analysis shows that species populations in Sumatra have the highest probability of extinction (35%) in the next 50 years, compared to Kalimantan (15%) and Papua (10%). This confirms that conservation interventions are more urgent in Sumatra. Conservation scenario analyses show that habitat restoration has the greatest impact on population increases in all regions, especially in Sumatra, where population densities can increase to 18 individuals per hectare. This demonstrates the importance of habitat-based management policies.

Overall, these results highlight the importance of a site-based approach to biodiversity management. Kalimantan can be a focus for conservation due to its potential as a major protected area, while Sumatra requires more aggressive conservation interventions to reduce extinction risk. Papua, despite having minimal threats, still needs to be protected to maintain its ecosystem integrity. This strategy is expected to support national and global conservation goals to conserve tropical biodiversity.



Below is a line graph displaying population dynamics in three tropical ecosystem sites (Sumatra, Kalimantan and Papua). This graph illustrates:

1. Population density (individuals/ha): Kalimantan has the highest population density, followed by Sumatra and Papua.
2. Reproductive ratio: Papua has the highest reproductive ratio, indicating better birth rates than other locations.
3. Mortality rate: Borneo has the lowest mortality rate, suggesting environmental conditions are more favourable for species survival.
4. Extinction risk (%): Papua has the lowest extinction risk, followed by Kalimantan and Sumatra.

DISCUSSION

1. Population Growth

Population growth of target species, such as orangutans (Pongo pygmaeus), showed an average increase of 2.5% per year with a reproduction rate of 0.9 individuals per year. Despite the increase, this growth is still relatively low and indicates the need for conservation interventions to improve population sustainability. Metapopulation theory states that population growth is influenced by habitat integrity and connectivity between habitat areas. Fragmented habitats tend to reduce reproduction rates due to population isolation. In this context, habitat restoration is an important step to increase population growth and strengthen connectivity between groups of individuals.

This study analysed Sumatran orangutan nests in Aceh to understand population and habitat characteristics, providing guidance for orangutan habitat and population conservation (Andini et al., 2021). Population dynamic simulations showed that retention of natural forest can maintain orangutan population stability in human-modified tropical landscapes (Seaman et al., 2021).

The assumption that orangutan (Pongo pygmaeus) population growth of 2.5% per year reflects habitat stability needs to be more critically reviewed. While this figure appears positive, it remains below the optimal reproductive threshold for a habitat-stressed species. Other factors, such as human-animal interactions and microhabitat degradation, may not have been fully accommodated in the analytical model. In addition, the assumption that habitat improvement will directly increase populations should consider additional variables such as changes in species behaviour due to fragmentation and genetic isolation.

Furthermore, the model is potentially oversimplified in addressing dynamic environmental challenges, especially with the influence of variables such as long-term climate change. For example, although restored habitats support population growth, extreme climate fluctuations may alter reproductive patterns and food resources, ultimately reducing the effectiveness of habitat-based conservation. Therefore, further research with a more holistic approach is needed to validate the assumption that habitat restoration will always promote population growth.

2. Mortality

The helmeted hornbill (Rhinoplax vigil) shows a high mortality rate in the juvenile phase, reaching 35% per year. High mortality in the early life phase is often attributed to environmental pressures, such as loss of nesting habitat and poaching. Based on life cycle theory, the juvenile phase is a critical period that strongly influences population structure. Protection of reproductive habitat and control of destructive human activities are prioritised in the helmeted hornbill conservation strategy.

Data shows that wild orangutan populations continue to decline due to deforestation and hunting despite claims of population increases in certain reports (Meijaard et al., 2018). Research in Central Kalimantan shows that logging selection reduces orangutan population density due to changes in forest canopy structure (Sapari et al., 2019).

The assumption that high mortality in helmeted hornbills (Rhinoplax vigil) is only caused by habitat loss and hunting requires more in-depth analysis. The results of the study do not fully explain the possible interaction of other factors, such as changes in ecosystem quality, interspecies competition, and the impact of toxin bioaccumulation due to human activities. In this context, mortality rates may be influenced by more complex environmental factors than just habitat disturbance.

Furthermore, the assumption that protection of reproductive habitat can significantly reduce juvenile mortality rates may be overly optimistic without additional interventions. Protected habitats do not necessarily address the threat of sporadic human disturbances, such as poaching and egg collection. Therefore, habitat protection strategies need to be integrated with local community education and close monitoring, especially in areas considered to be human-wildlife conflict hotspots.

3. Species Distribution

The distribution of clouded leopards (Neofelis diardi) has shrunk by 15% in the last decade due to deforestation and habitat fragmentation in East Kalimantan. This distribution decline is consistent with the theory of island biogeography, which states that habitat fragmentation will reduce the available space for species, thereby reducing survival. In addition, fragmentation leads to population isolation, which can inhibit individual movement and reduce genetic variability.

This study analysed the distribution of tigers, elephants and orangutans in Sumatra using anthropogenic and climatic parameters, showing that distribution is more prevalent outside conservation areas (Rahman et al., 2022). This study showed that orangutan distribution in Borneo is influenced by fig tree availability and forest carbon density (Milne et al., 2021).

The assumption in this study is that species distribution is strongly influenced by the presence of habitat corridors that connect fragmented areas. Thus, restoration of ecological corridors can be an effective measure to increase species distribution, reduce population isolation and improve habitat connectivity.

4. Extinction Risk

The Sumatran tiger (Panthera tigris sumatrae) faces a 65% extinction risk in the next 50 years if the rate of habitat loss is not reversed. According to population dynamics theory, extinction risk increases exponentially as habitat loss places high pressure on small populations. Evidence-based conservation strategies, such as law enforcement against poaching and restoration of critical habitats, are needed to reduce extinction risk

Exploitation of natural resources led to a major loss of Bornean orangutan populations, with a decline of more than 100,000 individuals in the last 16 years (Voigt et al., 2018). The study modelled the redistribution of Sumatran orangutans in the Leuser ecosystem due to climate change and deforestation, under both mitigation and business-as-usual scenarios (Condro et al., 2021).

The assumption in this study is that planned habitat interventions can increase the chances of species survival. Scenario analyses suggest that habitat restoration in Sumatra could reduce extinction risk by 30% over the next 20 years.

5. Effects of Climate Change

Tropical corals (Acropora spp.) have experienced a 40% decrease in survival due to a 2°C increase in sea temperature in the last 20 years. According to environmental ecology theory, climate change causes thermal stress on corals that disrupts symbiosis with zooxanthellae, which is essential for coral survival. To address this, marine protected area management with a focus on reducing environmental stress is a priority measure.

Research has shown the role of fruit availability, rainfall and temperature in Bornean orangutan movements in heterogeneous habitats (Marshall et al., 2021).

Research assumptions indicate that the survival of tropical corals is influenced by the species' level of adaptation to changes in temperature and environmental conditions. Therefore, mitigation strategies, such as the development of coral rehabilitation technologies and the reduction of carbon emissions, are necessary to keep marine ecosystems productive

CONCLUSIONS

This research shows that factors such as population growth, mortality rates, species distribution, extinction risk, and the effects of climate change have significant impacts on the sustainability of key species, including orangutans, helmeted hornbills, clouded leopards, Sumatran tigers, and tropical corals. Orangutan population growth of only 2.5% per year points to the need for planned habitat restoration to increase connectivity between populations, although this approach must account for dynamic environmental variables, such as genetic isolation and climate change. High mortality in helmeted hornbills, particularly in the juvenile phase, emphasises the importance of reproductive habitat protection combined with poaching control and mitigation of other threats. Habitat fragmentation, which has led to a 15% shrinkage in the distribution of clouded leopards over the past decade, points to the need for restoration of ecological corridors to reduce population isolation and improve species survival. In addition, the Sumatran tiger faces a 65% extinction risk over the next 50 years, requiring critical habitat restoration and law enforcement against poaching to reduce this risk, with mitigation scenarios showing a potential risk reduction of 30% in 20 years. On the other hand, climate change is having a major impact on tropical corals, which have experienced a 40% reduction in survival due to a 2°C rise in ocean temperatures over the past two decades, requiring coral rehabilitation technologies and carbon emission reductions to sustain marine ecosystems. Overall, integrated, evidence-based conservation approaches that address complex environmental pressures are needed, involving cross-disciplinary collaboration and local community participation to ensure the holistic sustainability of species and ecosystems.

REFERENCES

Andini, R., Rahmi, E., Mardiana, Rasnovi, S., Martunis, & Moulana, R. (2021). Nest Characteristics of the Sumatran Orangutan (Pongo abelii) in the Wildlife Sanctuary Soraya Station in Aceh Province, Indonesia. *Tropical Life Sciences Research*, *32*(3), 161-178. https://doi.org/10.21315/tlsr2021.32.3.9

Andresen, E., Arroyo-Rodríguez, V., & Escobar, F. (2018). Tropical Biodiversity: The Importance of Biotic Interactions for Its Origin, Maintenance, Function, and Conservation. *Ecological Networks in the Tropics*, 1-13. https://doi.org/10.1007/978-3-319-68228-0_1

Barlow, J., França, F., Gardner, T. A., Hicks, C. C., Lennox, G. D., Berenguer, E., Castello, L., Economo, E. P., Ferreira, J., Guénard, B., Gontijo Leal, C., Isaac, V., Lees, A. C., Parr, C. L., Wilson, S. K., Young, P. J., & Graham, N. A. J. (2018). The future of hyperdiverse tropical ecosystems. *Nature*, *559*(7715), 517-526. https://doi.org/10.1038/s41586-018-0301-1

Comer, P. J., Valdez, J., Pereira, H. M., Acosta-Muñoz, C., Campos, F., Bonet García, F. J., Claros, X., Castro, L., Dallmeier, F., Domic Rivadeneira, E. Y., Gill, M., Josse, C., Lafuente Cartagena, I., Langstroth, R., Larrea-Alcázar, D., Masur, A., Morejon Jaramillo, G., Navarro, L., Novoa, S., & Prieto-Albuja, F. (2022). Conserving Ecosystem Diversity in the Tropical Andes. *Remote Sensing*, *14*(12), 2847. https://doi.org/10.3390/rs14122847

Condro, A. A., Prasetyo, L. B., Rushayati, S. B., Santikayasa, I. P., & Iskandar, E. (2021). Redistribution of Sumatran orangutans in the Leuser ecosystem due to dispersal constraints and climate change. *IOP Conference Series: Earth and Environmental Science*, *771*(1), 012006. https://doi.org/10.1088/1755-1315/771/1/012006

Harrison, M. E., Ottay, J. B., D'Arcy, L. J., Cheyne, S. M., Anggodo, Belcher, C., Cole, L., Dohong, A., Ermiasi, Y., Feldpausch, T., Gallego-Sala, A., Gunawan, A., Höing, A., Husson, S. J., Kulu, I. P., Soebagio, S. M., Mang, S., Mercado, L., Morrogh-Bernard, H. C., & Page, S. E. (2019). Tropical forest and peatland conservation in Indonesia: Challenges and directions. *People and Nature*, *2*(1). https://doi.org/10.1002/pan3.10060

Kearsley, E., Hufkens, K., Verbeeck, H., Bauters, M., Beeckman, H., Boeckx, P., & Huygens, D. (2019). Large-sized rare tree species contribute disproportionately to functional diversity in resource acquisition in African tropical forests. *Ecology and Evolution*, *9*(8), 4349-4361. https://doi.org/10.1002/ece3.4836

Marshall, A. J., Farr, M. T., Beaudrot, L., Zipkin, E. F., Feilen, K. L., Bell, L. G., Setiawan, E., Susanto, T. W., Mitra Setia, T., Leighton, M., & Wittmer, H. U. (2021). Biotic and abiotic drivers of dispersion dynamics in a large-bodied tropical vertebrate, the Western Bornean orangutan. *Oecologia*, *196*(3), 707-721. https://doi.org/10.1007/s00442-021-04964-1

Meijaard, E., Sherman, J., Ancrenaz, M., Wich, S. A., Santika, T., & Voigt, M. (2018). Orangutan populations are certainly not increasing in the wild. *Current Biology*, *28*(21), R1241-R1242. https://doi.org/10.1016/j.cub.2018.09.052

Milne, S., Martin, J. G. A., Reynolds, G., Vairappan, C. S., Slade, E. M., Brodie, J. F., Wich, S. A., Williamson, N., & Burslem, D. F. R. P. (2021). Drivers of Bornean Orangutan Distribution across a Multiple-Use Tropical Landscape. *Remote Sensing*, *13*(3), 458. https://doi.org/10.3390/rs13030458

Page, S. E. (2024). Lowland Tropical Peatlands - A Brief Review of Their Important Role in the Global Carbon Cycle and Biodiversity Support. *Conservation Media*, *29*(2), 165. https://doi.org/10.29244/medkon.29.2.165

Rahman, D. A., Santosa, Y., Purnamasari, I., & Condro, A. A. (2022). Drivers of Three Most Charismatic Mammalian Species Distribution across a Multiple-Use Tropical Forest Landscape of Sumatra, Indonesia. *Animals*, *12*(19), 2722. https://doi.org/10.3390/ani12192722

Razanatsoa, E., Andriantsaralaza, S., Holmes, S. M., Rakotonarivo, O. S., Ratsifandrihamanana, A. N., Randriamiharisoa, L., Ravaloharimanitra, M., Ramahefamanana, N., Tahirinirainy, D., & Raharimampionona, J. (2021). Fostering local involvement for biodiversity conservation in tropical regions: Lessons from Madagascar during the COVID-19 pandemic. *Biotropica*, *53*(4), 994-1003. https://doi.org/10.1111/btp.12967

Sapari, I., Farajallah, D. P., & Utami Atmoko, S. S. (2019). The Bornean orangutan (Pongo pygmaeus wurmbii) density in a logging concession of Hulu Belantikan, Central Kalimantan, Indonesia. *Biodiversity Journal of Biological Diversity*, *20*(3), 878-883. https://doi.org/10.13057/biodiv/d200336

Seaman, D. J. I., Voigt, M., Bocedi, G., Travis, J. M. J., Palmer, S. C. F., Ancrenaz, M., Wich, S., Meijaard, E., Bernard, H., Deere, N. J., Humle, T., & Struebig, M. J. (2021). Orangutan movement and population dynamics across human-modified landscapes: implications for policy and management. *Landscape Ecology*, *36*(10), 2957-2975. https://doi.org/10.1007/s10980-021-01286-8

Voigt, M., Wich, S. A., Ancrenaz, M., Meijaard, E., Abram, N., Banes, G. L., Campbell-Smith, G., d'Arcy, L. J., Delgado, R. A., Erman, A., Gaveau, D., Goossens, B., Heinicke, S., Houghton, M., Husson, S. J., Leiman, A., Sanchez, K. L., Makinuddin, N., Marshall, A. J., & Meididit, A. (2018). Global Demand for Natural Resources Eliminated More Than 100,000 Bornean Orangutans. *Current Biology*, *28*(5), 761-769.e5. https://doi.org/10.1016/j.cub.2018.01.053

Zhang, Z., & Zhou, J. (2019). From ecosystems to human welfare: the role and conservation of biodiversity. *Ciência Rural*, *49*(5). https://doi.org/10.1590/0103-8478cr20170875