Zootec Vol. 46 No. 2 : 73 – 81 (2026) pISSN 0852 – 2626 eISSN 2615 – 8698

Behavioral responses of the endemic maleo (*Macrocephalon maleo*) in a non-typical upland forest habitat

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ABSTRACT

Behavioral ecology provides a critical framework for understanding how wild birds adjust their activity patterns in response to environmental variability and anthropogenic disturbance. The Maleo (*Macrocephalon maleo*), an endemic bird of Sulawesi, is ecologically specialized for reproduction in hot, sandy coastal habitats; however, individuals are occasionally reported in upland forest environments that differ markedly from their typical ecological niche. This study examined daily activity patterns and behavioral responses of Maleo inhabiting a suboptimal upland forest habitat at approximately 600 m above sea level, characterized by low ambient temperature and high relative humidity. Behavioral observations were conducted using instantaneous scan sampling at 10-minute intervals from early morning to late afternoon, accompanied by concurrent microclimatic measurements and non-invasive pathogen surveillance at the wildlife–livestock interface. Results indicated that foraging behavior dominated the activity budget, often occurring in proximity to domestic chickens and anthropogenic food sources, while vigilance and rapid escape responses were observed in relation to human presence. Maleo activity was reduced during rainfall and more frequently recorded under clear or lightly clouded conditions, suggesting sensitivity to microclimatic variation. This study demonstrates that Maleos inhabiting an atypical upland forest environment exhibit flexible behavioral strategies that facilitate their short-term persistence under suboptimal ecological conditions. However, this behavioral plasticity entails critical trade-offs, notably increased exposure to human disturbance and elevated health risks, while ultimately failing to fulfill the species' specialized reproductive requirements. Consequently, conservation efforts must prioritize the rigorous protection and restoration of natural coastal nesting habitats, complemented by ongoing behavioral monitoring and wildlife-livestock health surveillance. Ultimately, integrating behavioral ecology into conservation planning is essential for delineating the limits of species adaptability and ensuring the effective, long-term management of this threatened endemic bird

Keywords: behavioral ecology, behavioral plasticity, Maleo, non-typical habitat, wildlife–livestock interface

ABSTRAK

RESPONS TINGKAH LAKU BURUNG MALEO ENDEMIK (*Macrocephalon maleo*) DI HABITAT HUTAN DATARAN TINGGI NON-TIPIKA. Bahasan Ekologi perilaku memberikan landasan penting untuk memahami bagaimana burung liar menyesuaikan pola aktivitasnya sebagai respons terhadap variabilitas lingkungan dan gangguan akibat ulah manusia. Maleo (*Macrocephalon maleo*), burung endemik Sulawesi, secara ekologis sangat terspesialisasi untuk bereproduksi di habitat pantai berpasir panas; namun, individu Maleo kadang-kadang ditemukan di lingkungan hutan pegunungan yang sangat berbeda dari ceruk ekologis alaminya. Penelitian ini meneliti pola aktivitas harian dan respons perilaku Maleo yang mendiami habitat hutan pegunungan suboptimal pada ketinggian sekitar 600 meter di atas permukaan laut, yang ditandai dengan suhu lingkungan rendah dan kelembapan relatif tinggi. Observasi perilaku dilakukan menggunakan metode pengambilan sampel pada interval setiap 10 menit dari pagi hingga sore hari, disertai pengukuran mikroklimat secara bersamaan serta pemantauan patogen secara non-invasif pada area berbatasan antara satwa liar dan hewan domistikasi. Hasil penelitian menunjukkan bahwa perilaku mencari makan mendominasi alokasi waktu aktivitas hewan ini, sering kali terjadi di dekat ayam domestik dengan sumber makanan hasil limbah/sisa manusia, sementara perilaku waspada dan reaksi melarikan diri yang cepat diamati ketika hewan ini menyadari kehadiran manusia. Aktivitas Maleo cenderung menurun saat hujan dan akan lebih aktif saat kondisi cuaca cerah atau berawan ringan, yang mengindikasikan sensitivitas terhadap variasi mikroklimat. Studi ini menunjukkan bahwa Maleo yang menghuni lingkungan hutan dataran tinggi yang bukan merupakan habitat khasnya menunjukkan strategi perilaku fleksibel dalam kondisi ekologis yang tidak optimal. Namun, plastisitas perilaku ini memerlukan trade-off penting, terutama peningkatan paparan gangguan manusia dan peningkatan risiko kesehatan. Sebagai konsekuensi, upaya konservasi harus memprioritaskan perlindungan dan pemulihan habitat pesisir alami, dilengkapi dengan pemantauan perilaku berkelanjutan dan pengawasan kesehatan satwa liar dan ternak sekitarnya. Pada akhirnya, mengintegrasikan ekologi perilaku ke dalam perencanaan konservasi sangat penting untuk menggambarkan batas kemampuan beradaptasi spesies dan memastikan pengelolaan efektif dan jangka panjang dari burung endemik yang terancam ini

Kata kunci: ekologi perilaku, plastisitas perilaku, Maleo, habitat non-tipikal, interaksi satwa liar–ternak

INTRODUCTION

Avian behavior mediates interactions between individuals and their environments, shaping resource acquisition and threat avoidance. Within the framework of behavioral ecology, daily activity patterns represent adaptive outcomes that optimize fitness under specific constraints. As noted in Fisher *et al.* (2025), the ability of endemic specialists to adjust to non-typical habitats is a critical component of contemporary evolutionary rescue. While foraging typically dominates activity budgets , environmental heterogeneity, encompassing variations in climate and human disturbance, can substantially alter these behaviors. Behavioral plasticity represents the first line of defense against anthropogenic habitat degradation (White *et al.*, 2017)

Environmental heterogeneity, encompassing variations in climate, habitat structure, and human disturbance, can substantially alter avian behavior. While birds in optimal habitats generally exhibit stable behavioral patterns aligned with predictable resources and favorable microclimates, those occupying non-typical or suboptimal habitats often display altered activity budgets, increased vigilance, and opportunistic resource use (Greggor, 2016). Although such behavioral plasticity may facilitate short-term persistence, it does not necessarily indicate long-term habitat suitability, particularly when key life-history requirements remain unfulfilled.

The Maleo (*Macrocephalon maleo*) possesses highly specialized reproductive requirements, necessitating sandy substrates heated by solar or geothermal energy. Although they forage in forests, successful reproduction is strictly dependent on these unique thermal conditions. The presence of Maleo in upland forest environments, characterized by lower temperatures and higher humidity, raises significant conservation concerns. This shift mirrors patterns observed in other megapodes facing habitat fragmentation, as detailed in Joseph *et al*. (2021). As coastal nesting sites are lost to sea-level rise or human encroachment, upland forests may become the only refuge despite their reproductive unsuitability, a trend predicted in Staines *et al*. (2025). This study aims to describe daily activity patterns in upland habitats, examine the relationship with microclimates, and assess epidemiological risks associated with domestic poultry.

Despite extensive research focusing on Maleo nesting ecology, the behavioral responses of this species within non-typical habitats remain poorly documented. Understanding how the Maleo adjusts its behavior under suboptimal environmental conditions is critical for evaluating the limits of its ecological tolerance and the potential consequences for population persistence. By integrating behavioral observations with microclimatic data and preliminary health assessments, this study provides a comprehensive evaluation of how environmental constraints, disturbance, and interspecific interactions shape their behavioral strategies. Specifically, this study aimed to: (1) describe the daily activity patterns of Maleos in an upland forest habitat contrasting with their typical ecological niche; and (2) examine the relationship between these behaviors and microclimatic conditions. Ultimately, applying this behavioral ecology framework contributes to a broader understanding of how ecologically specialized endemic birds respond to non-ideal habitats, thereby nforming targeted conservation strategies for threatened species.

MATERIALS AND METHODS

Study area

The study was conducted in the Gunung Klabat Forest (coordinate: 1.432910 125.005556) (Fig. 1), North Sulawesi, Indonesia, at approximately 600 m above sea level. The area is characterized by dense forest cover, relatively low ambient temperatures (18–23 °C), high relative humidity, and frequent rainfall. These conditions differ markedly from the hot, sandy coastal environments typically used by Maleo for nesting.

Figure 1. Study Area at Mt. Klabat, Aermadidi

Figure 2. Maleo observed during Behavioral Investigation

Behavioral observation

Behavioral observations were carried out using instantaneous scan sampling at 10-minute intervals from 05:30 to 17:00 WITA. During each scan, the number of Maleo individuals observed and their behaviors were recorded (Fig. 2). Behavioral categories included foraging, locomotion, vigilance, vocalization, resting, and self-maintenance (*preening*) (Altmann, 1974). The estimated distance between Maleo individuals and humans or domestic chickens was also recorded (Carrete and Tella, 2011).

Microclimate measurement

Microclimatic variables were measured concurrently with behavioral observations. Air temperature and relative humidity were recorded using digital data loggers placed approximately 1 m above ground level in areas frequently used by Maleo. Ground surface temperature was measured at foraging and resting sites using an infrared thermometer. Weather conditions (clear, cloudy, or rainy) were noted during each observation period.

Data analysis

Behavioral data were summarized as frequencies and proportions of total observation time allocated to each behavioral category. Associations between behavioral activity and microclimatic variables were explored using descriptive and non-parametric analyses. Pathogen surveillance results were interpreted descriptively due to limited sample size.

Ethical considerations

All procedures were observational and non-invasive. No animals were captured or handled. The study design adhered to accepted ethical standards for wildlife research.

RESULTS AND DISCUSSION

Behavioral observations of Maleos conducted at an elevation of approximately 600 m above sea level, characterized by relatively low temperatures and high humidity, demonstrated that individuals maintained a comprehensive repertoire of basic behaviors. These activities included locomotion, foraging, vigilance, and limited social interactions. Notably, the birds exhibited *slow walking* accompanied by an *alert gaze* and *rapid escape responses* when approached by humans, indicating the retention of adaptive anti-predator mechanisms even within atypical environments.

Foraging constituted the majority of the observed activity budget. This behavior frequently occurred in areas shared with domestic chickens and involved the exploitation of anthropogenic food sources, such as split coconuts and commercial poultry feed. This opportunistic resource use highlights considerable behavioral plasticity in the foraging strategies of the Maleo when occupying suboptimal habitats.

During midday periods, individuals frequently exhibited *sheltering behavior* beneath dense tree canopies. This activity likely represents a behavioral response to the humid and relatively cool upland microclimate, a stark contrast to the open, heat-exposed environments of their natural coastal nesting sites. Furthermore, *vocalizations* were consistently recorded just before individuals emerged into open observation areas, suggesting this behavior functions either as intraspecific communication or as a preliminary alert signal.

Finally, individuals consistently approached the observation areas from the same direction, pointing to a reliance on established travel routes. Activity ceased entirely during rainfall, demonstrating a pronounced behavioral sensitivity to adverse weather conditions. Overall, these documented patterns reflect the Maleo’s short-term adaptive capacity to persist in non-ideal environments, characterized by heightened vigilance and an increased reliance on human-modified resources.

The Maleo exhibits substantial behavioral plasticity in atypical upland habitats. Foraging dominance and opportunistic resource use align with energy maximization strategies. This opportunistic shift, where energetic demands outweigh the risks of human proximity, is supported by Chesser *et al*. (2019). However, shared foraging with domestic chickens elevates the risk of interspecific disease transmission. Molecular surveillance via fecal DNA remains a robust method for monitoring these high-risk populations (McClenaghan *et al.,* 2019)

However, these behavioral adjustments introduce significant ecological and epidemiological trade-offs. Increased proximity to humans and shared foraging areas with domestic chickens likely elevate both disturbance exposure and the risk of interspecific disease transmission. Consistent with life-history theory, these short-term survival strategies may compromise long-term fitness, particularly because reproductive opportunities are severely constrained in this novel environment.

Consistent with life-history theory, these strategies may compromise long-term fitness. The decline of specialist species and the phenomenon of functional homogenization, which often results from species persisting in suboptimal (sink) habitats that do not support successful reproduction. These habitats may provide temporary refuge but ultimately do not sustain viable populations, thereby concealing the true risk of extinction. Adaptive phenotypic plasticity in response to environmental change, noting that survival in altered habitats can occur even when reproductive success is compromised (Charmantier *et al*., 2008; Clavel *et al*., 2011; Lalejini *et al*., 2021; Ibbett *et al.,* 2023).

This creates an *ecological trap*, as discussed in United Nations Environment Programme (2022), where anthropogenic food lures specialists into unsuitable environments. Furthermore, the metabolic cost of maintaining homeostasis in cool upland forests may divert energy from reproduction in birds (Hanssen *et al*., 2005; Both and Visser, 2000; Kuo *et al*., 2025; Socias-Martínez *et al*., 2025)

Microclimate factors were also essential in determining the Maleo's daily behavior patterns. For insect-eating forest birds that are sensitive to climate, localized cool microhabitats can buffer occupancy and breeding activity, even as broader climate conditions change (Martin, 2001; Sih *et al*., 2011; Hamer *et al*., 2012; Frey *et al*., 2016; Kim *et al*. 2022). Research suggests that microclimatic influence may surpass that of vegetation type or structure, though its effects can differ between bird species, potentially due to differences in thermal physiology and macroclimate preferences (Frey *et al*., 2016; Frishkoff *et al*. 2016; Nowakowski *et al*. 2018). For cold-blooded animals, deforested environments with high temperatures and low humidity can elevate metabolic rates and cause dehydration, pushing some species to local extinction as they reach their physical tolerance limits (Lemoine *et al*., 2014; Nowakowski *et al*., 2018; Wilson and Fox 2021; Williamson *et al*. 2022). Although evidence is increasing that a variety of forest-dwelling species depend on cooler microclimates, there remains limited understanding of how these conditions affect community structure or interactions across multiple trophic levels in restoration habitats. The Maleo's tendency to stop activity during rainfall and seek shade under dense foliage at midday reflects a pronounced behavioral response to heat and humidity stress. Importantly, the upland site does not offer the geothermal or sun-warmed sandy soils needed for egg incubation, making it an unsuitable environment for breeding and serving primarily as a non-reproductive, or 'sink', habitat.

From a conservation perspective, the presence of Maleos in these suboptimal environments should be interpreted as a behavioral response to ecological pressure or displacement, rather than evidence of long-term habitat expansion or suitability. Recognizing these behavioral shifts provides crucial, early-warning indicators of habitat stress, which can directly inform targeted conservation interventions designed to protect and restore their endemic coastal nesting sites.

CONCLUSION

This study demonstrates that Maleos inhabiting an atypical upland forest environment exhibit flexible behavioral strategies that facilitate their short-term persistence under suboptimal ecological conditions. However, this behavioral plasticity entails critical trade-offs, notably increased exposure to human disturbance and elevated health risks, while ultimately failing to fulfill the species' specialized reproductive requirements. Consequently, conservation efforts must prioritize the rigorous protection and restoration of natural coastal nesting habitats, complemented by ongoing behavioral monitoring and wildlife-livestock health surveillance. Ultimately, integrating behavioral ecology into conservation planning is essential for delineating the limits of species adaptability and ensuring the effective, long-term management of this threatened endemic bird.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to *Aqua Tirta Investama Aermadidi* for their invaluable support and assistance during this research. Their generosity in providing access to the study site and logistical resources was crucial to the successful completion of this project. We also thank all field assistants, local community members, and partner organizations whose collaboration and

dedication greatly contributed to the quality and depth of our fieldwork.

REFERENCES

Altmann J., 1974. Observational study of behavior: Sampling methods. Behaviour, 49(3–4), 227–267. https://doi.org/10.1163/156853974X00534

Both C. and M.E. Visser. 2000. Breeding territory size affects fitness: an experimental study on competition at the individual level. J Animal Ecol, 69:1021–30.

Carrete M., and J.L. Tella. 2011. Inter-individual variability in fear of humans and relative brain size of the species are related to contemporary urban invasion in birds. PLoS ONE, 6(4), e18859. https://doi.org/10.1371/journal.pone.0018859

Charmantier A., R.H. McCleery, L.R. Cole, C. Perrins, C., L.E. Kruuk, and B.C. Sheldon. 2008. Adaptive phenotypic plasticity in response to climate change in a wild bird population. Science (New York, N.Y.), 320(5877), 800–803. https://doi.org/10.1126/science.1157174

Chesser R., K. Burns, C. Cicero, J. Dunn, A. Kratter, I. Lovette, P. Rasmussen, J. Remsen, D. Stotz, and K. Winker. 2019. Sixtieth Supplement to the American Ornithological Society's Check-list of North American Birds. The Auk. 136. 1-23. 10.1093/auk/ukz042.

Clavel J., R. Julliard, and V. Devictor. 2011. Worldwide decline of specialist species: Toward a global functional homogenization? Frontiers in Ecology and the Environment, 9(4), 222–228. https://doi.org/10.1890/080216

Fisher J.C., M. Dallimer, G.E. Austen, K.N. Irvine, S.G. Aizlewood, P.M. King, H.A. Jackson, R.D. Fish and Z.G. Davies. 2025. Spatio-temporal variability in forest biodiversity associated with human well-being across socio-economic deprivation gradients. Nature Ecology & Evolution, 9: 1382-1392. 10.1038/s41559-025-02765-w.

Frey S.J.K., A.S. Hadley, and M.G. Betts. 2016. Microclimate predicts within-season distribution dynamics of montane forest birds. Diversity and Distributions. 22 (9): 944–59. doi:10.1111/ddi.12456.

Frishkoff L.O., D.S. Karp, J.R. Flanders, J. Zook, E.A. Hadly, G.C. Daily, and L.K. M'Gonigle. 2016. Climate change and habitat conversion favour the same species. Ecology Letters, 19 (9): 1081–90. doi:10.1111/ele.12645.

Greggor A. L., N.S. Clayton, A.J.C. Fulford, and A. Thornton. 2016. Street smart: Faster approach towards familiarity for opportunistic birds in urban environments. Animal Behaviour, 118, 135–142. https://doi.org/10.1016/j.anbehav.2016.06.002

Hamer S. A., E. Lehrer, and S.B. Magle. 2012. Wild birds as sentinels for zoonotic pathogens along urban to rural gradients. EcoHealth, 9(3): 261–276. https://doi.org/10.1007/s10393-012-0784-5

Hanssen S. A., D. Hasselquist, I. Folstad, and K.E. Erikstad. 2005. Cost of reproduction in a long-lived bird: incubation effort reduces immune function and future reproduction. Proceedings. Biological sciences, 272(1567), 1039–1046.

https://doi.org/10.1098/rspb.2005.3057

Ibbett H., J.P.G. Jones, L. Dorward, E.M. Kohi, A.A. Dwiyahreni, K. Prayitno, S. Sankeni, J. Kaduma, J. Mchomvu, A.W. Saputra, H. Sabiladiyni, J. Supriatna, and F.A.V. St John. 2023. A mixed methods approach for measuring topic sensitivity in conservation. People and nature (Hoboken, N.J.), 5(4): 1245–1261. https://doi.org/10.1002/pan3.10501

Joseph L., A.H. Burbidge, K. Delhey, B.D. Hansen, S. Kleindorfer, and G. Maure. 2021. Emu's first 120 years: landmark papers of change in austral ornithology. Emu - Austral Ornithology, 121(4): 284-291.

Lalejini A., A.J. Ferguson, N.A. Grant, and C. Ofria. 2021. Adaptive Phenotypic Plasticity Stabilizes Evolution in Fluctuating Environments. Front. Ecol. Evol., 9:715381. doi: 10.3389/fevo.2021.715381

Kuo Y.M., Y.F. Lee, B.Y. Chuang, Y.J. Kuo, H.C. Hsu, Y.Y. Chiang, Y.L. Tai, S.L. Chang, C.Y. Lin, Y.J. Huang, and W.C. Lee. 2025. Sexually Different Parental Inputs in Pheasant-tailed Jacanas and the Correlates with Brood Success. Integrative organismal biology (Oxford, England), 7(1), obaf035. https://doi.org/10.1093/iob/obaf035

Martin T.E. 2001. Abiotic vs. biotic influences on habitat selection of coexisting species: Climate change impacts? Ecology, 82(1), 175–188. https://doi.org/10.1890/0012-9658(2001)082[0175:AVBIOH]2.0.CO;2

McClenaghan B., E. Nol, K.C.R Kerr. 2019. DNA metabarcoding reveals the broad and flexible diet of a declining aerial insectivore, The Auk, Volume 136, Issue 1, 1 January 2019, uky003, https://doi.org/10.1093/auk/uky003

Nowakowski A.J., L.O. Frishkoff, M. Agha, B.D. Todd, and B.R. Scheffers, 2018. Changing thermal landscapes: merging climate science and landscape ecology through thermal biology.

Nowakowski A.J., J.I. Watling, M.E. Thompson, G.A. Brusch IV, A. Catenazzi, S.M. Whitfield, D.J. Kurz, Á. Suárez-Mayorga, A. Aponte-Gutiérrez, M.A. Donnelly, B.D. Todd. 2018. Thermal biology mediates responses of amphibians and reptiles to habitat modification. Ecol Lett, 21: 345-355. https://doi.org/10.1111/ele.12901

Sih, A., M.C.O. Ferrari, and D.J. Harris, 2011. Evolution and behavioural responses to human-induced rapid environmental change. Evolutionary Applications, 4(2): 367–387. https://doi.org/10.1111/j.1752-4571.2010.00166.x

Socias-Martínez, L., E. Álvarez, L.R. Peckre, and E. Barba. 2025. Unveiling Clutch Investment Strategies in Birds: A case study on great tits using generalized additive models. ecology and evolution, 15(7): e71700. https://doi.org/10.1002/ece3.71700

Staines M.N., D.T. Booth, J. Laloë, and G.C. Hays. 2025. The impact of sea level rise on nesting sea turtles: a global meta-analysis to highlight current understanding and knowledge gaps. Mar Biol 172, 171 (2025). https://doi.org/10.1007/s00227-025-04726-0

United Nations Environment Programme; 2022. Frontiers: Noise, Blazes and Mismatches– Emerging Issues of Environmental Concern. Nairobi. United Nations Environment Programme.

https://www.unep.org/frontiers. ISBN: 978-92-807-3917-6

Lemoine N.P., D.E. Burkepile, and J.D. Parker, 2014. Variable Effects of Temperature on Insect Herbivory. PeerJ 2 (May):e376. doi:10.7717/peerj.376.

White L.A., J.D. Forester, and M.E. Craft. 2017. Using contact networks to explore mechanisms of parasite transmission in wildlife. Biological reviews of the Cambridge Philosophical Society, 92(1): 389–409. https://doi.org/10.1111/brv.12236

Wilson R.J. and R. Fox. 2021. Insect responses to global change offer signposts for biodiversity and conservation. Ecological Entomology, 46 (4): 699–717. doi:10.1111/een.12970

Williamson J., E. Teh, T. Jucker, M. Brindle, E. Bush, A.Y. C. Chung, J. Parrett, O.T. Lewis, S.J. Rossiter, and E.M. Slade. 2022. Local-Scale temperature gradients driven by human disturbance shape the physiological and morphological traits of dung beetle communities in a bornean oil palm–forest mosaic. Functional Ecology, 36 (7): 1655–67. doi:10.1111/1365-2435.14062.