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Physiological Response of Sumatran Elephant (*Elephas Maximus Sumatranus*) to Land Cover Changes at TWA Holiday Resort, North Sumatra

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ABSTRACT

Land cover changes due to anthropogenic activities are one of the main threats to the sustainability of the Sumatran Elephant (*Elephas maximus sumatranus*) habitat. This study aims to analyze the relationship between the physiological conditions of Sumatran Elephants and land cover changes in the North Sumatra Holiday Resort Nature Tourism Park (Indonesian term: *Taman Wisata Alam*/TWA). The study was conducted on three individual elephants, namely Nurhalimah, Sudarwanto, and Merry. The physiological data observed included age, body temperature, body condition, appetite, fecal condition, rest duration, and stress levels. Land cover data were obtained through the interpretation of satellite imagery and secondary data from the area. Data analysis was carried out using multiple linear regression, beginning with classical assumption tests and hypothesis tests. The results of the study indicate that during the period 1990–2024, there was a very significant change in land cover, where secondary dryland forests were almost entirely converted into plantations, settlements, and other non-forest lands. The results of the F test indicate that all physiological variables simultaneously had a significant effect on land cover changes ($p<0.05$). The Adjusted R Square value of 0.652 indicates that the observed physiological variables can explain 65.2% of the variation in land cover change. Partially, only stress levels significantly influence land cover change with a significance value of 0.003 and a beta coefficient of 1.120. These results indicate that stress levels are the most sensitive physiological indicator in responding to habitat changes. Therefore, conservation efforts for Sumatran Elephants at the TWA Holiday Resort need to be directed at habitat restoration and reducing anthropogenic pressures to maintain the welfare and sustainability of the elephant population in the area.

Keywords: Land Cover Changes, Physiological Conditions, Stress Levels, Sumatran Elephants, TWA Holiday Resort

1. Introduction

Indonesia's tropical forests are among the most biodiverse ecosystems in the world, serving as habitats for a variety of endemic flora and fauna [1]. However, in recent decades, pressure on forest areas has continued to increase due to anthropogenic activities such as land clearing, encroachment, plantations, settlements, and infrastructure development [2]. This has led to changes in land cover, which have impacted the quality of wildlife habitat. Indonesia's deforestation rate in 2025 will reach 433,751 hectares according to data from the independent research institute Auriga Nusantara, which shows an increase of 66% compared to 2024 (261,575 hectares) [3]. One animal highly dependent on natural forest habitat is the Sumatran elephant (*Elephas*

maximus sumatranus), which is currently listed as critically endangered by the International Union for Conservation of Nature. [4].

Land cover change is a form of land use transformation from natural conditions to non-forest areas, generally caused by human activities [5]. Deforestation and habitat fragmentation not only reduce the size of animal ranges but also impact the availability of food, water sources, movement space, and habitat microclimate conditions [6]. These conditions can indirectly affect animal physiology, including health, behavior, stress levels, daily activity, and the ability to adapt to their environment. In large animals such as the Sumatran elephant, alterations in their living environment can cause ecological stress, which affects the body's internal balance.

The North Sumatra Holiday Resort Nature Tourism Park (Indonesian term: *Taman Wisata Alam* Holiday Resort/TWAHR) functions as a conservation area, playing an important role in providing a habitat and serving as a training center for Sumatran elephants [7]. This region possesses distinctive features because of its position in an area with considerable human activity, including plantations, farming, human dwellings, and transportation networks that pass through the forested land. Studies have indicated that the TWA Holiday Resort area has seen major changes in land cover over the last several decades, primarily caused by human activities and inadequate management of the conservation forest region [8].

Studies have indicated that over a period of 30 years, there has been significant deforestation in the TWAHR region, where a large portion of the forest has been transformed into plantations and residential zones. This condition interferes with the area's ability to support its natural ecosystems and may lead to a decline in the quality of the habitat that the Sumatran elephants depend on. Decreased habitat quality can lead to changes in activity patterns, decreased body condition, increased stress, and even health problems in wildlife [9]. Therefore, land cover change is a crucial factor that needs to be studied in sustainable Sumatran elephant conservation efforts.

Physiologically, Sumatran elephants are highly dependent on stable and natural habitat conditions [10]. The availability of food vegetation, water sources, shelter, and adequate roaming space significantly impacts elephant health. Habitat disturbance due to land cover change can trigger physiological changes such as decreased body condition, altered eating patterns, behavioral disorders, increased stress hormones, and changes in daily activity. The physiological condition of animals includes the body's ability to maintain stability (homeostasis), regulate body temperature (thermoregulation), and manage stress levels in the face of natural changes [11]. Non-invasive observation of animal physiological conditions is an effective approach to understanding the impact of environmental change on the health of conservation animals.

In addition to impacting animal health, changes in land cover can also increase the risk of human-elephant conflict. The reduction in natural habitat causes elephants to more frequently enter plantations and residential areas in search of food and water sources [12]. This situation not only harms the community but also increases pressure on the Sumatran elephant population in the wild. Therefore, information on the relationship between land cover changes and the physiological condition of Sumatran elephants is crucial as a basis for habitat management and the development of more effective conservation strategies.

To date, research on the relationship between land cover changes and the physiological condition of Sumatran elephants in the TWAHR, North Sumatra, is still very limited. Most previous studies have focused on deforestation, anthropogenic factors, and conservation area management [13], [14]. Therefore, this study was conducted to analyze the relationship between the physiological condition of Sumatran elephants and land cover in the TWAHR, North Sumatra.

2. Methods

This research was conducted in the Holiday Resort Nature Tourism Park area in Torganda Village, Torgamba District, South Labuhanbatu Regency, North Sumatra Province (Figure 1). Based on Decree Number 3913/Menhut-VII/KUH/2014 dated May 14, 2014, with an area of 2,100.42 hectares.

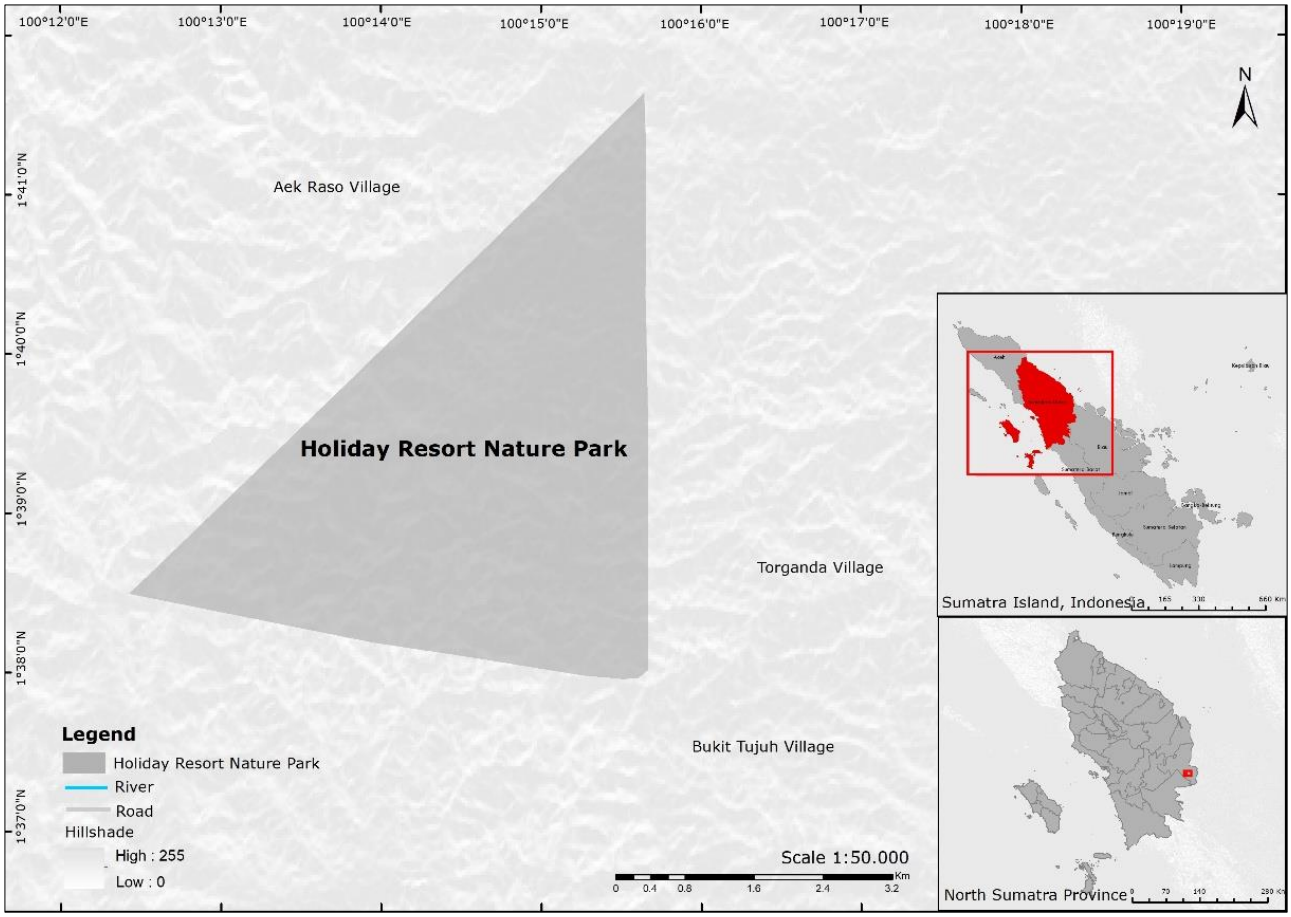

Figure 1. Map of the Research Site Location, geographically located at 1°41'37.5"-1°38'12.5" N and 100°15'39.8"-100°12'35.0" E.

2.1. Population and Sample

The population in this study consisted of all Sumatran elephants (*Elephas maximus sumatranus*) residing at the North Sumatra Holiday Resort Nature Reserve (TWA), along with all land cover classes within the area. The population consisted of three elephants: Nurhalimah (♀/±45 years), Sudarwanto (♂/19 years), and Merry (♀/±35 years). These three individuals were selected purposively because they were the only elephants present at the study site and could be observed for their physiological condition and daily activities.

2.2. Data Collection and Analysis Techniques

The data collected in this study consisted of data on the elephants' physiological condition and land cover (Table 1). Data on the elephants' physiological condition was obtained through direct observation, daily records, interviews with mahouts/managers, and non-invasive visual inspection. Parameters observed included sex, age, body temperature, body condition, appetite, fecal matter, rest duration, roaming activity, and stress levels.

Table 1. Research Variables

No	Component	Variables	Indicator
1	Variable X	Physiological condition of Sumatran elephants	Age, body temperature, body condition, appetite, fecal condition, daily activity, resting period, stress level
2	Variable Y	Land cover	Hp/2001: Secondary Dryland Forest, Br/20071: Swamp Shrub, T/2014: Open Land, Pk/2010: Plantation, Pm/2012: Settlement/Land Construction, Pt/20091: Agriculture on Dryland

Land cover data were obtained through interpretation of satellite imagery, area maps, secondary data from area managers, and ground checks. The land cover classes observed included secondary dryland forest, swamp

scrub, open land, plantations, settlements/built-up land, and dryland agriculture. The data were then analyzed to determine land cover changes and their relationship to elephant physiological conditions.

2.3. Data Analysis Method

Data were analyzed using multiple linear regression, a descriptive and inferential statistical method used to determine the relationship between more than two research variables [15]. This analysis was used to examine the influence of several land cover indicators on the physiological conditions of Sumatran elephants.

The analysis stages included classical assumption tests, hypothesis tests, and model interpretation. Classical assumption tests included tests for normality, multicollinearity, heteroscedasticity, and autocorrelation. The multiple linear regression model that can be used is:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + e \quad (1)$$

Notes:
Y = Land Cover Change
a = Constant
b_1–b_6 = Regression coefficient
X_1 = Age
X_2 = Body Temperature (°C)
X_3 = Body Condition
X_4 = Appetite
X_5 = Fecal Condition
X_6 = Daily Activity
X7 = Resting Period
X8 = Stress Level
e = Error

The analysis results were used to determine which land cover class was most related to the physiological condition of Sumatran elephants at the TWAHR.

3. Result and Discussions

3.1. Land Cover Change

The results of the land cover change analysis indicate that the TWAHR area experienced significant changes during the period 1990–2024. At the initial observation, the area was dominated by secondary dryland forest, which served as a natural habitat for various wildlife, including the Sumatran elephant (*Elephas maximus sumatranus*). However, with increasing anthropogenic activity, much of the area was converted to non-forestry land uses such as plantations, agriculture, and settlements.

According to research, the area of secondary dryland forest that experienced deforestation reached 2,079.34 ha. A small portion was converted to swamp scrubland, covering 30.5 ha (1.5%), while the majority was converted to non-forest land cover, covering 2,048.8 ha (98.6%). The largest forms of change were plantations, covering 1,990.8 ha (95.7%), and settlements, covering 57.8 ha (2.8%). Classification of land cover classes at the TWAHR. The Elephant Training Center utilized Landsat 5 satellite images from the years 1990, 1996, 2000, 2003, 2006, 2009, and 2012, and Landsat 8 images from 2015, 2019, and 2024 (Table 2).

Table 2. Area of Land Cover Change

No	Year	Layer/Area Code (Ha)											
		Hp/ 2001	%	Br/ 20071	%	T/ 2014	%	Pk/ 2010	%	Pm/ 2012	%	Pt/ 20091	%
1	1990	2079.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	1996	2079.3	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
3	2000	0	0.0	52.0	2.5	1959.0	94.2	59.2	2.8	9.0	0.4	0	0.0
4	2003	0	0.0	52.0	2.5	1958.1	94.1	59.2	2.8	9.7	0.4	0	0.0
5	2006	0	0.0	52.0	2.5	1954.6	94.0	59.2	2.8	13.2	0.6	0	0.0
6	2009	0	0.0	52.0	2.5	0.0	0.0	59.2	2.8	19.9	0.9	1947.9	93.6
7	2012	0	0.0	52.0	2.5	0.0	0.0	59.2	2.8	37.6	1.8	1930.2	92.8
8	2015	0	0.0	52.0	2.5	0.0	0.0	1982.6	95.3	44.4	2.1	0	0.0
9	2019	0	0.0	30.5	1.5	0.0	0.0	1990.8	95.7	57.8	2.8	0	0.0
10	2024	0	0.0	30.5	1.5	0.0	0.0	1990.8	95.7	57.8	2.8	0	0.0

Description:
Hp/2001 : Secondary Dryland Forest
Br/20071 : Swamp Scrub
T/2014 : Open Land
Pk/2010 : Plantation
Pm/2012 : Settlement/Built-Up Land
Pt/20091 : Dryland Agriculture

The total area of the TWAHR, calculated using the Conservation SHP Map provided by the Ministry of Environment and Forestry, is 2,079,342 hectares. This data differs slightly from the document SK.3913/Menhut-VII/KUH/2014 dated May 14, 2014, which specifies an area of 2,100.42 hectares. Based on land cover data from the years 1990 to 2020, six distinct types of land cover were identified, each with varying areas recorded for every year. Land cover from 1990 to 1998, with an area of 2079,342 (100.00%), was still in the form of secondary dryland forest. Secondary dryland forests are all lowland, hill, and mountain forest features that show signs of logging (grooves and logging scars), including dwarf forests, heath forests, forests on limestone, forests on ultrabasic rock, coniferous forests, deciduous forests, and moss forests [16]. Abandoned slash-and-burn forest areas, areas that have been burned, or areas that have regrown from degraded land are also included in this category. Severely logged areas that are not HTI (industrial timber plantations), plantations, or agricultural areas are categorized as savanna, scrubland, or open land.

Furthermore, at the beginning of the 1998 reforms, significant land cover changes occurred in 2020, with swamp scrubland or the PLG core zone covering 52 ha (2.5%), open land 1,959.0 ha (94.8%), plantations 59.2 ha (2.4%), and settlements 9.0 ha (0.4%). The most extensive conversion of secondary dryland forest to open land due to encroachment by communities and conversion to plantations by companies. Open land is defined as all open land features devoid of vegetation (rock outcrops, snow-capped peaks, volcanic craters, sandbars, beach sand, river sediments) and open land affected by fires [16]. Open land features for mining are classified as mining, while open land from land clearing is categorized as open land. Open land within the framework of rice paddy/pond crop rotation remains classified as rice paddy/pond.

Furthermore, until 2009, there was a change in land cover classification from open land to dryland agriculture. The remaining settlement area continued to increase, from 9 hectares (0.4%) in 2000 to 37.6 hectares (1.8%) in 2012. Settlements are residential areas, whether urban, rural, industrial, or otherwise, that exhibit dense land use patterns [16]. Following the issuance of the 2014 Decree and subsequent community conflicts over the area, land cover changes were observed in 2019, with plantations covering 1,990.8 hectares (95.7%), settlements 57.8 hectares (2.8%), and swamp scrub 30.5 hectares (1.5%). Plantations comprise all plantation areas, whether planted or unplanted (still vacant land). Identification can be obtained from plantation distribution maps (large plantations) [16].

The remaining area is now the Elephant Training Center and the TWA Resort office, which is currently maintained at only 1.4%, which is a very ironic thing. The land cover classification in this area is classified as swamp scrub. Swamp scrub is an area of former swamp forest/mangrove that has grown back, or an area with sparse tree coverage (natural) or an area with low vegetation dominance (natural). This area usually no longer shows any signs of logging [16].

3.2. Physiological Condition of Sumatran Elephants (Elephas maximus sumatranus)

Animal physiological condition is an important indicator in assessing their health, well-being, and adaptability to changes in their habitat. In this study, physiological responses were measured on three individual Sumatran elephants (*Elephas maximus sumatranus*) at the TWAHR. These parameters included body temperature, body condition, appetite, fecal matter, daily activity, rest duration, and stress levels.

Table 3. Physiological Condition of Sumatran Elephants (*Elephas maximus sumatranus*)

No	Elephant Name	Gender/ Age	Body Temperature (°C)	Body Condition	Appetite	Fecal Condition	Daily Activities	Rest Period	Stress Level
1	Nurhalimah	♀ / ±45 th	36,2	3	Good	Normal density	Moderately active	5 hours/ days	Low
2	Sudarwanto	♂ / 19 th	36,8	4	Very Good	Normal	Very active	4 hours/ days	Medium
3	Merry	♀ / ±35 th	36,4	3	Good	A little soft	Moderately active	6 hours/ days	Low

Based Table 3 on physiological observations of three Sumatran elephants (*Elephas maximus sumatranus*) at the TWAHR, it was found that all individuals had body temperatures within the normal range for Asian elephants, namely between 36.2–36.8°C. Nurhalimah's body temperature was 36.2°C, Merry's was 36.4°C, and Sudarwanto's was 36.8°C. The normal body temperature of an elephant ranges from 35.9–37.5°C, so the values obtained indicate that all three individuals were in a stable physiological condition [17]. This condition indicates that the body's thermoregulatory mechanisms are still functioning well despite the significant changes in land cover in the TWAHR habitat [18]. Normal body temperatures also indicate no indication of serious health problems related to infection or acute physiological stress [19].

According to the Body Condition Score, Sudarwanto achieved the highest score of 4, whereas Nurhalimah and Merry each received a score of 3. A BCS score ranging from 3 to 4 signifies good to excellent body condition, which means the animal has sufficient fat stores and well-developed muscle structure [20]. Sudarwanto's higher BCS score is believed to be connected to his young age, which is still within a productive range, his high level of activity, and his greater efficiency in acquiring and using food compared to others. This is supported by observations of appetite, which showed that Sudarwanto had a very good appetite, whereas Nurhalimah and Merry had a good appetite. Adequate food supply is essential for keeping elephants' energy levels stable, supporting their reproductive health, and ensuring their body functions work properly over time (Figure 2).

(a) (b) (c)

Figure 2. Elephants in the TWA area: (a) Nurhalimah, ±45 years old; (b) Sudarwanto, 19 years old; (c) Merry, ±35 years old

Fecal condition plays a significant role in evaluating the digestive health of elephants. The observations indicated that Nurhalimah and Sudarwanto had regular stools with a firm consistency, whereas Merry's stools were somewhat softer. Normal feces indicate that the digestive system is working properly and that the food provided is suitable for the animal's requirements [21]. Merry's somewhat loose stools may be due to the type of food she's eating, the increased moisture in her feed, or her overall health状况. However, if the condition is not accompanied by other symptoms like reduced appetite, dehydration, or marked changes in behavior, it can still be regarded as within normal bounds. The findings suggest that all three elephants typically maintain healthy digestive systems.

Daily activity, rest duration, and stress levels show differences between the individual elephants. Sudarwanto is highly active, with a rest period of 4 hours per day and moderate stress levels, while Nurhalimah and Merry are classified as moderately active, with rest periods of 5 and 6 hours per day, respectively, and low stress levels. Elephants spend most of their time foraging and moving around [22]. Sudarwanto's high activity is thought to be influenced by his younger age and his male gender, which tends to be more mobile than females. In general, all three individuals still exhibited good physiological condition, although habitat changes and human activity in the surrounding area have the potential to increase stress levels in the long term.

3.3. Relationship between Land Cover Change and Physiological Responses of Sumatran Elephants

The analysis of the relationship between Land Cover Change and Physiological Responses of Sumatran Elephants is needed to draw valid conclusions. Therefore, conclusions will be drawn by examining the notes during the analysis and recognizing procedures, topics, principles, relationships, and similarities in order to reach conclusions. Based on the assessment results, before the ANOVA test, a classical assumption test was conducted to ensure compliance with the ANOVA test (Table 4).

Table 4. Results of the Anthropogenic F-Test on Deforestation

No	ANOVA[a]					
	Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	182.191	7	26.027	8.767	.000[b]
2	Residual	65.309	22	2.969		
	Total	247.5	29			

a. Dependent Variable: Perubahan Tutupan Lahan
b. Predictors: (Constant), Feces Level, Feces Condition, Appetite, Age, Body Temperature, Body Condition, Length of Rest

Table 5. Results of the Anthropogenic T-Test on Deforestation

No	Coefficients[a]					
	Model	**Unstandardized B**	**Coefficients Std. Error**	**Standardized Coefficients Beta**	**t**	**Sig.**
1	(Constant)	-237.388	193.371		-1.228	0.233
2	Age	0.018	0.069	0.067	0.266	0.792
3	Body Temperature	6.776	5.583	0.607	1.214	0.238
4	Body Condition	-3.406	4.124	-0.559	-0.826	0.418
5	Appetite	-2.566	1.522	-0.584	-1.686	0.106
6	Feces Level	1.075	1.128	0.306	0.953	0.351
7	Long Break	0.93	2.123	0.317	0.438	0.666
8	Fecal Level	3.402	1.014	1.12	3.355	0.003

a. Dependent Variable: Land Cover Change

Based on Table 5, the regression equation is as follows:

Y = -234.338 + 0.067 X1 + 0.607 X2 - 0.559 X3 - 0.584 X4 + 0.306 X6 + 0.317 X7 + 1.120 X8,Errorvar = 0.348, and Adjusted R-square = 0.652.

The F-test results show that the variables age, body temperature, body condition, appetite, fecal matter, rest duration, and stress level simultaneously significantly influence land cover change, with a significance value of 0.000 ($p<0.05$). The Adjusted R-square value of 0.652 indicates that the observed physiological variables can explain 65.2% of the variation in land cover change, while factors outside the research model influence 34.8%. This indicates that the physiological condition of Sumatran elephants is strongly related to habitat changes occurring at the TWAHR.

The t-test results showed that only stress level significantly influenced land cover change, with a significance value of 0.003 and a beta coefficient of 1.120. Meanwhile, age, body temperature, body condition, appetite, fecal matter, and rest duration did not show a significant effect ($p>0.05$). This finding suggests that land cover change significantly impacts animal behavior and welfare, as reflected in stress levels, rather than baseline physiological conditions, which remain relatively stable due to intensive elephant management and care.

Land cover change plays a significant role in influencing the quality of wildlife habitats, including that of the Sumatran elephant (*Elephas maximus sumatranus*). The decrease in forest area caused by changing land use leads to a reduction in the availability of natural food, water sources, shelter, and space for movement [23]. These conditions may change how elephants behave and lead to higher stress levels in their environment. Therefore, changes in habitat are typically a main reason for physical and behavioral issues in elephant groups that reside in areas that have been broken up.

The findings indicated that stress level was the only factor that had a significant impact on changes in land cover. These findings are consistent with existing research that indicates habitat destruction and greater human presence can lead to higher levels of stress hormones in elephants [24]. Habitat fragmentation leads to animals losing their natural habitats, which increases the chances of them coming into contact with humans and results in higher levels of mental stress. This condition can affect how animals behave on a daily basis, how they move around, and their overall well-being over time.

The small changes in body temperature, body condition, appetite, fecal consistency, and time spent resting suggest that the elephants' overall health is still within normal ranges. Elephants that have enough food, consistent medical care, and proper management are able to keep their body functions stable even when the environment changes [24]. This matches the situation at the TWAHR, where the elephants seen were wild elephants that were regularly supervised and cared for by the local management team.

The adjusted R-squared value of 65.2% suggests that a significant portion of the changes in land cover can be attributed to the physiological variables that were measured, especially stress levels. However, 34.8% of the variation is still accounted for by factors not included in the model. According to Sahusilawane (2025), factors like the level of human activity, noise, habitat fragmentation, the availability of natural food sources, the quality of vegetation, and social disruptions within elephant groups also significantly influence how animals respond to changes in their habitat [25]. Conservation of Tropical Forest Biodiversity. Therefore, conservation initiatives must not only prioritize the well-being of individual elephants but also aim to rehabilitate their natural habitats and decrease human-related impacts in the region.

This observation shows that stress serves as the most sensitive indicator of physiological change when there are alterations in habitat, highlighting how easily elephants are affected by environmental changes caused by changes in land cover. In contrast, factors like age, body temperature, general physical health, appetite, the quality of feces, and periods of rest did not show any major changes, indicating that key bodily functions stayed consistent even though the habitat changed. This observed trend could be the result of careful management and consistent care given to the elephants, which probably reduce the impact of environmental changes on their general health. As a result, stress levels can act as an early warning sign for habitat degradation, highlighting their importance in monitoring the ecological effects of changes in land cover and supporting effective conservation management at the TWAHR in North Sumatra.

4. Conclusions

The physiological condition of Sumatran Elephants (*Elephas maximus sumatranus*) was significantly associated with land cover changes in the TWA Holiday Resort, North Sumatra ($p < 0.05$). The adjusted R^2 value of 0.652 indicates that the physiological variables explained 65.2% of the variation in land cover changes. Among these variables, only stress level showed a significant effect ($p = 0.003$; $\beta = 1.120$), whereas age, body temperature, body condition, appetite, fecal condition, and rest duration were not significant. These findings identify stress level as the most sensitive physiological indicator associated with land cover changes.

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