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An Extensive Coverage Anoa Distribution Modelling in Sulawesi Using Maximum Entropy

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ABSTRACT

As an endangered species, Anoa (*Bubalus depressicornis* and Mountain *Bubalus quarlesi*) inhabiting the Sulawesi island requires proper conservation both in and out of their native habitat. The study of anoa habitat is mainly conducted through field studies based on firsthand observations of anoa appearance, footprints, or excrement or through social surveys from residents who saw it directly. The studies are carried out specifically in a particular area with a relatively narrow. However, in practice, this method has limitations, such as the research location determined based on the possibility of anoa, limited research area, and inefficient use of resources. Therefore, this study aimed to model the potential habitat of anoa in the whole of Sulawesi island. This study was based on physical and environmental independent variables such as DEM, surface slope, LST, NDVI, and access to inland water, as well as in-situ species distribution retrieved from scientific papers and reports. This study discovered the likely anoa distribution on Sulawesi island, both inside and outside of its native habitat. LST is the most important independent variable in determining habitat suitability, accounting for 80% of the total, followed by water (15.3%), NDVI (2.9%), DEM (1.6%), and slope (0.3%).

1. Introduction

Wallacea is a region in Indonesia that is recognized for its biodiversity. It is a biogeographical term for a group of islands separated from Asia and Australia's continents, surrounded by a variety of ocean basins, such as the Banda Sea, the Molucca Sea, the Java Sea, the Flores Sea, and the Straits of Makassar. The area has a particular fauna (also fauna) that combines Asian and Australasian animals due to its geographical isolation. As part of the Wallacea area, the island of Sulawesi offers a range of unique fauna species that only exist in this area (WWF 2021). Sulawesi is the home of Anoa: Lowland (*Bubalus depressicornis*) and Mountain (*Bubalus quarlesi*), classified as endangered endemic wildlife because of its small populations of less than 2,500 adult individuals and a 20% loss rate over the last 14 to 18 years (Arini *et al.* 2020; Burton *et al.* 2016a, 2016b). Anoa habitat research is mainly conducted through field studies based on firsthand observations of anoa appearance, footprints, or excrement or through social surveys from residents who saw it directly. The studies are carried out specifically in a particular area with a relatively narrow area (Arini 2013; Burton *et al.* 2005, 2016a, 2016b; Priyono *et al.* 2020; Ranuntu and Mallombasang 2015; Wardah *et al.* 2012). However, in practice, this method has limitations, such as the research location determined based on the possibility of anoa (no exploration outside the native habitat), limited research area, and inefficient use of resources (time and expense). Therefore, this study aims to model the potential habitat of anoa in the whole of Sulawesi Island, not only in their native habitat but also outside. *Ex-situ* conservation will be possible once new areas outside of native habitats are discovered. This study was based on physical and environmental independent variables and *in-situ* species distribution retrieved from open and public data sources.

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2. Materials and Methods

This study focuses on a large area of Sulawesi (01.7°N- 05.8°S and 112.7°E to 125.3°E). It is the world's eleventh-largest island (180,680.7 km^2), situated east of Borneo, west of the Maluku Islands, south of Mindanao, and north of the Lesser Sunda Islands. This area has a maximum altitude of 3,478 m m above sea level, which is administratively in a part of six provinces: Gorontalo, West Sulawesi, South Sulawesi, Central Sulawesi, Southeast Sulawesi, and North Sulawesi, as presented in Figure 1.

2.1. Data Sources

The data used in this study were a) physical topographic data: Digital Elevation Model (DEM) and surface slope; b) environmental data: Land Surface Temperature (LST), Normalized Different Vegetation Index (NDVI), and in-land water (lake and rivers); and c) *in-situ* species data. The DEM was derived from a 30 m Shuttle Radar Topography Mission (SRTM) data mosaic. SRTM mission was run from 11 to 22 February in 2000 (it was a one-off mission, with no update data after this date) as a joint operation of the National Aeronautics and Space Administration

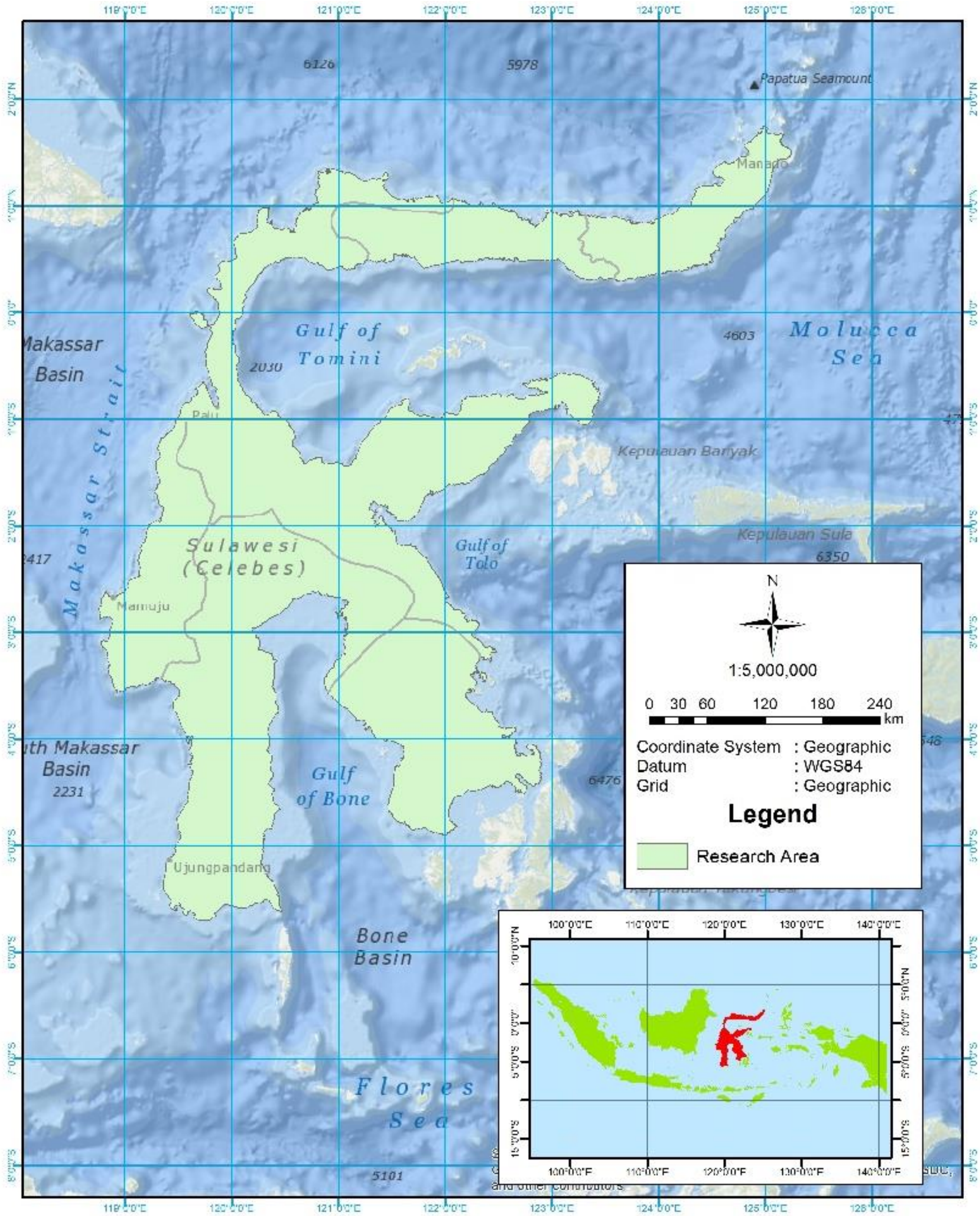

Figure 1. Research Area, Sulawesi Island

(NASA), the National Geospatial-Intelligence Agency (NGA), the German and Italian Space Agencies. The main objective of this mission was to acquire a DEM of all land between latitudes 60 N and 56 S, about 80% of the Earth's land surface (NASA 2008; Rabus *et al.* 2003). SRTM data are organized into individual rasterized cells of 1, 3, or 30 arcsec (roughly 30 m, 60 m, and 90 m in the equator). This data was used for purposes as diverse as geology, geomorphology, water resources and hydrology, glaciology, evaluation of natural hazards, and vegetation surveys (Yang *et al.* 2011). In this study, an SRTM 30 m was used as elevation and a source of surface slope data, retrieved and processed in Google Earth Engine (Farr *et al.* 2007; Google Earth Engine 2021c). The LST used in this study was the MOD11A1 Version 6 product that provides daily per-pixel LST and Emissivity with 1 km spatial resolution retrieved from a dataset of Google Earth Engine (Google Earth Engine 2021b; USGS 2021). NDVI used in this study was Landsat 8 Collection 1 Tier 1 composite from the computed top-of-atmosphere (TOA) reflectance based on Chander (Chander *et al.* 2009). These composites were created from all the scenes every 32 days and retrieved from Google Earth Engine (Google Earth Engine 2021a). At the same time, water data were retrieved from Indonesia Geospatial Portal run by Geospatial Information Agency (BIG) (BIG 2021). The in-situ data were retrieved from scientific papers and reports, as presented in Table 1.

Table 1. The source of *in-situ* species distribution

Species	Longitude (°)	Latitude (°)	source
bubalus depressicornis	122.12180	-4.49525	(Analuddin *et al.* 2016)
bubalus depressicornis	120.52510	-1.58031	(Ranuntu and Mallombasang 2015)
bubalus depressicornis	120.52360	-1.57728	(Ranuntu and Mallombasang 2015)
bubalus depressicornis	120.51810	-1.56668	(Ranuntu and Mallombasang 2015)
bubalus quarlesi	120.51870	-1.57008	(Ranuntu and Mallombasang 2015)
bubalus quarlesi	120.04250	-0.80722	(Wardah *et al.* 2012)
bubalus quarlesi	120.04050	-0.81842	(Wardah *et al.* 2012)
bubalus quarlesi	120.04510	-0.80831	(Wardah *et al.* 2012)
bubalus quarlesi	120.21340	-1.52712	(Stephens 2014)
bubalus quarlesi	120.00920	-1.68975	(Stephens 2014)
bubalus quarlesi	123.80960	0.47658	(Arini 2013)
bubalus quarlesi	123.80990	0.46652	(Arini 2013)
bubalus quarlesi	121.00570	0.60439	(Allo *et al.* 2018)
bubalus quarlesi	120.00180	-0.82303	(Valentino 2013)
bubalus quarlesi	120.01500	-0.80661	(Valentino 2013)
bubalus quarlesi	120.03370	-0.83094	(Valentino 2013)
bubalus quarlesi	120.01270	-0.82683	(Valentino 2013)
bubalus depressicornis	123.76800	0.51530	(Burton *et al.* 2005)
bubalus depressicornis	122.61000	0.62516	(Burton *et al.* 2005)
bubalus depressicornis	120.21500	-1.55003	(Burton *et al.* 2005)
bubalus depressicornis	120.79300	0.66886	(Burton *et al.* 2005)
bubalus depressicornis	119.61900	-1.30254	(Burton *et al.* 2005)
bubalus quarlesi	120.77800	-2.20443	(Burton *et al.* 2005)
bubalus quarlesi	120.96800	-1.69737	(Burton *et al.* 2005)
bubalus depressicornis	122.06100	-1.13299	(Burton *et al.* 2005)
bubalus quarlesi	120.97300	-2.39240	(Burton *et al.* 2005)
bubalus quarlesi	119.87400	-3.07609	(Burton *et al.* 2005)
bubalus depressicornis	121.87800	-4.45523	(Burton *et al.* 2005)
bubalus depressicornis	122.80600	-4.20800	(Burton *et al.* 2005)
bubalus depressicornis	122.87000	-4.35533	(Burton *et al.* 2005)
bubalus depressicornis	122.72800	-4.47538	(Burton *et al.* 2005)

2.2. Methodology

This modeling used Maxent software—a machine-learning technique based on Maximum Entropy Modelling. Maxent's goal is to find the distribution with the highest entropy and then constrain the expected value of each feature under this estimated distribution to match the empirical average. (Phillips 2017; Phillips *et al.* 2006; Phillips and Schapire 2004).

There are two kinds of data used in this study: a) dependent variable (*in-situ* species distribution) as presented in Table 1, and b) independent variable (DEM, Slope, LST, NDVI, and Waters). The dependent data were directly retrieved from scientific papers (Allo *et al.* 2018; Analuddin *et al.* 2016; Burton *et al.* 2005; Ranuntu and Mallombasang 2015; Wardah *et al.* 2012) and reports (Arini 2013; Valentino 2013; Stephens 2014), and then stored in comma-separated values format (.csv) file. At the same time, the dependent one needs some pre-processing. DEM was retrieved from GEE categorized into five classes for a specific range of data and. The slope was calculated from DEM, then categorized into four classes. LST was retrieved from GEE, then categorized into four classes. NDVI was retrieved from GEE, then categorized into five classes. Waters are inland water bodies, including rivers and lakes, retrieved from Indonesia National Geoportal. A Euclidian distance from water data was calculated and stored in raster format. It was also categorized into five classes. All independent data were categorized based on their range of data as presented in Table 2, then converted into ASCII format (.asc) as required by MaxEnt Figure 2. Based on the data source, this modeling produced an anoa suitability habitat map on a medium scale (1:60,000).

Table 2. Environmental variables and their classes

Variables	Pixel size (m)	Source	Class	Range data
DEM (m)	30	Shuttle Radar Topography Mission (SRTM)	1	0–1,000
			2	1,000–1,500
			3	1,500–2,000
			4	2,000–2,500
			5	>2,500
Slope (%)	30	Processed from (1)	1	0–8
			2	8–25
			3	25–40
			4	40–100
LST (°C)	100 (reduce to 30)	MOD11A1 Version 6 product	1	<20
			2	20–25
			3	25–30
			4	>30
NDVI	30	Landsat 8 Collection 1 Tier 1 8-Day NDVI Composite	1	(-0.4)–0
			2	0–0.25
			3	0.25–0.5
			4	0.5–0.75
			5	0.75–1
Waters(m)	30	Geospatial Information Agency (BIG)	1	0–500
			2	501–1,000
			3	1,001–1,500
			4	1,501–2,000
			5	2,001–15,300

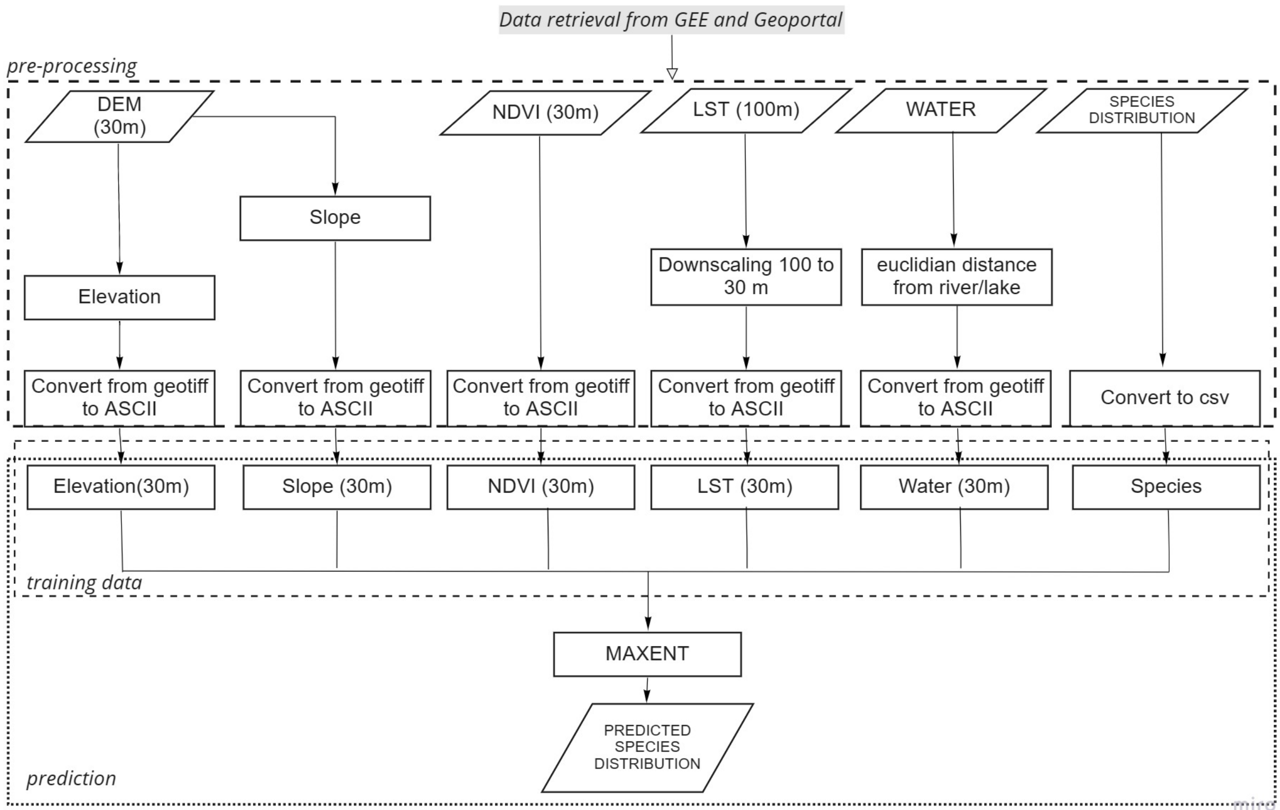

Figure 2. Processing flow-chart

3. Results

Even though two species of anoa are employed in this modeling (mountain and lowland), the modeling was performed simultaneously with no distinction between species. Figure 3 presents the potential distribution of anoa in Sulawesi. There is a likelihood of finding a suitable region to be inhabited or that is currently the original habitat of anoa in areas with a probability of more than 50%. This area stretches across the island's highland. The response of independent variables (DEM, Slope, LST, NDVI, and Waters) was presented in Figure 4. The presence of anoa was most common between 1,500 and 2,000 m (class 3) and was least common below 1,000 m (class 1). Temperatures of >20 (class 1) and 20-25 (class 2) are the best for the existence of anoa. Anoa lived in a sparsely vegetated habitat (class 2). Anoa was not impacted by land slope changes and was located near a water supply (less than 500 m from a river or lake) (class 1).

Physical and environmental variables that most affect anoa habitat's suitability were land surface temperature (LST) and the distance to water sources with a percent contribution of 80% and 15.3%, respectively Table 3. In contrast, vegetation cover (NDVI), land elevation (DEM), and slope did not highly affect the suitability. Figure 5 describes the contribution of each variable and cross contribution with other variables. LST produced the most contribution if only LST was used for modeling, and the contribution declined to the lowest if this variable was not included. Simultaneously, if the slope variable was not included, this variable contributes the most, and if only this slope was utilized, it contributes the least.

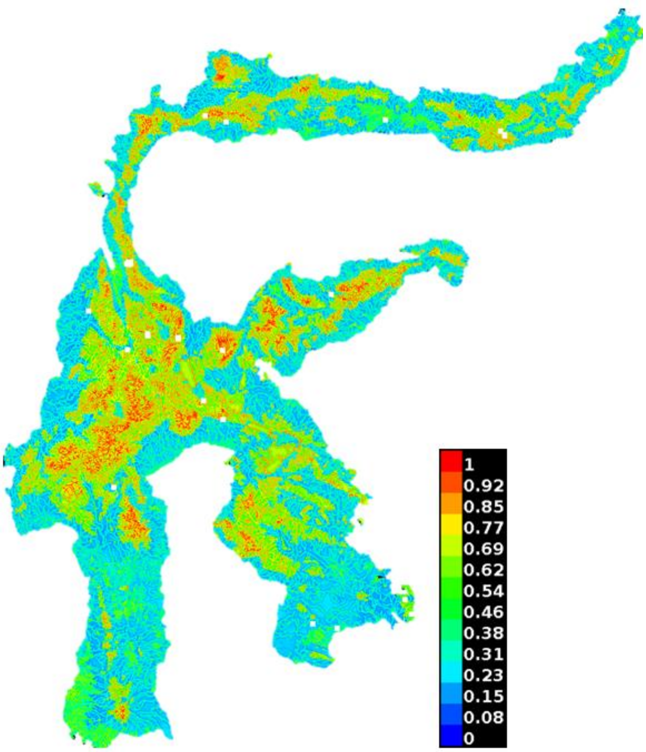

Figure 3. Predicted species distribution

4. Discussion

4.1. New Distribution Model

The new distribution map modeled by physical and environmental parameters such as DEM, Slope, LST, NDVI, and Waters as well as *in-situ* species distribution data collected from scientific and governmental reports, promise more promising results in the term scale (1:60,000) and coverage (169,046 km^2). Figure 6A presented a species distribution map filtered by a minimum 50% possibility. This area covered an area of 67438.4 km^2 (40% of the total area of Sulawesi). A potential improvement will be performed by modeling with more independent environmental parameters primarily related to human-induced that negatively impact anoa habitat.

Table 3. Variable contribution to the model

Variable	Percent contribution	Permutation importance
lst_terra	80.0	73.8
waters	15.3	15.8
ndvi	2.9	2.4
dem	1.6	1.7
slope	0.3	6.5

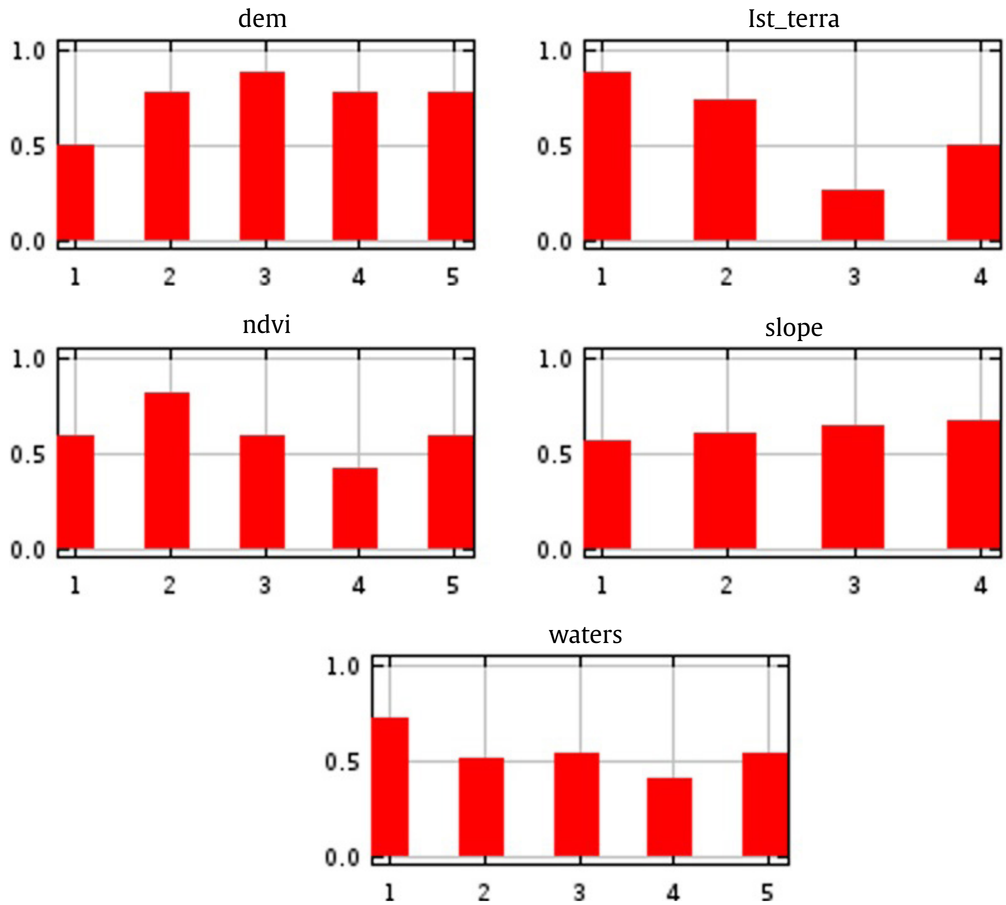

Figure 4. Response curves

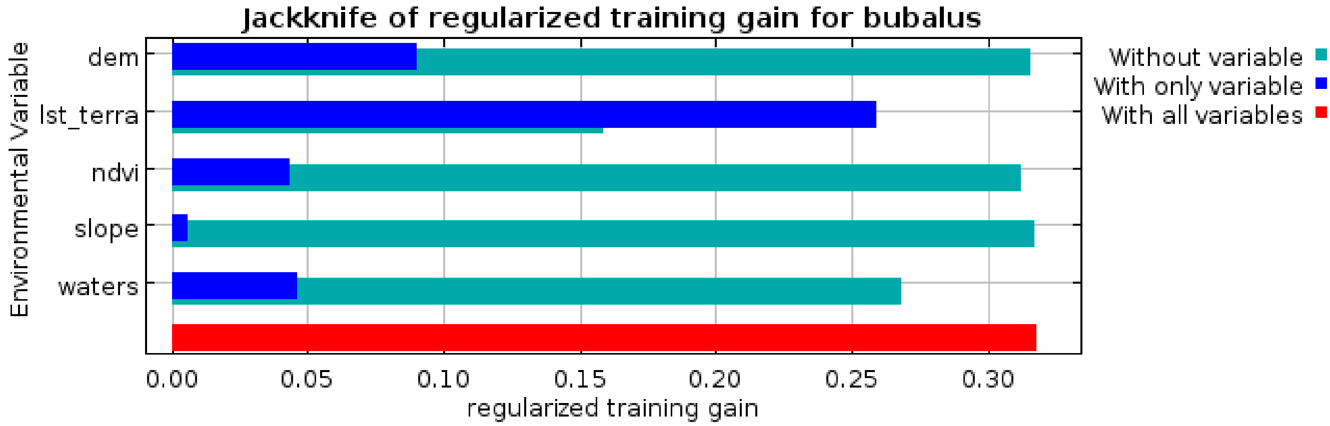

Figure 5. Jackknife of training gain for anoa

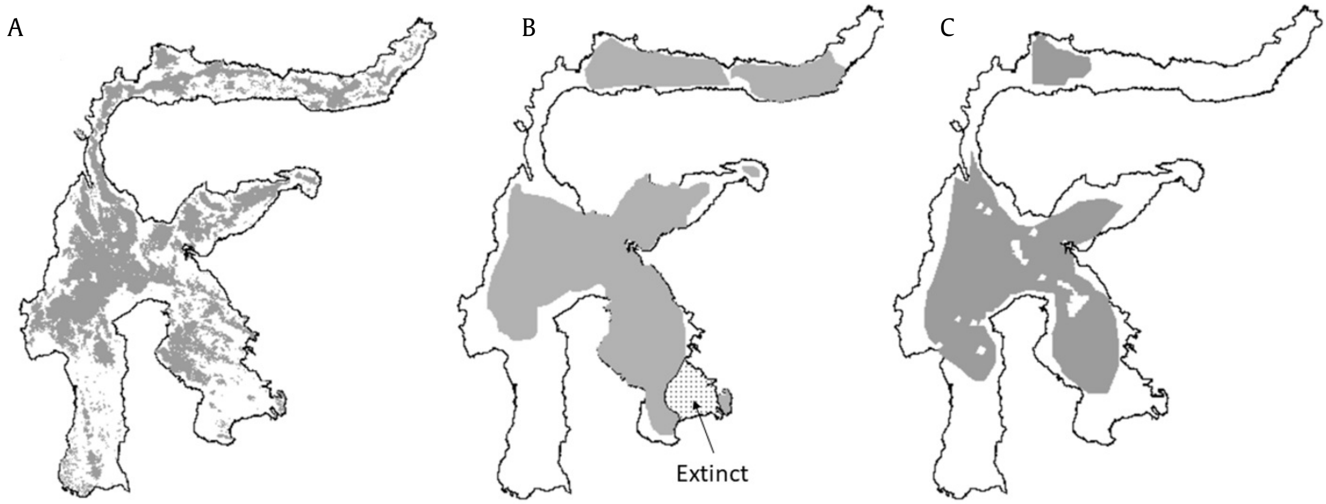

Figure 6. Anoa prediction: (A) *Bubalus depressicornis* and quarlesi (this study), (B) *Bubalus depressicornis* (IUCN 2016), (C) *Bubalus depressicornis* (IUCN 2016), *Bubalus quarlesi* (IUCN 2016)

4.2. Validation

The International Union for Conservation of Nature (IUCN) distribution model of Bubalus depressicornis (Burton *et al.* 2016a), and *Bubalus quarlesi* (Burton *et al.* 2016b) in Figure 6B and C, is more likely to have similar patterns and areas. *Bubalus quarlesi* and *Bubalus depressicornis* were predicted to inhabit or be suitable in 70,967.1 km^2 and 97,800.7 km^2, respectively. This area was more expansive than the predicted area in this study. The predicted area also has a corridor that connects central Sulawesi with northern Sulawesi, which was not in the previous study. Bubalus depressicornis has a possible extinct area in South-eastern Sulawesi, the overlap with the new distribution model shown in Figure 7. The predicted area did not exist in the extinct area of IUCN and existed in the east area where both models (new distribution map and IUCN model). In Figure 8, the new distribution model covered the original habitat of anoa in the Taman Nasional Gandang Dewata (TNGD) forest area. We also found an existing anoa footprint in the predicted model.

4.3. Limitation

Anoa distribution models were developed utilizing 31 in situ dataset points gathered over a lengthy period: 2005 (14 points), 2012 (5), 2013 (4), 2014 (2), 2015 (4), 2016 (1), and 2018. (1). Over time, the existence of anoa might alter owing to shifts in location or probably become extinct.

In conclusion, Anoa is a threatened species that must be conserved. Anoa protection is accomplished by conserving the anoa inside and outside its native environment. Because the presence of anoa in its

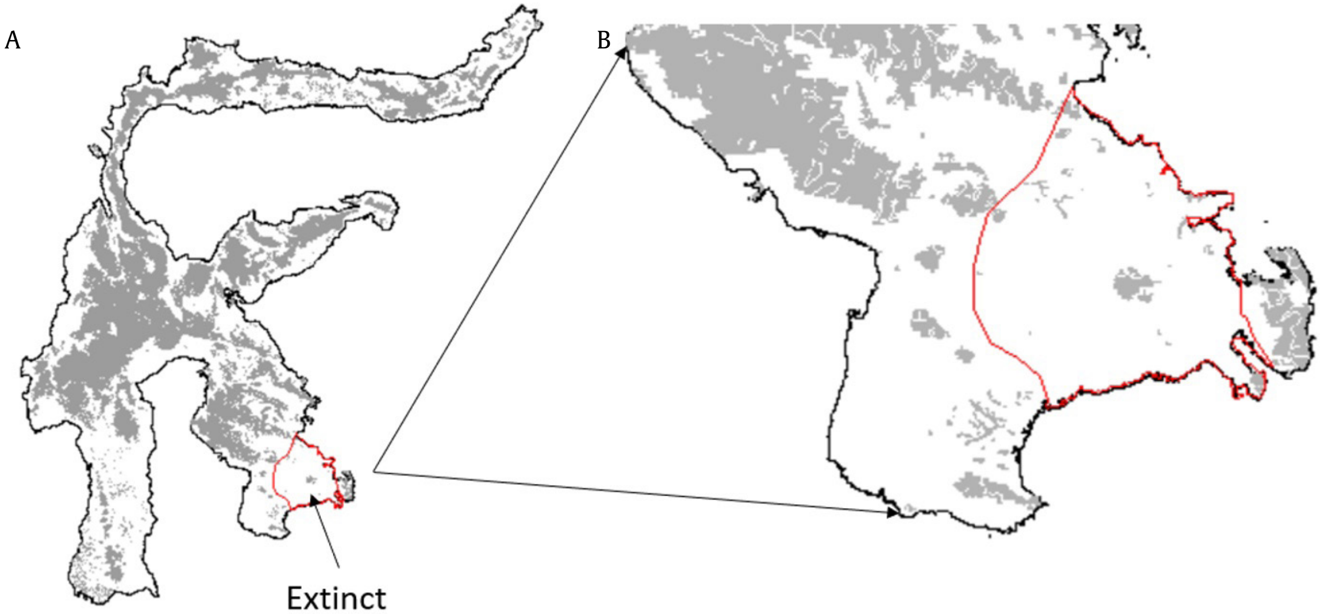

Figure 7. Anoa prediction and possibly extinct: (A) Sulawesi (B) South-eastern Sulawesi

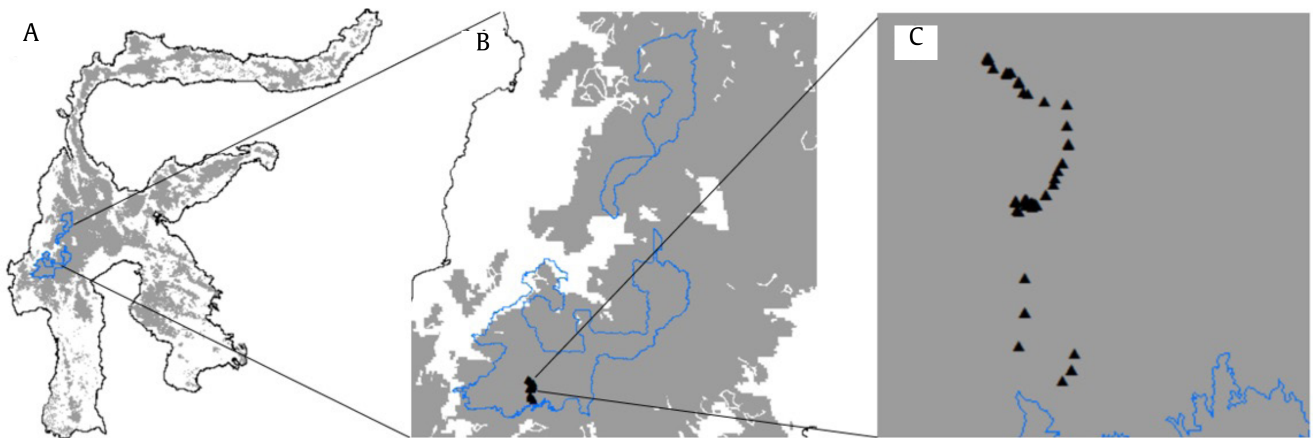

Figure 8. Anoa prediction overlap with TNGD forest area: (A) Sulawesi, (B) TNGD forest area (blue), (C) Anoa footprint in October 2021

native habitat is based on firsthand observations in the field, there may be more locations in the native habitat that have not been noticed. Aside from that, according to the suitability of physical and environmental parameters, anoa may occupy a new area. This study discovered the likely distribution of anoa both inside and outside its native habitat on the island of Sulawesi by analyzing data on elevation, land slope, plant cover, soil surface temperature, the existence of surface water sources, and, of course, reports on the presence of anoa. LST is the most important independent variable in determining habitat suitability, accounting for 80% of the total, followed by water (15.3%), NDVI (2.9%), DEM (1.6%), and slope (0.3%). Anoa dwells in areas with temperatures ranging from 20 to 25 degrees Celsius, are close to water sources (within 500 m), and are found at elevations ranging from 1,500 to 2,000 m above sea level. Anoa lived in a sparsely vegetated area unaffected by changes in land slope. The amount of species observation data in the field (31 sites) and the independent variables' diversity limit this investigation's scope. Some of these constraints will be addressed in future studies. Despite these constraints, this study produced a map of potential species habitats on a medium scale (1:60,000) with extensive coverage (one island of Sulawesi). This discovery provides the opportunity for both *in-situ* and *ex-situ* conservation efforts.

Acknowledgements

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