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Land Cover Analysis and Habitat Identification of Tanimbar Corella (*Cacatua Goffiniana*) on Tanimbar Islands, Maluku

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Abstract: The Tanimbar Corella (*Cacatua goffiniana*) is a protected bird species endemic to the Tanimbar Islands (Yamdena and its satellite islands) in the Maluku province of Indonesia. The major threats identified to this species are hunting, illegal trade, and habitat loss. Therefore, this study aims to classify the land cover, distribution, and habitat types occupied by *C. goffiniana* on the Tanimbar Islands. Classification of land cover was analyzed using a supervised classification method of the Erdas Imagine 2014 software. Direct field observations were conducted to identify the distribution of Tanimbar Corella and its habitat use. The land cover was classified into six classes: forest (54.26 %), open area (20.76%), plantation (14.81%), mangrove (6.89%), settlement (1.85%), and wetland (1.43%). *C. goffiniana* is distributed on five islands, Yamdena, Selaru, Larat, Sera, and Molu. Furthermore, this species was observed in forest, plantation, and open land habitats. The results identified seventeen nest trees of six species: *Canarium Indicum*, *Pometia pinnata*, *Instia bijuga*, *Sterculita foetida*, *Maranther corymbosa*, and *Alstonia scholaris*, with a range diameter of 40.00-136.71 cm and nest cavity heights of 9.00-34.22 m (n = 17). This research brings new data in three areas: 1) a reassessment of the distribution of *C. goffiniana* on the Tanimbar Islands; 2) a detailed classification of the land cover concerning habitat types of the Tanimbar Islands; 3) an identification of the tree species utilized by nesting Tanimbar Corellas. Information on preferred habitats and nesting trees is crucial for selecting release sites of confiscated birds to ensure post-release survival.

Keywords: conservation, distribution, habitat use, nesting tree, Tanimbar Islands, Tanimbar Corella.

马鲁古塔尼巴尔群岛坦尼巴尔科雷拉(仙人掌)的土地覆盖分析和栖息地识别

摘要：塔尼巴尔科雷拉 (仙人掌) 是印度尼西亚马鲁古省塔尼巴尔群岛 (亚姆德纳及其附属岛屿) 特有的受保护鸟类。该物种面临的主要威胁是狩猎、非法贸易和栖息地丧失。因此，本研究旨在对塔尼巴尔群岛仙人掌占据的土地覆盖、分布和栖息地类型进行分类。使用埃尔达斯想象 2014 软件的监督分类方法分析土地覆盖分类。进行了直接的实地观察，以确定

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坦尼巴尔科雷拉的分布及其栖息地的利用。土地覆盖分为六类：森林（54.26%）、空地（20.76%）、人工林（14.81%）、红树林（6.89%）、聚落（1.85%）和湿地（1.43%）。仙人掌分布于五个岛屿，亚姆德纳、塞拉鲁、拉腊、色拉和摩路。此外，在森林、种植园和开阔的陆地栖息地中观察到了该物种。结果确定了 6 个物种的 17 棵巢树：金丝雀、番红花、荸荠、胖大海、马兰瑟伞房花 和草地早熟禾，范围直径为 40.00-136.71 厘米，巢腔高度为 9.00-34.22 仪表(n = 17). 这项研究在三个领域带来了新数据：1）重新评估了仙人掌在坦尼巴尔群岛的分布；2）关于坦尼巴群岛栖息地类型的土地覆盖的详细分类；3) 确定筑巢坦尼巴尔科雷利亚斯所使用的树种。有关首选栖息地和筑巢树的信息对于选择被没收鸟类的释放地点以确保释放后的生存至关重要。

关键词：保护、分布、栖息地利用、筑巢树、坦尼巴尔群岛、坦尼巴尔科雷拉。

1. Introduction

The Tanimbar are small islands in the Regency of the Maluku Province, Indonesia, located between 6° 35'24" – 8 °.24'36" S and 130° 37'47" – 132 ° 4'12" E. The Banda Sea borders this area (in the North), East Sea and Arafura Sea (South), Southwest Maluku Regency (West), and Arafura Sea (East) [1]. Yamdena Island is the largest in the Tanimbar Islands, covering approximately 325,725 ha. A timber company was exploited from 1991 to 2008 [2]. The highest points of the Tanimbar Islands are below an elevation of 300 meters above sea level. The climate is seasonal, and forest cover comprises seasonal evergreen forest, dry deciduous forest, and moist deciduous forest [3]. The Tanimbar Islands are part of the Banda Sea Islands Endemic Bird Area (EBA165). Besides being important for birds, the Tanimbar Islands have contributed discoveries to science. For example, the discovery of seven new species of the Genus Trignopterus was recorded for the first time on these islands [4]. In addition, 142 bird species were recorded in forests, open land, swamps, mangroves, and coastal areas [5]. One endemic bird species distributed on Yamdena, Larat, and Selaru islands are the Tanimbar Corella (*Cacatua goffiniana*). Introduced populations are reported in the Kai Islands, Puerto Rico, and Singapore [6]. The Tanimbar Corella is one of the smallest cockatoos of the seven species of cockatoos, with a total length of 30-32 cm [7] and a body weight of approximately 300 g (females being slightly smaller) [6].

The habitats of Tanimbar Corella on Yamdena are agricultural lands, disturbed and undisturbed monsoon, semi-evergreen, moist deciduous forest, dry deciduous forest, mangrove forest, agriculture fields (coconut plantation), moist deciduous – logged, dry and moist deciduous forest mosaic, freshwater swamp forest, as well as grasslands [8]. In 1991, the population was estimated at 300,000-445,000 individuals [6]. However, Tanimbar Corella is threatened by the declining population, restricted distribution, and overexploitation. The legal trade recorded 14,144 birds per year from 1981 to 2018 [9]. In addition, habitat fragmentation is caused by development and human population growth. Endemic species with limited distribution may have difficulty adapting to modified habitats [2].

Various conservation efforts to protect Tanimbar Corella have been carried out nationally and internationally. Based on the laws of the Republic of Indonesia No. 5 in 1990, the government undertakes conservation efforts for biological resources through protection, preservation, and sustainable use. The species designated as a protected animal by the Ministry of Environment and Forestry regulation number P.106/MENLHK/SETJEN/KUM.1/12/2018 and included in Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) since 1992 and categorized as 'Near Threatened' in the IUCN Redlist. In addition, Tanimbar Wildlife Reserve was established to preserve and protect *C. goffiniana* in its natural habitat through the Minister of Forestry Decree No. 149/Kpts-II/1999. Other conservation actions include law enforcement, ex-situ breeding programs, and the release of confiscated individuals back to the wild. Comprehensive scientific data should supplement conservation efforts targeting Tanimbar Corella to conserve wildlife sustainably and adequately.

The study of this species in the wild and its habitat is relatively limited. It was carried out several decades ago and focused mainly on the population and conservation statuses [6]. More recent studies investigated the behavior [10-13], genetics [14], ecology [8, 15], and trade [9] of this species. The current study provides a detailed classification of the land cover and the habitat types available to Tanimbar Corella on the Tanimbar Islands. In addition, it

provides insight into the species' distribution and breeding ecology. These data are fundamental for successfully reintegrating confiscated birds into the wild.

2. Material and Methods

2.1. Land Cover Classification

Landsat 8 OLI imagery data for the study area was downloaded from the United States Geological Survey (USGS) website **(**http://earthexplorer.usgs.gov/**).** It has a spatial resolution of 30 m covering the entire area of the Tanimbar Islands contained in two scenes, namely path/row: 106/065 and path /row: 106/066. Most of the Tanimbar Islands' land area was recorded at path/row 106/65, while path/row 106/66 recorded fewer land and ocean areas (Fig. 1). In 2019, as many as 22 photos of Landsat imagery recorded the Tanimbar Islands.

In addition, relatively straightforward and clean imagery of cloud cover was taken on November 14, 2019, at 01:21:57 and 01:22:21 am. The land cover was assessed using a supervised classification method in Erdas Imagine 2014. Before the classification, the image pre-processing step was conducted: exporting the Geotiff format into Erdas raster format (*.img), image stacking, mosaicking, and subsetting. Then, the digital classification was conducted using the supervised classification technique. Training areas of 315 points on the Tanimbar Islands were produced randomly from Google, and direct object recognition was utilized for digital classification. Evaluation of the classes was observed by using the value of separability and contingency. Finally, the classification accuracy was assessed based on overall accuracy and kappa statistics.

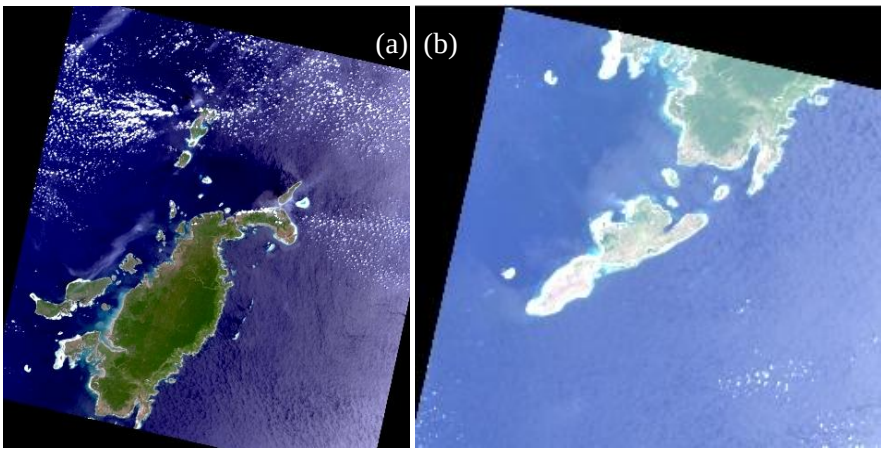

Fig. 1 Landsat scenes of Tanimbar Islands (a) path/row: 106/065 (b) path/row: 106/066

2.2. Distribution and Identification of the Habitat

Direct field observations were carried out to identify the habitat used, distribution of Tanimbar Corella, and the nest tree occupied by the species. Observations were conducted in August-November 2015, October 2017, April-May 2018, December 2018, and October 2021 on Yamdena, Selaru, Larat, Sera, and Molu Island. Data collections on the distribution and habitat used by birds were conducted using the area search method [16]. Furthermore, nest information was obtained from local people, confirmed with observation, identification, and measurements of the tree characteristics (such as the height and diameter of the trees). Active nest indicators were assessed by observing nesting activity or the presence of eggs/ chicks in the nest.

3. Result and Discussion

3.1. Land Cover Classification

The Tanimbar Islands are recorded in Landsat satellite imagery in two area codes: path/row: 106/65 and 106/66. The layer stacking image, mosaic, and clip mosaic are presented in Fig. 2.

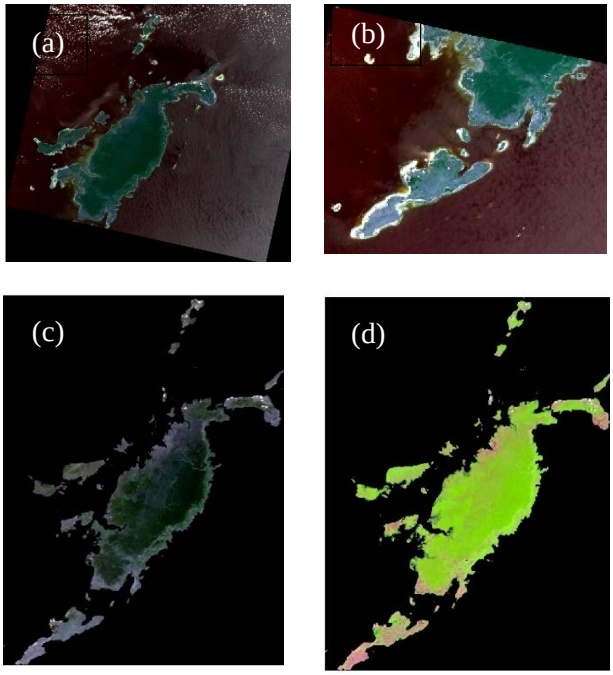

Fig. 2 Image stacking layer results at (a) path/row 106/65 (b) path/row 106/66; (c) mosaic results, (d) clip mosaic of the Tanimbar Islands

The image's appearance of land cover types in different colors is in Fig. 3. Wetlands are represented in

blue, while vegetation is in bright green. The brightness of the green color represents the density of the vegetation. High-density forests will appear dark green compared to low-density forests or mixed forests. Furthermore, the forest class had the lowest user accuracy (97.22%), while wetlands, settlements, open lands, and mangroves were well separated with a high user and producer accuracy (100%). Plantation land cover class was assessed using coconut plantations as training data. The forest vegetation has similar morphology to the plantation class due to difficulty identifying object boundaries and the lack of training data from direct observation. This procedure was performed to reduce bias in interpreting land cover classifications. The number of classes constituting land cover is less than the classification by the Ministry of Forestry in 2020 [17]. It is divided into 23 categories, of which forest is further subdivided into seven classes (such as lowland primary dryland forest, lowland secondary dryland forest, swamp forest, production forest, etc.). Open land is separated from shrubs, savanna, agricultural land, rice fields, ponds, airports, or transmigration land.

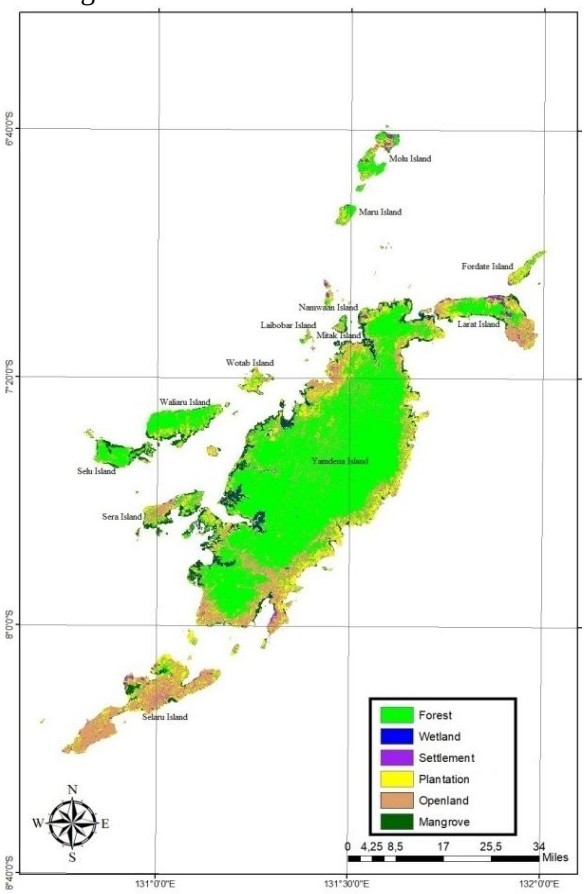

Fig. 3 Land cover classification of the Tanimbar Islands based on satellite imagery in 2019

It is difficult to distinguish between settlements and open land based on visual interpretation. However, the 'settlements' category used training data on residential areas, and the 'open land' category used training data on fields and land without vegetation. The results of the classification evaluation show that the lowest separability occurs between residential and open land classes with a divergence transformation value of 480,151, which means that the two classes are not separated. In contrast, the other classes value separation between 1800-2000 since the classes can be well differentiated. Based on contingency, the highest level of suitability for training data was forest class (99.64 %), while the lowest was plantation (29.39 %). However, the overall classification and kappa accuracy was 99.60% and 99.54%, thus providing high accuracy. Therefore, the land cover classification resulting from processing Landsat image data on November 14, 2019, has high precision, and the pixels have been appropriately classified. The results of the land cover classification area for each class are shown in Table 1.

Table 1 Land cover classification based on Landsat imagery 2019 of the Tanimbar Islands

No	Classification	Area (Ha)	Percentage (%)
1	Forest	240,661.00	54.26
2	Wetland	6,351.48	1.43
3	Settlement	8,190.81	1.85
4	Plantation	65,713.20	14.81
5	Open land	92,100.70	20.76
6	Mangrove	30,541.40	6.89
	Total	443,558.59	100.00

The land cover classification analysis resulted in six categories: forest, open area, plantation, mangrove, settlement, and wetland. However, forest cover was not detailed, including primary forest, secondary forest, and production forest.

Open areas consisted of shrubs, grasslands, agricultural fields with annual crops, and land without vegetation. Plantation classification identified land with planted crops, such as coconut and bananas. Mangrove land cover typically consists of mangrove vegetation around rivers and coasts. Settlements included residential areas, airports, ports, and other infrastructure, while the classification of wetlands consisted of swamps and rivers.

Furthermore, forests dominate land cover, specifically Yamdena, Waliaru, Selu, Molu, and Maru Island. Land cover on Selaru, Larat, and Sera islands was dominated by open land, while plantation land was dominant on Wotab and Laibobar islands. Settlements were located primarily along coastal areas and scattered on large islands (Yamdena, Larat, and Selaru). The Tanimbar Islands have wetlands of swamps and several rivers. Mangroves are dominant in watersheds, estuaries, and coastal areas.

3.2. Distribution and Habitat Identification

The Tanimbar Corella is scattered on Yamdena, Selaru, Larat, Sera, and Molu islands of the Tanimbar archipelago. Individuals were observed to exhibit several activities within forests, plantations, and open land, including foraging, nesting, and perching. Furthermore, nesting was observed in seventeen trees of six species, namely *Canarium Indicum*, *Pometia*

pinnata, *Instia bijuga*, *Sterculita foetida*, *Maranther corymbosa*, and *Alstonia scholaris*, with a range diameter of 40.00-136.71 cm. Nest cavities were located at 9.00-34.22 m high (Table 2).

Table 2 The nesting tree of *C. goffiniana* on the Tanimbar Islands

Nest Tree Name	Diameter (cm)	Height (m)	Egg number	Elevation (m asl)
Habitat Type: Forest				
C indicum	136.71	29.38	1	82
C.indicum	136.71	30.32	2	97
C indicum	70.00	20.00	0	2
C.indicum	80.00	30.00	1	36
C. indicum	80.00	30.00	2	73
C. indicum	74.36	21.14	0	101
C. indicum	110.30	33.46	0	115
P. pinnata	91.93	21.91	0	68
P. pinnata	117.93	34.22	0	161
P. pinnata	98.55	27.69	1	136
P. pinnata	95.42	21.55	0	104
P. pinnata	101.83	18.07	2	79
A. scholaris	110.00	25.00	0	21
M .corymbosa	67.64	18.44	1	164
I. bijuga	82.28	16.18	1	197
Type Habitat Type: Open Land				
S. foetida	60.00	12.00	0	1
S. foetida	40.00	9.00	2	6

Most nest trees were located in the forest, while two nests of *Sterculia foetida* were found in the open land of Selaru Island (see Table 2). Observations made in August-December confirmed active nests in cases where the parent entered the cavity. Meanwhile, direct observations confirmed eggs and chicks in the nests. The number of eggs ranged from one to two eggs, and typically only one chick was found in the nest. The findings of active nests suggested that the breeding of Tanimbar Corella occurs during this period [8, 15]. However, additional breeding seasons cannot be excluded [15].

The Tanimbar Corella was confirmed to occur on Yamdena, Selaru, Larat, Sera, and Molu islands. However, its distribution on Sera and Molu islands has not been reported prior to this study. Previous studies stated that Tanimbar Corella has a natural distribution on Yamdena, Larat, and Selaru islands [6]. However, the distribution records are limited to only a few islands since the Tanimbar archipelago consists of 65 islands [1]. This limited data on distribution is due to restricted access to these small islands. Therefore, further studies should be conducted to determine the distribution of this species on the remaining islands of the Tanimbar archipelago.

Tanimbar Corella was observed to carry out several activities in forest, plantation, and open land habitats. The plantation and open area habitat types could have initially been forests. With a 9.473 ha/year degradation rate on Yamdena Island between 1998-2008, forest clearing played a role in converting land functions to form agricultural land, fields, and open land [2]. The shifting agriculture system has caused the expansion of available land and created new food sources for birds, such as corn and beans. Some agricultural areas extend far into the forest, resulting in these habitats for foraging, nesting, and perching. This study did not find Tanimbar Corella inhabiting mangrove forests, settlements, and wetlands. Instead, they were only observed flying over these land classes. That contrasts with previous studies that report Tanimbar Corella using those habitats. There are no records of potential food sources or nesting trees in those classes. That is likely because Tanimbar Corella is a feeding generalist with a large diversity of food sources, confirmed to consume 32 food items and potentially to consume further 35 food items [8, 15].

The distribution of Tanimbar Corella overlaps with the habitat of 142 bird species on the Tanimbar Islands. There were competitive associations and sharing of feeding, nesting, and perching sites between *C. goffiniana* and other bird species such as *Corvus orru*, *Eclectus roratus*, *Eos reticulata*, *Aplonis crassa*, *and Ducula concinna* [5]. The limited availability of nest cavities can lead to competition for the nesting sites, specifically when two or more species have overlapping breeding periods [18]. This type of competition also occurs in Tanimbar Corella, a breeding season similar to *E. roratus*, resulting in competition for tree holes as nesting sites [5, 8]. The study confirmed that the breeding time of Tanimbar Corella occurs between August-December. Previous studies reported that the breeding period was estimated to start between June or early July and between December to February [8, 15], and it is similar to the white Cockatoo (*C.alba*) on Halmahera and Bacan islands (Northern Maluku). Observations of *C. alba* indicated the breeding season starts in mid-October [18]. It differs from the Little Corella (*C.sanguinea*), which has a breeding season between May-October [19], while the Philippine Cockatoo (*C. haematuropygia*) breeds between May-June [20].

Most nests were encountered in *C.indicum* and *P. pinnata*, suggesting that the tree species may be preferred for breeding. The Canarium tree has also been proposed as the main nesting site for White Cockatoo on Halmahera Island [18]. The selected trees have a larger diameter and are usually higher than the surrounding trees. In addition, such characteristics are likely chosen to prevent predators from threatening the eggs or chicks in the nest holes. The potential predators include Brahminy Kite (*Haliastur indus*), Varied Goshawk (*Tachyspiza hiogastra*), Bonelli's Eagle (*Aquila fasciata*), Yellow-throated Martens (*Martes flavigula*), feral cats (*Felidae sp.*), as well as the Western Pacific Monitor Lizard (*Varanus indicus*) and the Tanimbar Python (*Simalia nauta*) [8].

Knowledge of nest trees is crucial to successfully conserve the Tanimbar Corella, as it enables targeted preservation of specific trees from illegal logging. The loss of a nesting site could threaten birds' reproduction

and directly affect their ability to maintain a stable population. Such a loss of suitable nest trees may have occurred on Selaru Island, where the two encountered nests were found in small and low trees located in open land areas close to settlements. These nests experienced disturbances by hunters who monitored the nest hole and harvested the chicks before they were fully fledged. The threat of biodiversity loss occurs primarily due to changes in land use, the introduction of invasive alien species, damage to ecosystems and habitats, and overexploitation of biological (flora and fauna) resources.

3.3. Conservation Implications

Identification of land cover and habitat of Tanimbar Corella on the Tanimbar Islands provides crucial information for conservation activities. The government's community activities and development, which result in land cover changes on the Tanimbar Islands, should consider the availability of habitat and nest trees for Tanimbar Corella. The loss of its habitat accelerates the extinction of this endemic bird species. Conservation projects requiring significant effort and substantial investment are necessary to preserve this species. However, the cost and effort to restore an extinct life exceeds the cost of such conservation initiatives. The cooperation of all parties should protect and preserve the habitat and population of Tanimbar Corella to provide a noble legacy for future generations.

4. Conclusion

This presented study investigated the wild population of *C. goffiniana* in its natural environment of Tanimbar Island. The research included land cover classification of Tanimbar Islands and identification of distribution, habitat use, and the breeding period. The study provides new data in three areas. Firstly, it recorded new distribution of *C. goffiniana* on the Tanimbar Islands. Its distribution on Sera and Molu islands has not been reported. Secondly, this research classified the land cover of the habitat types used by *C. goffiniana* on the Tanimbar Islands. The land cover classification analysis resulted in six categories: forest, open area, plantation, mangrove, settlement, and wetland. The forests, plantations, and open land were the most favorable habitat for this species among the six land cover classes. Thirdly, this study identified the nesting sites used by the Tanimbar Corella. In the breeding season, the preferred nest trees were *C.indicum* and *P. pinnata*.

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