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Population survey and red list assessment of *Kandelia candel* (L.) Druce, a critically endangered mangrove species in the Philippines

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Abstract. *Malabrigo PL Jr., Eduarte GT, Macandog DM, Maldia LSJ, Pampolina NM, Sotto RC, Buot IE Jr.. 2023. Population survey and red list assessment of* Kandelia candel *(L.) Druce, a critically endangered mangrove species in the Philippines. Biodiversitas 24: 982-989.* Mangroves (particularly the members of the Rhizophoraceae) are viviparous species that produce propagules capable of long-distance dispersal. Hence, endemism in mangroves is not common, as countries share species through currents and wave actions. In the Philippines, it is extremely surprising that *Kandelia candel*, despite viviparous, is restricted in Baler, Aurora. Furthermore, to determine the real conservation status of the species, we conducted a 100% inventory of all mature individuals in known populations of *K. candel* in Aurora. Our survey has revealed the natural stands of *K. candel* have been restricted along the riverbanks of the Zabali and Castillo rivers in Baler, Aurora. The rivers are connected and should be treated as a single population. A total of 1,114 matured individuals have been observed in the two sub-populations. The conservation status of *K. candel* has been assessed following the categories and criteria set by the International Union for Conservation of Nature (IUCN). Landsat analysis has been conducted to determine the population reduction of the species between 2010 and 2020. The extent of occurrence (EOO) and area of occupancy (AOO) of *K. candel* have been estimated based on the recorded populations and geo-tagged sampling points during the inventory. The present study result has revealed the least concern status of *K. candel* for 'Criterion A'; Critically Endangered status for 'Criterion B1 and B2'; and Near Threatened status for 'Criterion C and D'. Accordingly, the overall conservation status of *K. candel* in the Philippines is assessed here as Critically Endangered (CR B1ab(iii) + B2 ab(iii)).

Keywords: Aurora, Baler, IUCN criteria and categories, Philippine red list, viviparous

INTRODUCTION

Mangroves are highly regarded as the champions in environmental adaptation with various adaptive mechanisms that allow them to live in the least inviting estuarine habitats. Most mangrove species have special adaptations for reproduction, including vivipary, where seed germination begins on top of the tree. The viviparous mangroves are the most quoted example of long-distance dispersal through currents and wave actions (Van der Stocken et al. 2019; Wang et al. 2019). But on the other point of view, some authors (Zainol et al. 2022; Binks et al. 2019) consider vivipary as a hindrance to long-distance dispersal because the seedlings (instead of seeds as the unit of dispersal) lack protection and nutritional support once detached from the mother plant. For those studying population connectivity, the limit for such dispersal has long been the topic of speculation (Yando et al. 2020).

Kandelia candel is a true mangrove species known to produce buoyant viviparous propagules and presumably capable of long-distance dispersal (Malabrigo et al. 2021). However, *K. candel* has limited global distribution compared to other mangrove species, and its distributional range was considered to be nowhere abundant (Malabrigo and Pasion 2022). In a study of propagule dispersal in a natural stand of *K. candel* in Guangdong, China, it was observed that the mean mother-seedling distance estimated by the direct parentage analysis is only 9.4 m (Geng et al. 2008, as cited in Van der Stocken et al. 2019). The significantly short-distance dispersal of seedlings could be related to their reproductive mode. The large (40 cm) and heavy (13.6 g) pencil-shaped propagules of *K. candel* would normally fall and would fix firmly into the ooze beneath the crown of the mother tree (Geng et al. 2008 as cited in Van der Stocken et al. 2019).

One key factor controlling mangrove propagules' dispersal is the number of days they remain buoyant and viable in seawater (Zhang et al. 2021; Robert et al. 2015). In their study of the mangrove population in Vietnam, Ha et al. (2003) reported that *K. candel* propagules are buoyant for 18 days maximum. Although the obligate dispersal period can be extended to 3-6 weeks, especially when exposed to seawater, which could increase the dispersal distance. However, they also found that the percentage of mortality among seedlings after settlement in another environment is very high (74%). That could explain why *K.*

candel is not as common as other mangroves and always non-dominant in any locality where they occur.

A comprehensive molecular study (Chiang et al. 2001) in fourteen major populations of *Kandelia candel* around the South China Sea (from Bako, Sarawak to Ryuku, Japan) revealed long-distance seedling dispersal resulting in extensive gene flow among populations across the ocean. Furthermore, the genetic variation of cpDNA *trn*L-*trn*F spacer suggests no geographical subdivision between populations of the northern (China and Vietnam) and eastern part (Japan) of the South China Sea (Chiang et al. 2001).

In the Philippines, *K. candel* has a very narrow distribution and is known to occur in only one municipality of Aurora province (Malabrigo et al. 2021). With this very restricted distribution, *K. candel* is categorized as critically endangered in the Philippine red list for plants (DENR 2017). However, unlike the red list assessment of the International Union for Conservation of Nature (IUCN), the Philippine red list has no clear criteria to determine the reason for species endangerment. Knowing the red list criteria where the species fall as threatened species is very important in crafting effective conservation measures to prevent further degradation of the species population. In this study, we conducted a 100% inventory of all the matured individuals of *K. candel* in the known populations in Aurora to understand the species' basic ecology and stand structure and assess its real conservation status vis-à-vis the IUCN red list criteria.

MATERIALS AND METHODS

Population inventory

A 100% inventory of all mature individuals was conducted from July 12-14, 2019, in known populations of *K. candel* in Aurora, particularly in the municipalities of Baler and Casiguran, Philippines (Figure 1). Matured individuals considered in this study were those with a diameter of ≥ 3cm measured at 1 foot above ground (diameter at foot height or dfh) or 10 cm above the highest buttress. Based on earlier observations, *K. candel* is a precocious species that start bearing flowers and fruits as early as it reaches 3cm dfh. Therefore, using dfh instead of diameter at breast height (DBH) is extremely rational since *K. candel* could start flowering before reaching the height of 1.3 meters. Total height and dfh were measured to account for the stand structure and dominance of the species. GPS coordinates of each individual were also noted to aid in constructing an interactive distribution map for future assessment and monitoring studies.

Assessment of conservation status

Following the criteria and categories set by the International Union for Conservation of Nature (IUCN) for the global red listing, the conservation status of *K. candel* was assessed. In addition, the mangrove forest loss/gain information from the areas of occurrence was used as a proxy measure of population size reduction/gain for the species. This study utilized Landsat satellite records to account for the mangrove coverage of the municipality of Baler province of Aurora, Philippines. The satellite imageries (Landsat scenes) were queried and captured from the United States Geological Survey (USGS) Earth Explorer portal. Specifically, the Landsat-5 and Landsat-8 satellites assessed mangrove cover for 2010 and 2020, respectively (Figure 2).

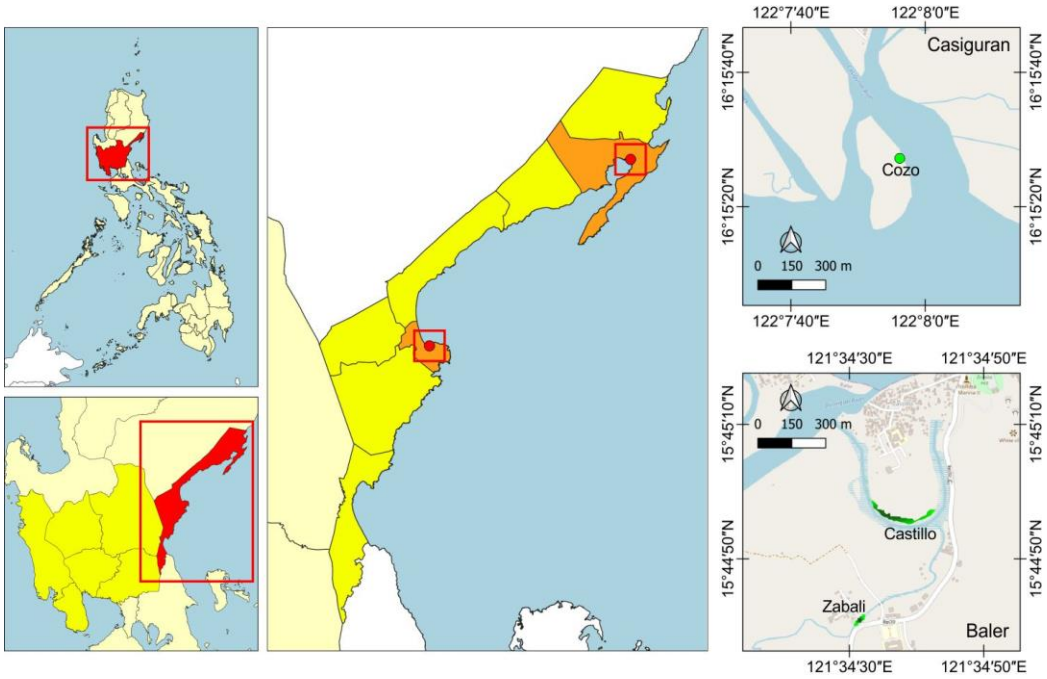

Figure 1. Locations of *Kandelia candel* populations in the Province of Aurora, Philippines

Figure 2. Acquired Landsat scenes for analysis. *Left*: Landsat 5, year 2010; *Right*: Landsat 8, year 2020

Table 1. Satellite scenes for mangrove cover classification

Satellite	Sensor	Path/row	Month/date	Year
Landsat 5	TM	116/49	07 Jan	2010
Landsat 8	OLI-TIRS	116/49	06 Jul	2020

Note: TM: Thematic Mapper; OLI: Operational Land Imager; TIRS: Thermal Infrared Sensor

The Landsat collection two surface reflectance (SR) was prioritized to improve comparison among images across the area of interest (AOI). The scenes in this collection were atmospherically corrected, accounting for the effects of aerosol scattering and thin clouds. The algorithm used in applying atmospheric correction is the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) and Land Surface Reflectance Code (LaSRC) for Landsat 5 and Landsat 8, respectively (Vermote et al. 2016). The Landsat scenes were filtered and chosen based on the relative location (path 116 and row 49) using the worldwide reference system (WRS).

Additionally, the percent cloudiness was set to 15% to delimit scenes with the least amount of clouds and shadow. That is vital in reducing the possible conflict in the classification process and estimating mangrove coverage. The summary of details for each satellite image is presented in Table 1.

The corrected satellite images were then clipped to the boundary of the study area (Figure 3), which was acquired through the database of Global Administrative Areas (GADM 2012). This study adopted the supervised classification method using the maximum likelihood algorithm. That is the most used image classification method in remote sensing (Barrett et al. 2014). Each period requires training samples showing different spectral signatures, which was done using visual interpretation and field validation. This study utilized 500 pixels/samples to produce a signature for water (80), clouds (67), shadow (54), mangroves (158), and non-mangrove (141). These generated signatures were utilized for both periods to extract each land cover. The classification was performed using free and open-source Geographic Information System (GIS) software (QGIS v.3.22.5) utilizing the Semi-Automatic Classification (SCP v.7.10.8). Furthermore, the classified images were then reclassified to limit the classes to mangrove and non-mangrove. The accuracy assessment of classified images was calculated using the overall percentage and Kappa coefficient using the SCP plugin (Congedo 2021).

Furthermore, to examine the differences in mangrove coverage between the two periods, results were presented using the annual rate of deforestation, which is expressed in either rate (area/time) or percentage (Ghebrezgabher et al. 2016; Nesperos et al. 2021). Therefore, the annual rate of change is expressed as:

$$r = (1/Y^2 - Y^1) \times \ln(A^2/A^1)$$

Where:
r : Annual rate of change
Y^n : Year
A^n : Area cover of mangrove (ha)

The extent of occurrence (EOO) and area of occupancy (AOO) of each species were estimated based on the recorded populations and geo-tagged sampling points during the actual inventory using the GeoCAT online application (http://geocat.kew.org/editor). The number of matured individuals was derived from the 100% inventory conducted.

Figure 3. Satellite images masked in the boundary of Baler, Aurora, Philippines

RESULTS AND DISCUSSION

Population and stand structure

Our recent inventory of all matured individuals of *K. candel* in the province of Aurora revealed that *K. candel* trees in Casiguran were not natural but artificially planted. Our local assistant guide during the survey was the same person who first planted *K. candel* trees in Brgy, Cozo, Casiguran, as early as 1990. Accordingly, of the 200 propagules (from mother trees in Baler) he initially planted, less than 50 trees survived. Furthermore, our survey only recorded four small individuals with a diameter ranging from 6cm - 8cm, but our local guide narrated that there were larger trees before that were already cut.

We also visited the mangrove in Dipaculao, where the first author personally observed three (3) *K. candel* saplings planted along a fishpond periphery at the back of the municipal market in 2013. Unfortunately, in our recent survey, not a single individual of the species was encountered. Instead, significantly larger fishponds were observed than in the 2013 survey. It is important to note that the first author never thought that the *K. candel* individuals he observed in 2013 were native to the area.

In Baler, Aurora, two large natural stands have been surveyed, one along the main river tributary in Brgy-Sabang, known as Castillo river. Another one from Brgy-Zabali is called Zabali river, a smaller inner tributary drains to the main river (see Figure 1). *Kandelia candel* along the Zabali river stretches from 820 meters to 1,000 meters from the river opening. It has a smaller area (≈900m^2) but with larger and taller trees (Plate 1), as compared to Castillo. A total of 186 matured (≥ 3cm diameter at foot height) individuals were observed in Zabali. Of which, 89 (48%) belonged to the small diameter class, 67 (36%) were medium-sized, and 30 (16%) had a diameter of more than 10 cm (Table 2). The largest tree recorded has a diameter of 17 cm, while the tallest tree has a height of 9 m. The average diameter and height found in the study are 6.88 cm and 5.19 m, respectively (Table 3).

The *K. candel* stand in Castillo river is only about 500 meters from the Zabali stand. It has a long stretch of about 330 meters (≈1,650m2), starting from 320 meters to 650 meters from the river opening. Castillo stand has significantly higher numbers, with 928 matured individuals but relatively smaller and shorter individuals. Not a single tree in this stand reached a diameter of 10 cm. Most (890 out of 928) of the individuals belonged to small-diameter trees, while the rest (38) were medium-sized trees. The largest diameter recorded is only 8 cm, while the tallest tree has a height of 6 m. The average diameter and height found in the study are 3.63 cm and 3.34 m, respectively.

Red list assessment and conservation status

The mangrove coverage in the municipality of Baler for the year 2010 was ~26.43 ha covering 0.24% of its total land area. On the other hand, the 2020 classification estimated a total of 42.04 ha or around 0.38% area coverage (Table 4). The spatial distribution showed that the majority of the mangrove areas in 2010 were clustered in Barangay Sabang (~7.21 ha) and Zabali (~7.15 ha) (Figure 4), where the two sub-populations of *K. candel* are located. That is similar to the result in 2020, where approximately 13.21 ha and 17.39 ha were recorded in Sabang and Zabali, respectively. That covers almost 73% of the total mangrove cover in Baler.

The annual rate of change of mangrove cover in the municipality of Baler for the ten years is approximately 5%. That reflects an increase in mangrove cover and indicates a good and healthy ecosystem that can accommodate regeneration. On the other hand, Baler's relative change in mangrove cover from 2010 to 2020 showed a gain of 15.61 ha or almost 59% of the original mangrove cover (Table 5). The increase in mangrove cover has been recorded largely in Zabali, around 143%, equivalent to a 10.24 ha gain for ten years, followed by the Sabang (84%) and Barangay V (23%). Further, a new mangrove area (0.17 ha) has also been observed in Barangay IV in 2020. However, Barangays Pingit and Buhagin have witnessed a loss of 39% (-0.81 ha) and 15% (-1.0 ha) of mangrove cover between 2010 and 202, respectively. In addition, the increased infrastructure development and continuous proliferation of houses along the riverbanks, particularly in Zabali, has resulted in the siltation and shallowing of the river over time. That has resulted in the reduction in potential areas for mangrove expansion.

Table 2. Number of *Kandelia candel* individuals per diameter class in Baler, Aurora, Philippines

Diameter class (cm)	Zabali	Castillo	Across sites
3.0 - 5.0	89	890	979
5.01 - 10.0	67	38	105
>10	30	0	30
Total	186	928	1114

Table 3. Summary of inventory of *Kandelia candel* in Baler, Aurora, Philippines

Parameter	Zabali	Castillo	Across sites
No. of individuals	186	928	1114
Average diameter (cm)	6.88 ± 3.22	3.63 ± 0.87	4.18 ± 1.96
Maximum diameter (cm)	17	8	17
Average height (m)	5.19 ± 1.60	3.34 ± 0.68	3.57 ± 1.14
Maximum height (m)	9	6	9

Table 4. Mangrove coverage in different barangays of Baler, Aurora, Philippines for the years 2010 and 2020

Barangay	Year 2010		Year 2020	
	Area	Percent	Area	Percent
Barangay IV			0.17	0.41%
Barangay V	4.24	16.05%	5.24	12.45%
Buhangin	5.31	20.10%	4.50	10.71%
Pingit	2.53	9.58%	1.53	3.65%
Sabang	7.20	27.23%	13.21	31.43%
Zabali	7.15	27.04%	17.39	41.36%
Grand total	26.43		42.04	

Table 5. Change of mangrove coverage in different barangays of Baler, Aurora, Philippines between 2010 and 2020

Barangay	Area (ha)		Gains/loss	Relative change
	2010	2020		
Barangay IV		0.17	0.17	
Barangay V	4.24	5.24	0.99	23%
Buhangin	5.31	4.50	-0.81	-15%
Pingit	2.53	1.53	-1.00	-39%
Sabang	7.20	13.21	6.02	84%
Zabali	7.15	17.39	10.24	143%
Grand total	26.43	42.04	15.61	59%

Plate 1. A natural stand of *Kandelia candel* along the Zabali river, Philippines. A. The small but highly dense stand as viewed from the river; B. Flowering twigs; C. Fruiting twigs; D. The largest trees in the stand

Discussion

Earlier, Rotaquio et al. (2007) studied the distribution of *K.candel* in the Philippines and recorded the occurrence of *K. candel* in the municipalities of Baler, Dipaculao, and Casiguran. Rotaquio et al. (2007) have also noted that the sample specimens of *K. candel* are collected from the "main population in Baler mangroves, as the *K. candel* trees in the two other sites (Dipaculao and Casiguran) are not yet bearing fruits." Further, they have specifically stated that in Casiguran, "only a small pocket of *K. candel* trees can be seen." While in Dipaculao, "they are sparsely scattered near private milkfish (*Chanos chanos*) and tilapia (*Oreochromis niloticus niloticus*) brackish water fishponds." However, there is no further quantitative or even qualitative characterization to determine how many individuals or how much area is occupied by the "small pocket" stand in Casiguran and the "sparsely scattered" stand in Dipaculao. The 100% inventory conducted in this study revealed that the *K. candel* stands along Zabali and Castillo rivers in Baler, Aurora, are the only natural populations of the species in the country. Therefore, the two rivers are interconnected and considered one location for red list assessment purposes. The study also confirmed that *K. candel* is a major mangrove species capable of forming a pure, dense stand and could dominate the area where it occurs.

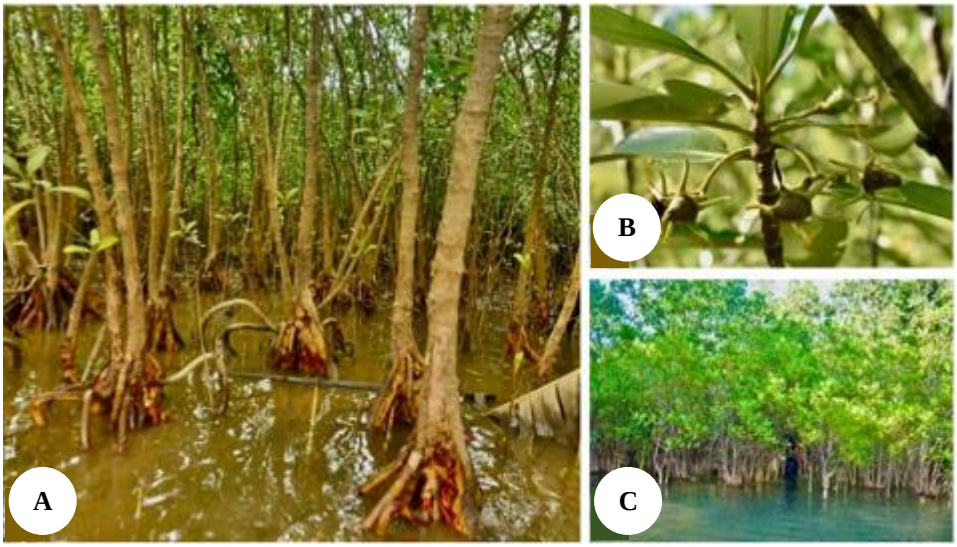

Plate 2. A natural stand of *Kandelia candel* along Castillo river, Philippines. A. The largest trees in the stand showing the complex root system; B. Fruiting twigs; C. A portion of the dense stand as viewed from the river

Figure 4. Distribution of mangroves in the municipality of Baler, Aurora, Philippines, in 2010 and 2020

Furthermore, to determine the true conservation status of *K. candel*, the IUCN assessment guidelines (IUCN 2012; IUCN 2019) has been adopted in the present study. Our Landsat analysis for 2010-2020 showed a significant increase in the mangrove cover where the sub-populations of *K. candel* occur. This suggests a least concern status for Criterion A (Population reduction). Both the actual ground survey (using GPS, compass, and meter tape) and the use of the GeoCAT online application (http://geocat.kew.org/editor) estimated the extent of occurrence (EOO) to be 0.115 km^2. It is quite understandable because of the very narrow strip (average width of 5 m) of *K. candel* stands along the riverbanks in both Zabali and Castillo rivers and the very short distance (less than 500 m) between the two sub-populations. For the area of occupancy, the GeoCAT automatically computed 4 km^2, the smallest area for any species, because *K. candel* is only present in a single location (one location is equivalent to 1 grid measuring 2 km × 2 km). However, our field survey, including the 100% tree inventory of the two sub-populations, revealed that the actual area occupied by *K. candel* is much smaller, only about 2,550 m^2 or 0.00255 km^2 (900 m^2 for Zabali and 1,650 m^2 for Castillo). Both the extent of occurrence (Criterion B1) and the area of occupancy (Criterion B2) are far below the thresholds of a critically endangered species, which are 100 km^2 and 10 km^2, respectively. To qualify as critically endangered under criterion B, the population must satisfy at least two other sub-criteria from any of the three: A) severely fragmented or in a single location, B) Continuing decline in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or sub-populations; (v) the number of mature individuals, and C) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or sub-populations; (iv) the number of mature individuals. In the case of the *K. candel* population in Baler, it qualifies for sub-criterion A for a single location and sub-criterion B because of the continuing decline in the quality of habitat

brought about by siltation due to continues infrastructure development along the riverbanks.

The 100% inventory counted 1,114 matured individuals of *K. candel* from the two sub-populations, 186 individuals in Zabali and 928 individuals in Castillo. This is below the threshold of criterion C (Small population size and continuing decline) for endangered species, which is 2,500 individuals. However, another sub-criterion that should be satisfied for the population size is the continuing population decline at a specified rate or any unspecified rate. In the case of the two sub-populations in Baler, our Landsat analysis revealed a significant increase (Table 5) in the mangrove cover of Zabali (143% increase) and Castillo in Sabang (84% increase). Hence, *K. candel* population in Baler should be assessed as Near Threatened (NT) under criterion C. However, due to its single location, *K. candel* population in Baler can be assessed under a very small or restricted population (Criterion D), where the threshold for the least threatened category (vulnerable) is 1,000 individuals. Therefore, considering that *K. candel* population in Baler (1,114 individuals) is just above the vulnerable threshold, the species should be assessed as Near Threatened under Criterion D.

As defined in the *IUCN Red List Categories and Criteria (Version 3.1),* "A quantitative analysis is any form of analysis which estimates the extinction probability of a taxon based on known life history, habitat requirements, threats, and any specified management options" (IUCN 2012a). One technique used for estimating the probability of extinction in the wild is the Population Viability Analysis (PVA). However, in the absence of any population study and the lack of information regarding threats, habitat requirements, and management of *K. candel* in Baler, it cannot be evaluated for Criterion E (Quantitative analysis to estimate the probability of extinction in the wild).

Based on the above discussion, following the assessment criteria of the International Union for Conservation of Nature, the conservation status of *K. candel* in the Philippines is assessed as Critically Endangered (CR B1ab(iii) + B2 ab(iii)) as summarized in Table 6. It should be noted, however, that this assessment only considered the population of *K. candel* in the Philippines, not the global distribution. However, considering that the Philippines is isolated from other countries with naturally occurring *K. candel*, this assessment can be considered a national conservation status of the species. As clearly stated in Guidelines for Application of IUCN Red List Criteria at Regional and National Levels (Version 4.0)."Provided that the regional population to be assessed is isolated from conspecific populations outside the region, the *IUCN Red List Categories and Criteria* can be used without modification within any geographically defined area. The extinction risk of such an isolated population is identical to that of an endemic taxon" (IUCN 2012b).

This study provided much information on the true conservation status of *K. candel* in the Philippines. However, the restricted distribution of *K. candel* in Baler, which causes its critically endangered status, is still a mystery to unmask, considering the viviparous nature of its fruits, which is buoyant and therefore capable of being dispersed to other coastal areas in the country. We hypothesize that the Kuroshio current might influence its limited dispersal in the country. The strong equatorial current from the north Pacific might have forced the *K. candel* propagules from Baler to be transported northwest to Japan and then back to the long pelagic world of the Pacific Ocean until it lost its viability. On the other hand, the absence of the species in the adjacent coastal areas of the nearby municipalities of Casiguran and Dilasag, where other mangrove species are profusely growing, posts another riddle to resolve.

Analysis of mangrove cover change from 2010 to 2020 revealed a significant increase in the mangrove stands of *K. candel*, which suggests natural population expansion of the species since no artificial planting was conducted in the area. The presence of numerous regenerations of *K. candel* is also very evident during the population survey. It shows that the population will continue to persist and expand without human intervention. It suggests further that the best conservation strategy for the species is the protection of the existing mangrove forest. Although, introduction to other mangrove areas is also important in case some tragic human-induced events cause severe destruction to the natural population. From the population genetics point of view, the fact that the species occur only in one location implies the species' vulnerability. Therefore, a population genetic study that will include geographic variation, mating systems, heterozygosity, and individual relatedness, among others, is necessary to promote a better understanding of the species for its better protection and conservation.

Table 6. Summary of assessment for the *Kandelia candel* population in the Philippines

IUCN criteria	CR	EN	VU	*K. candel* in Baler	Assessment
A. Population reduction (over 10 years or 3 generations)	> 90%	> 70%	> 50%	increasing	LC
B1. Extent of Occurrence (EOO)	<100 km^2	<5,000 km^2	<20,000 km^2	0.115 km^2	CR
B2. Area of Occupancy (AOO)	<10 km^2	<500 km^2	<2,000 km^2	0.00255 km^2	CR
C. Small Population Size and Continuing Decline (Number of matured individuals)	< 250	< 2,500	< 10,000	1,114	NT
D. Very small restricted population (Number of matured individuals)	< 50	< 250	< 1,000	1,114	NT
E. Quantitative Analysis (Probability of extinction in the wild)	50% w/in 10 years	20% w/in 20 years	10% w/in 100 years	N/A	NE

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