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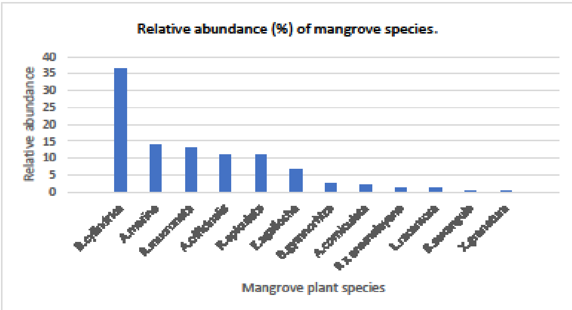
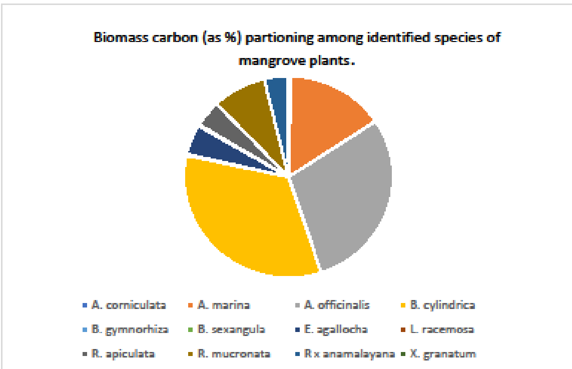
RESEARCH ARTICLE

Floristic diversity and distribution of biomass carbon: A preliminary study of mangroves in Chilaw lagoon, Sri Lanka

O.W. Kotagama*, K.A.R.S. Perera and D.D.G.L. Dahanayaka

This preliminary study looks at the diversity of mangrove species in the Chilaw lagoon and the partitioning of biomass carbon among the recorded species.





Highlights

- The mangroves at Chilaw Lagoon show high species diversity.
- *Bruguiera cylindrica* was the most abundant mangrove species in the Chilaw lagoon.
- The biomass carbon pool in mangrove forests was calculated to be 102.8 Mg Carbon ha $^{-1}$.
- *B. cylindrica* and *Avicennia officinales* contributed relatively more to biomass carbon in the Chilaw lagoon.

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RESEARCH ARTICLE

Floristic diversity and distribution of biomass carbon: A preliminary study of mangroves in Chilaw lagoon, Sri Lanka

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Abstract: Mangrove ecosystems across the island face many threats to their survival despite the multitude of benefits provided by them. Their superior carbon sequestration and storage capacity make them ideal for climate change mitigation. However, the conservation and management of these ecosystems are difficult mainly due to the lack of baseline information. The present study is a preliminary investigation of the diversity of mangroves and the distribution of biomass carbon across mangrove species in the Chilaw lagoon in the western coast of Sri Lanka. The study identified 12 species of mangroves belonging to six families in the Chilaw lagoon complex. Shannon's diversity index (1.90) and evenness (0.76) indicates a relatively higher diversity compared to other lagoon complexes in the island. The most abundant species identified was *Bruguiera cylindrica* followed by *Avicennia marina* and *A. officinalis*. *Xylocarpus granatum* and *B. sexangula* were the least abundant species identified. Biomass carbon was calculated from 357 plant stems. The above- and below-ground biomass carbon were 12.80 and 2.6 Mg C, respectively, and thus total biomass carbon content of the Chilaw lagoon was estimated to be 102.8 Mg C ha^{-1}. The highest contribution to biomass carbon was from *B. cylindrica*. *A. marina* too contributed significantly to the biomass carbon, despite fewer individuals encountered.

***Keywords**:* Mangroves; Diversity; Biomass carbon; Chilaw Lagoon

INTRODUCTION

Mangroves represent a unique group of plants that are found well adapted to highly saline, water-logged, anaerobic soils exposed to periodic inundation. Sri Lanka's coastline of approximately 1,700 km is home to mangrove forests which are found distributed as highly localized patches, most of which are under threat owing to anthropogenic effects such as overexploitation, prawn farming, pollution, habitat degradation, and climate change (Miththapala, 2008). The total extent of mangrove forests of the island is estimated to be 19,758 ha (Premakantha *et al*., 2021), and are distributed in all major climatic zones of the island, with about 5,009 ha of mangrove forests found in the dry and arid zones, 430 ha in the wet zone, and 644 ha in the intermediate zone (Arulnayagam *et al*., 2021). A majority of mangrove forests are found in association with lagoons. The Puttalam lagoon in Kalpitiya located in the north-western coast of the island is the single largest mangrove forest patch in Sri Lanka, accommodating approximately 2,300 ha of continuous mangrove forest.

Previous studies on the mangrove ecosystems of Sri Lanka have noted a high floristic diversity and abundance (Arulnayagam *et al*., 2021). True mangroves, as well as mangrove associates are identified from Sri Lanka. To date, the most comprehensive documentation of species diversity and threat status to mangrove species in Sri Lanka is included in the 2020 National Red List for Flora. It indicates a total of 27 true mangrove species belonging to 14 families. Twelve of these species are belonging to the threatened category, with 4 critically endangered species (*Lumnitzera littorea, Sonneratia apetala, Xylocarpus rumphii*, and *Ceriops decandra*). One critically endangered (possibly extinct) species of mangrove associate - *Acanthus ilicifolius var. integrifolius* is also identified in mangrove ecosystems of Sri Lanka. Other more common species that are encountered on the island include *Rhizophora mucronate*, *Aegiceras corniculatum*, and *Sonneratia caseolaris*.

However, other publications indicate varying numbers of true mangrove species present in the island. The previous Red Data List (2012) records 22 species of true mangroves belonging to 12 families (Jayatissa, 2012). However, a more recent review identifies 28 species that belong to 13 families (Arulnayagam *et al*., 2021). In other sources, the number of species of true mangroves is indicated to range from 17 – 25 (Pinto, 1986; Jayasuriya, 1991). Thus, the need for a more thorough review of the species of mangroves reported from the island is required. Apart from the intrinsic values of diversity provided by mangrove ecosystems, they also provide extensive benefits to the human community. The ecosystem services rendered by these ecosystems include provisioning services such as timber, fisheries and aquaculture, regulating services such as coastline protection against erosion and flood retention, supporting services such as land accretion and carbon sequestration and cultural services such as aesthetic services (Miththapala, 2008). A particular focus of the present study is to explore the ability of mangrove forests to capture and store large quantities of carbon. Due to their high capacity to capture and store carbon, mangroves, seagrass beds, and salt marshes are identified as blue carbon ecosystems and ecosystems vital in mitigating climate change (Donato *et al*., 2011; Perera

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and Amarasinghe, 2015; Bertram *et al*., 2021). A study by Taillardat *et al.* (2018) identified that the carbon-storing capacity of mangrove ecosystems is considerably superior at the plot scale, despite some overlooked biogeochemical processes which may lead to an overestimation.

On average, mangrove forests store approximately 1,023 Mg C ha^{-1} based on studies carried out in the Indo-Pacific regions (Donato *et al*., 2011). These carbon reserves are mainly found in two main pools which include the living organic carbon pool found in the plant body and the soil carbon pool found belowground. The soil carbon pool includes soil (inorganic carbon) and dead roots (organic carbon), which make up the major carbon reserve that is found in mangrove forests and accounts for about 60 - 85% of carbon stocks (Amarasinghe and Perera, 2017; Perera and Amarasinghe, 2019; Kauffman *et al*., 2020). Rapid carbon burial owing to sediment accumulation results in the burial of about 174 g C $m^{-2}year^{-1}$, which indicates the ability of mangrove soils to store carbon (Alongi, 2012). The high and long-term carbon storage below ground is due to the physicochemical conditions prevalent in mangrove soils. High saline, anaerobic conditions, with limited exposure to oxygen, greatly slow down the rate of decay of organic matter and restricts the amount of carbon released back into the atmosphere. In addition to this, mangrove forests also accumulate organic sediment matter which adds to stored carbon in these ecosystems (Perera and Amarasinghe, 2019). These extensive belowground carbon reserves benefit mangrove forests as they provide a high nutrient reservoir, help stabilise mangroves against tidal action, and facilitate adequate nutrient turnover - litterfall may be washed away due to tidal action, hence belowground reserves maintain continuous nutrient cycling (Alongi, 2012). The accumulation of carbon in soil within mangrove forests is dependent mainly on the local climatic conditions and other hydrogeological factors (Alongi, 2012: Perera and Amarasinghe, 2019).

Despite their benefits, mangrove forests are subject to high threats on both global and local scales. In Sri Lanka, the extent of mangrove forests is not only limited but also highly fragmented and influenced heavily by human activities (Gunawardena *et al*., 2016). As mangrove forests on the island are found in intertidal zones which may be as low as 75 cm and are not tide dominant, they tend to occur as narrow strands (Ellepola and Ranawana, 2015; Perera and Amarasinghe, 2019). Apart from their highly fragmented nature, these forests are found in very close proximity to human settlements and provide many subsistent uses to the community (fisheries, firewood, wood, etc.) meaning they face high risks of destruction and disturbance. A study by Dahdough-Guebas et al. (2002) focusing on the expansion of prawn farms in the Chilaw lagoon indicated that shrimp farms grew by 25 ha between the period of 1994 and 1998, predominantly at the expense of mangrove forests. This resulted a loss of 6.1% of mangrove forests from the lagoon (Dahdough-Guebas et al., 2002).

The present study was undertaken with two main objectives in mind. The first is to explore the richness in diversity of mangrove communities that are found within the Chilaw lagoon. The second is to determine the living biomass carbon pool in mangroves identified within the study site and the contribution of each species to the total biomass carbon pool within the mangrove forest. The information generated from this study is expected to help to provide a baseline upon which more information regarding the diversity of mangrove communities and biomass carbon portioning among species in the Chilaw Lagoon can be developed. Such information can be helpful generate an incentive for the conservation of mangrove ecosystems and more representative studies on the mangrove communities of Sri Lanka as well as their contributions to local and global carbon dynamics.

METHODOLOGY

The present study is a preliminary study to explore the diversity and distribution of biomass carbon among mangrove species in the Chilaw lagoon. The site selected for the study was the Chilaw Lagoon complex, focusing on mangrove islands in the upper region of the lagoon (Figure 1). Constraints which arose during the period of study restricted sampling to only the mangrove forest islands on the upper region of the lagoon. Thus, we consider this to be a preliminary study. The lagoon is found in Pambala (7°31’08.5”N 79°49’26.6” E) on the Western coast of the island in the Puttalam District of the North-western province. The average temperature and annual precipitation recorded from the lagoon are 27.9 °C and 150.8 mm respectively (de Silva *et al*., 2022). The lagoon is 29.5 km in length and 2 km wide at its broadest and has a surface area of approximately 1800 ha. The lagoon is not very deep where the depth ranges between 0.8 – 3.0 m. The lagoon connects to the sea through two outlets; the Northern outlet is a narrow canal of 7.8 km and the Southern outlet is one of 5.5km. The total direct catchment of the lagoon is 45.3 km^3 (DFAR, 2013; CEA, 1994).

Four belt transects, divided into 10 m × 10 m plots were laid down in the upper region of the lagoon, focusing on the mangrove forest islands (Figure 2). As islands of mangrove forest were sampled, the length of the each transects varied. Transects were laid down to capture the maximum level of vegetation diversity, structure and zonation, thus when similarity in species composition was noted such as in the inner regions of the mangrove islands, the transects were not extended.

Within each transect, the circumference of the stems of mangrove trees (> 5 cm) was measured using a standard tape to calculate the diameter at breast height (DBH). Species identification was carried out on each enumerated plant. Species identification was carried out in the field with the use of the Handbook to the Flora of Ceylon and other resources.

The collected species data (species identified and the number of each species identified) was used to determine Shannon – Weiner’s diversity index of richness and evenness using the conventional equations mentioned below. These two indexes provide an appropriate tool to compare the mangrove diversity of the lagoon with other sites on the island.

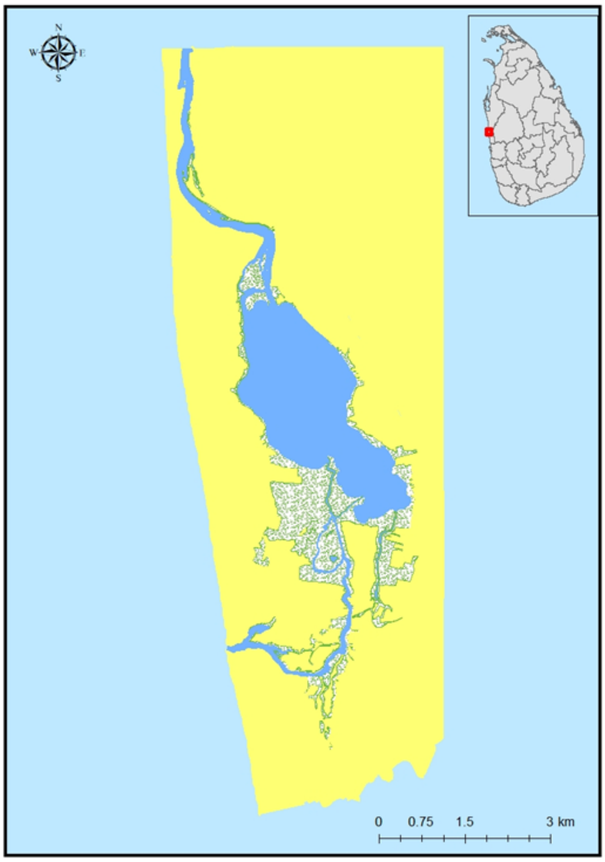

Figure 1: The map highlighting the study site, the Chilaw lagoon complex.

Figure 2: Positions of belt transects in the study site.

For Shannon – Weiner diversity index;

Species richness is given by;

$H=\sum[(pi)\times\ln(pi)]$

where pi = proportion of total sample represented by species I

Species evenness is given by; $\frac{H}{H_{max}}$

$H_{max} = ln(S)$ = maximum diversity possible (where S = number of species)

To determine the biomass carbon, the DBH of plants was calculated from the circumference of stems of mangrove stands measured. Depending on the availability, species-specific allometric equations were applied to calculate the above-ground biomass (AGB) and the below-ground biomass (BGB) of each tree. Species-specific allometric equations are preferable as they account for the specific wood density. However, in the absence of such species-specific equations, common equations were used. The calculated biomass was pooled and multiplied by 0.56[1] to determine the total biomass carbon (TBC) that is present in the trees. The allometric equations utilized are summarised below (Table 1). Wherever available, species-specific allometric equations were used. In all other scenarios, common allometric equations were used.

RESULTS

Diversity and Species Composition

A total of 213 individual trees were identified, enumerated, and DBH calculated. A total area of 0.15 ha (1,500 m^2) was surveyed during the study. The average stand density of the mangrove forests amounted to 1,420 trees/ha. The average DBH of the enumerated mangrove stands was 7.00 cm. Zonation of mangroves was observed in the islands; *Rhizophora mucronata* and *R. apiculata* were found only in the outer fringes of islands that were surveyed while other recorded species were predominantly observed in the interior.

Twelve true mangrove species belonging to six families were reported from the studied sites of the Chilaw lagoon complex. The most common species recorded was *B. cylindrica,* of which 78 individual plants were encountered. They accounted for 36% of the individuals that were identified and measured in the study site. *A. marina, R. mucronata,* and *R. apiculata* were also identified in considerable frequencies, accounting for around 14%, 13%, and 10% of the recorded individuals. In comparison, species such as *B. sexangula* and *X. granatum* were found to be the least abundant with only one individual from both species being identified. The relative abundance of the species in the study site is indicated below in Figure 3 and a complete list of species identified is shown in Table 2. Among the species recorded, two Endangered species (*B. cylindrica* and *X. granatum*), and two Vulnerable species (*B. sexangular* and *B. gymnorhiza*) were identified. It is worth noting that 78 individuals of endangered *B. cylindrica* were recorded from the study sites.

The diversity and the evenness of mangrove species in the study site were calculated assuming that the four transects were representative of the entire mangrove community in the lagoon. Accordingly, calculated Shannon's index and the evenness were 1.90 and 0.76, respectively.

Biomass and Biomass Carbon Distribution

In relation to biomass and biomass carbon content calculations, the DBH of a total of 357 plant stems was calculated. The average stem density was calculated at

1 Total biomass carbon accounts for 56% of biomass (IPCC, 2001).

Table 1: Allometric equations used to determine biomass in mangrove species.

Species	Allometric Equations		Source
	Above Ground Biomass	Below Ground Biomass	
Common Equation	$0.251\ \rho\ dbh^{2.46}$	$0.199\ \rho\ 0.899\ dbh^{2.4}$	Komiyama et al., 2005
Rhizophora mucronata	$\log_e(AGB) = 6.247+2.64\ \log_e(dbh)$		Amarasinghe and Balasubramanium, 1992
Avicennia marina	$\log_e(AGB) = 5.551+2.153\log_e(dbh)$		Amarasinghe and Balasubramanium, 1992
Bruguiera gymnorrhiza	$0.289(dbh)^{2.327}$	$0.100(dbh)^{2.364}$	Perera et al., 2011
Lumnitzera racemosa	$0.114\ (dbh)^{2.523}$	$0.118\ (dbh)^{2.063}$	Perera et al., 2011

dbh: Diameter at breast height (cm)
ρ: wood density of the corresponding mangrove species

Table 2: The list of mangrove species identified in the survey, their abundance and threat status.

Species	Family	Abundance	Relative abundance (as a %)	Threat status[2]
Bruguiera cylindrica	Rhizophoraceae	78	36.62	EN
Avicennia marina	Acanthaceae	30	14.08	LC
Rhizophora mucronata	Rhizophoraceae	28	13.15	LC
Avicennia officinalis	Acanthaceae	23	10.80	NT
Rhizophora apiculata	Rhizophoraceae	23	10.80	NT
Excoecaria agallocha	Euphorbiaceae	14	6.57	LC
Bruguiera gymnorhiza	Rhizophoraceae	5	2.35	VU
Aegiceras corniculata	Primulaceae	4	1.88	LC
Rhizophora x anamalayana[1]	Rhizophoraceae	3	1.41	-
Lumnitzera racemosa	Combretaceae	3	1.41	NT
Bruguiera sexangula	Rhizophoraceae	1	0.47	VU
Xylocarpus granatum	Meliaceae	1	0.47	EN

2 As indicated by the IUCN Red List Categories and Criteria (IUCN, 2013).

2380 stems/ha. The total biomass and biomass carbon content of the Chilaw lagoon were estimated to be 183 and 102.8 $MgCha^{-1}$ respectively. The contribution of each species to the overall biomass and carbon content in the mangrove community of the Chilaw lagoon is depicted in Table 3 below.

DISCUSSION

The present study which was carried out focusing on the mangrove islands in the upper region of the Chilaw lagoon provides vital baseline information on both the diversity and living biomass carbon pool in the mangrove forests of the lagoon. Given the restriction in the sampling sites, the authors acknowledge that this may not be a representative interpretation of the entire lagoon complex. Nonetheless, the information provided through this study helps to develop a foundation upon which further studies can be carried out. Jayasundera et al. (1999) similarly restricted their study sites to the lower region of the Chilaw lagoon and identified 13 species, while Cooray et al. (2021) and Jayasuriya (1991) identified 10 and 15 species respectively from field surveys carried out in the Chilaw lagoon.

The most common species, and thus the dominant mangrove species identified from the study site was *B. cylindrica*. Previous studies carried out in the Chilaw lagoon, show differences in dominant mangroves. Jayasuriya (1991) and Nigamuni & Subasinghe, (2015) reported *E. aggalocha* to be the most common species encountered while Jayasundera *et al*., (1999) have reported *A. officinalis* as the most abundant mangrove species in the lagoon. Amarasinghe and Perera (2017) identified *L. racemose* as the most abundant species encountered in the Chilaw lagoon and Cooray et al., (2021) identified *R. apiculata* and *R. mucronata* as co-dominating species in the lagoon complex**.** Further, species such as *Sonneratia alba* and *Sonneratia caeseolaris* which were previously encountered in the lagoon (Jayasuriya, 1999) were not recorded in the present study. The restricted nature of the sampling sites may account for the differences in species composition that are observed.

Table 3: Contribution of each species to biomass and biomass carbon content from the total biomass (as a %).

Species	No. of individuals	Biomass (Mg ha^{-1})	Organic C (Mg C ha^{-1})	% Biomass/carbon contribution
A. corniculata	4	0.73	0.40	0.41
A. marina	30	28.07	15.73	15.27
A. officinalis	23	53.67	30.07	29.21
B. cylindrica	78	61.53	34.47	33.50
B. gymnorhiza	5	0.33	0.20	0.20
B. sexangula	1	0.13	0.07	0.06
E. agallocha	14	8.80	4.93	4.78
L. racemosa	3	0.47	0.27	0.25
R. apiculata	23	7.73	4.33	4.22
R. mucronata	28	15.40	8.60	8.37
R x anamalayana	3	6.73	3.80	3.68
X. granatum	1	0.067	0.04	0.04

The Shannon diversity index and the evenness of diversity of the Chilaw lagoon were 1.90 and 0.76 respectively. When comparing Shannon's indexes calculated elsewhere; Negambo Lagoon indicates a value of 2.32 (Nigamuni and Subasinghe, 2015), Puttalam Lagoon, 0.76 (Nigamuni and Subasinghe, 2015), and Mandaitivu and Arali was 2.02 and 1.79, respectively (Arulnayagam, 2021). This indicates that the diversity in the Chilaw lagoon is comparatively high. However, Nigamuni and Subasinghe (2015) reported the Shannon index for the Chilaw lagoon as 2.18. The discrepancy could be due to differences in the species composition, dominance, and other flora characteristics of the limited area which were surveyed during field studies.

In regard to biomass carbon, the largest contribution to biomass carbon is from *B. cylindrica*. *B. cylindrica* contributed living biomass and biomass carbon content of 61.53 Mg ha^{-1} and 34.47 MgC ha^{-1}, respectively, representing 33.5% of the calculated total biomass carbon. *A. officinalis* was the second-highest contributor to living biomass and biomass carbon accounting for 29.2% of the calculated carbon stock (53.67 Mg ha^{-1} of biomass and 30.07 MgC ha^{-1} of biomass carbon). Living biomass and biomass carbon of mangrove species were found to increase with the abundance of the species under consideration, albeit to varying levels. However, it is interesting to note that while 78 individuals of *B. cylindrica* contributed to the highest recorded biomass and biomass carbon stock among mangrove species, only 23 individuals of *A. officinalis* contributed to almost equally high living biomass and biomass carbon content. This may be owing to the fact that many of the *A. officinalis* trees encountered were considerably older and larger in size.

Calculated living biomass and biomass carbon contents represent a considerably small portion of the total ecosystem carbon. In mangrove ecosystems, the predominant carbon reserves are found in association with the soil carbon reserves. Cooray *et al*. (2021) calculated soil carbon in the Chilaw lagoon to be 888.21 MgC ha^{-1} making use of the loss-on-ignition method, indicating that soil carbon accounts for almost eight times the living biomass carbon content calculated from the living pool (102.8 MgC ha^{-1}) in the current study. The high carbon content observed in mangrove ecosystems indicates the vast benefits these ecosystems have toward mitigating rising carbon emissions. Thus, these ecosystems can play a vital role in mitigating climate change and require urgent interventions for conservation. The identification of biomass carbon distribution among species can help to shape future replanting programs that aim to achieve more than species conservation. Replanting programs can be developed in such a way that species contributing to the highest biomass pools can be prioritised. It should be noted that species recommendations towards this end cannot be identified through the findings of this study as it does not explore the carbon sequestration capacities of different mangrove species.

The current study provides vital information for the conservation of species that are subject to high levels of threat. It provides a foundation upon which further studies may be carried out, identifies the variety of mangrove species which are present and also provides information regarding the high biomass carbon which is stored within these mangrove species. The present information is indicative of the potentially high diversity of mangrove species which may be found in the Chilaw Lagoon. Given that only a small region of the lagoon was sampled and the aforementioned results were obtained, a more thorough study may result in the identification of more species which could contest the importance of conserving the mangrove forests of the Chilaw lagoon. The large diversity evident from the Chilaw lagoon consolidates the importance of its conservation despite the Chilaw lagoon being overlooked by the wetland directory (IUCN, 2006). It also corroborates the statement by Jayathissa et al. (2012) regarding the high species divergence recorded in the Chilaw lagoon.

Apart from their intrinsic value toward biodiversity and the contribution to the carbon biomass pool, mangroves also provide a plethora of other ecosystem services that support communities throughout the lagoon. The extent of ecosystem service derived from mangroves also filtration, sediment retention, protection against coastal erosion and storm surges, and many other benefits (Miththapala, 2008) and the continued subsistence of these benefits requires the conservation of mangrove forests within the Chilaw lagoon as well as throughout the country.

As shown in this study the biomass carbon reserves in mangrove forests are large and thus are identified to be ideal tools for mitigating climate change owing to the large amount of carbon that can be sequestered by mangrove forests. Further studies which can provide information on the carbon sequestration capacities of different mangrove species can help to shape future replanting programs that aim to achieve more than species conservation. Using such information, replanting programs can be developed in such a way that species with the highest carbon sequestration capacities are planted, thereby increasing the carbon sequestration capacity of the mangrove forest and ultimately removing a high amount of carbon from the atmosphere.

CONCLUSION

The present study takes into consideration the diversity as well as the distribution of biomass and biomass carbon across different species of mangrove encountered in the Chilaw lagoon. The study shows that the lagoon complex is home to a large diversity of mangrove species, many of which are found to be in the threatened or near-threatened category. The most abundant species identified was *B. cylindrica*, an endangered species while species such as *B. sexangula* and *X. granatum* were among the least encountered species. *B. cylindrica* accounts for the highest biomass Carbon storage, while *A. officinalis* contributed secondly to the living pool of biomass and biomass carbon. The study is indicative of the high value of the Chilaw lagoon with regard to the diversity and carbon capture and storage potential of mangrove species present in the lagoon consolidating incentives for conservation. It also draws attention to means by which conservation strategies for species protection can be incorporated into climate change mitigation to achieve pragmatic solutions to climate change.

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THE AUTHORS DECLARE NO COMPETING INTERESTS.

The authors declare that they have no competing interests

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