# APPENDICES

**SEYCHELLES' BLUE CARBON ROADMAP**

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## APPENDIX A

### Estimating blue carbon stocks in Seychelles

Seychelles' mangrove forests extend across approximately 1,700 ha[1,2] and include up to 8 species[3] (Table 1, Figure 2). Two recent scientific publications improved the estimates for mangrove cover for Aldabra[1,4], while mangrove distribution for Mahé, Praslin, Silhouette, La Digue and Curieuse can be found in Senterre and Wagner (2014)[5] as part of a nationwide mapping exercise of terrestrial habitat types. Within Mahé, the mangrove forest of Port Launay has been mapped in detail by Alcindor (2015)[6], who provides an analysis of the species-specific cover of the mangrove forest (Box 1 in the Roadmap).

Seychelles' seagrass maps are currently being updated. Previous maps estimate seagrass coverage at 2.1 million ha[2] (Figure 1) however, new locally produced maps using field-verified data indicate that seagrasses cover an area of approximately 143,000 ha (Rowlands et al. in prep*). There are up to nine species of seagrass[3] reported for Seychelles (Table 1, Figure 3).

Despite the large distribution of seagrasses and mangroves throughout Seychelles, there are still large knowledge gaps in the distribution of these ecosystems and in the associated carbon stocks and sequestration rates[3].

This Seychelles' blue carbon stock assessment is based on the datasets identified by two comprehensive literature reviews conducted during 2021[3,7]. Table 2 shows the best available information on the spatial distribution of seagrasses and mangroves in Seychelles, while Table 3 shows the best available/existing information on carbon stocks for the region. Detailed information on the existing data on blue carbon ecosystems in the Tropical Western Indian Ocean is available in Palacios et al. (2021)[3].

For both mangroves and seagrass meadows, data on the plant and soil carbon stocks (tonnes of organic carbon per hectare; Table 3) was combined with the area extent of each ecosystem (in hectares, based on the best available distribution maps; Table 2) to estimate total carbon stocks across Seychelles. Results are displayed in Table 4. For seagrass meadows, we calculated both the upper and lower bound to account for existing uncertainties in the seagrass distribution extent.

The $CO_2$ equivalent ($CO_2$e) of blue carbon stocks stored within seagrasses and mangroves was calculated by multiplying the organic carbon values by 3.67 (which is a conversion factor based on the atomic weight of one carbon atom versus one carbon atom and two oxygen atoms). Our carbon stock estimates differ from those calculated by the Mapping Ocean Wealth Seychelles[8] due to differences in the input data used for the calculations (see Tables 2 and 3).

* Rowlands GP, Antat S, Baez SK, Barri PM, Cupidon A, Faure A, Harlay J, Lee CB, Martin LEC, Morgan M, Mortimer JA, Traganos D (in prep) The Seychelles Seagrass Mapping and Carbon Assessment. A report to be submitted to the Ministry of Agriculture, Climate Change and Environment (MACCE).

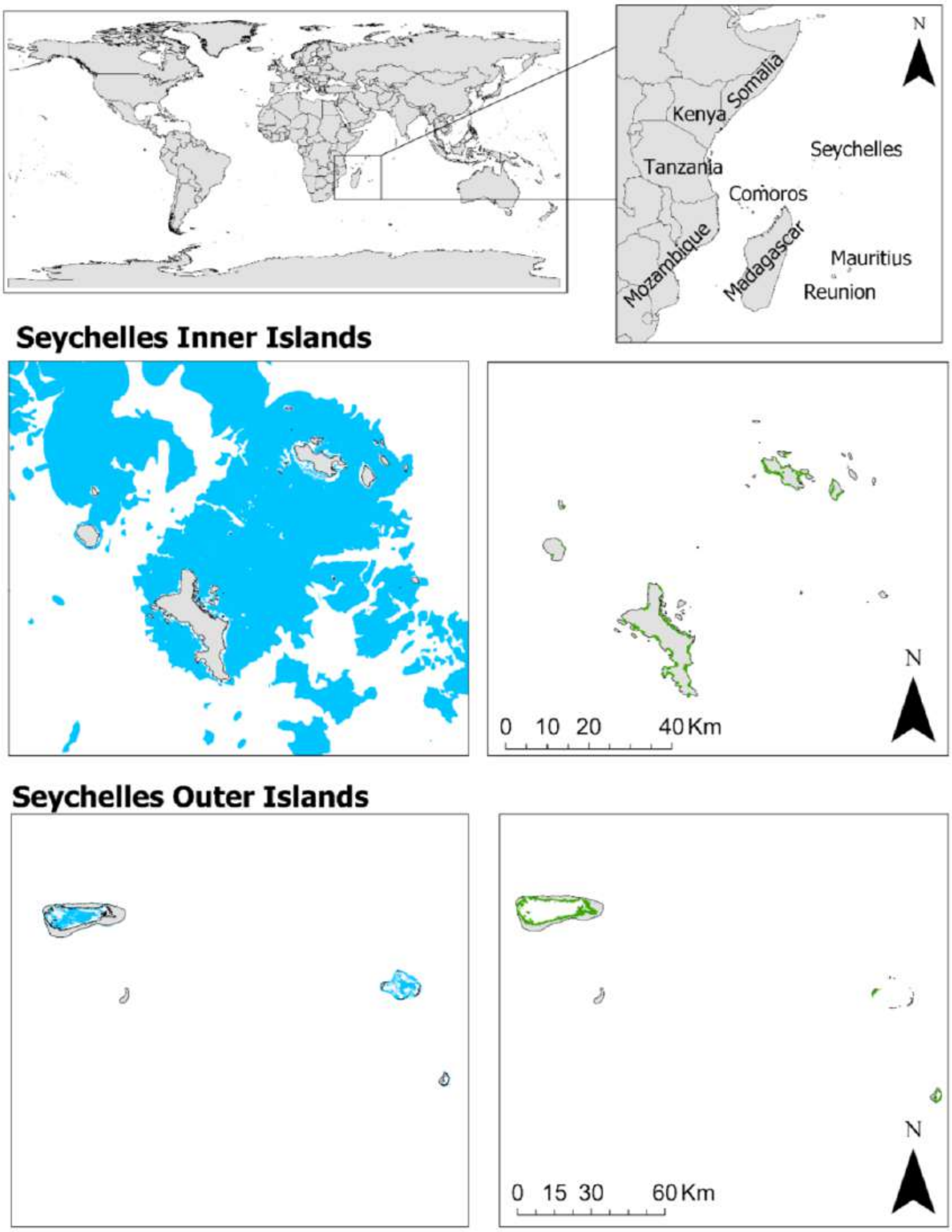


**Figure 1.** Distribution of seagrass meadows (representing upper bound of the potential distribution of seagrasses in Seychelles)[2] and mangrove forests in the tropical Western Indian Ocean region[1,2].
NOTE: There are no spatial files currently available representing the lower bound of the seagrass distribution in Seychelles. These maps using field-verified data are being generated by Rowlands et al. (in prep)*.

* Rowlands GP, Antat S, Baez SK, Barri PM, Cupidon A, Faure A, Harlay J, Lee CB, Martin LEC, Morgan M, Mortimer JA, Traganos D (in prep) The Seychelles Seagrass Mapping and Carbon Assessment. A report to be submitted to the Ministry of Agriculture, Climate Change and Environment (MACCE).

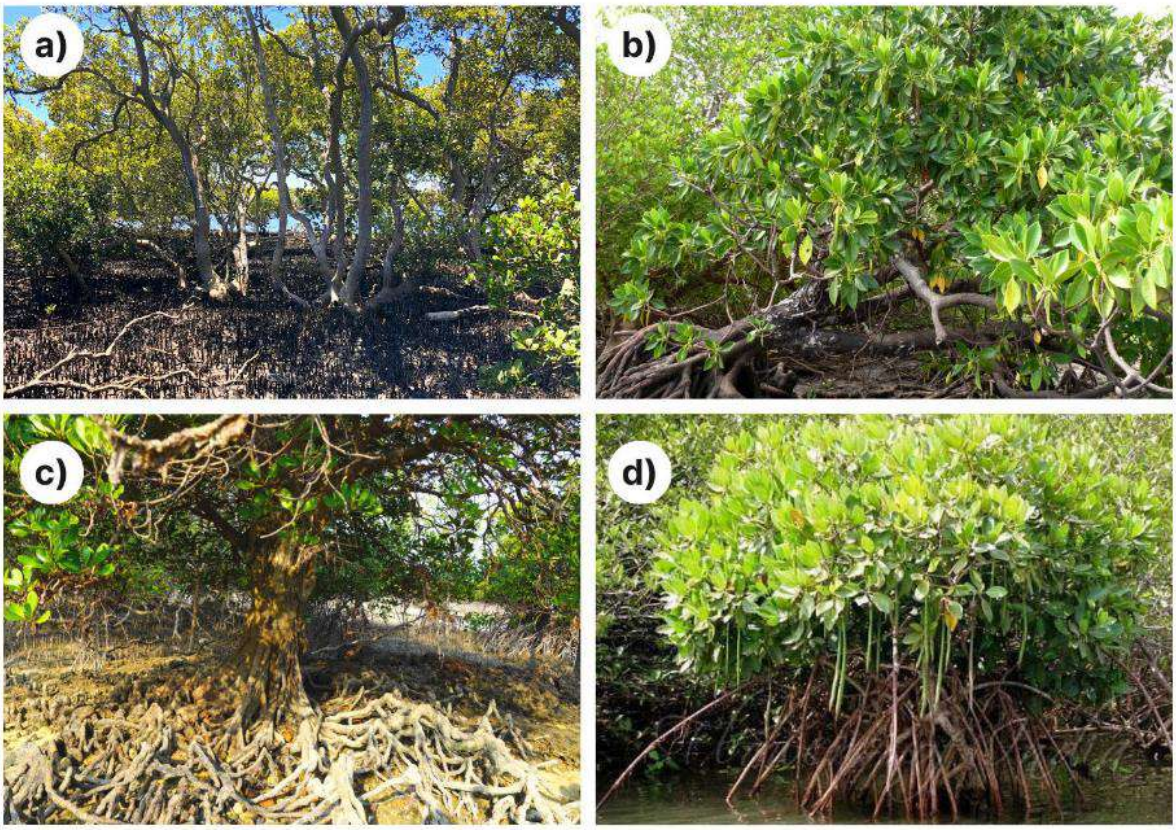


**Figure 2.** Common mangrove species in the tropical Western Indian Ocean region. (a) *Avicennia marina* (Source: MM. Palacios); (b) *Bruguiera gymnorrizha* (Source: mozambiqueflora.com); (c) *Ceriops tagal* (Source: Reuben Lim via flickr.com); (d) *Rhizophora mucronata* (Source: alchetron.com). Species displayed alphabetically.

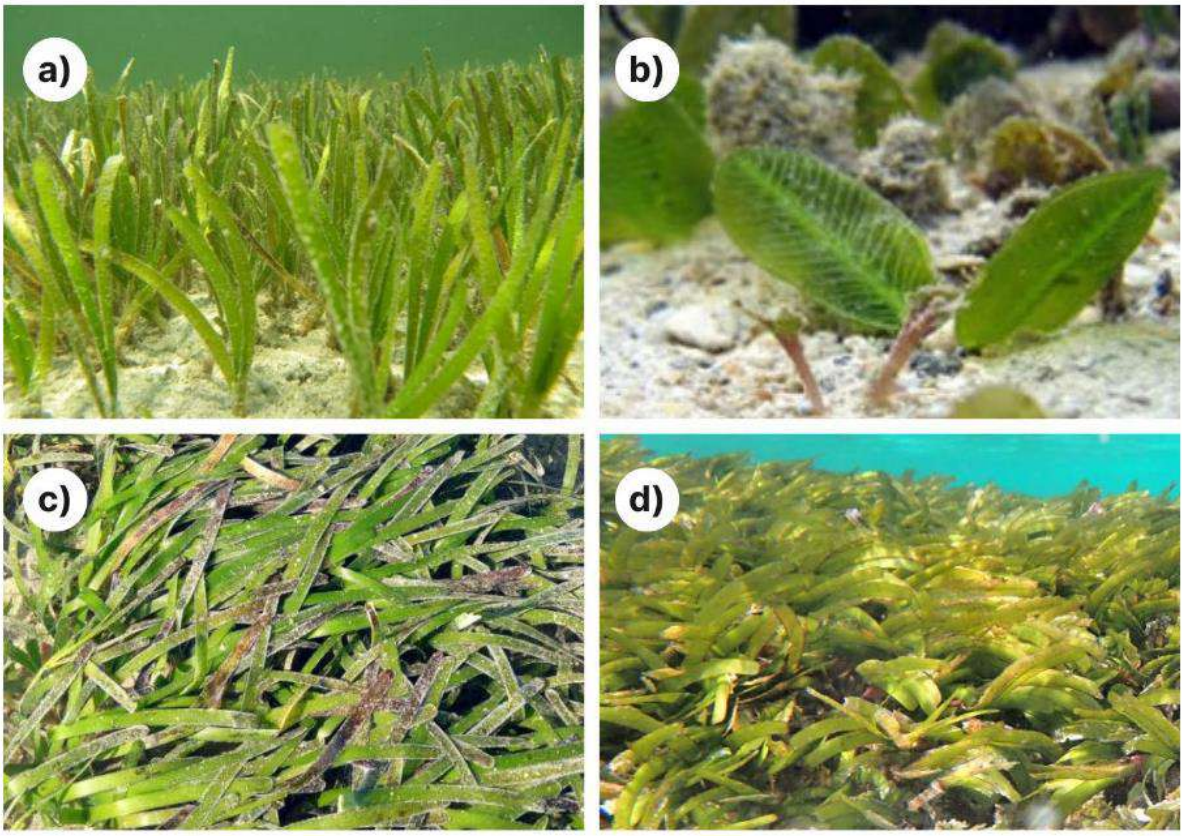


**Figure 3.** Common seagrass species in the tropical Western Indian Ocean region. (a) *Cymodocea serrulata* (Source: SeagrassWatch); (b) *Halophila ovalis* (Source: SeagrassWatch); (c) *Thalassia hemprichii* (Source: SeagrassSpotter); (d) *Thalassodendron ciliatum* (Source: SeagrassSpotter). Species displayed alphabetically.

**Table 1.** Mangroves and seagrasses recorded for Seychelles based on Palacios et al. (2021)[3].

| Mangroves | Seagrasses |
|---|---|
| *Avicennia marina* | *Cymodocea rotundata* |
| *Bruguiera gymnorrizha* | *Cymnodocea serrulata* |
| *Ceriops tagal* | *Enhalus acoroides* |
| *Lumnitzeria racemosa* | *Halodule sp. [uninervis / wrightii]* [a] |
| *Rhizophora mucronata* | *Halophila ovalis [minor]* [b] |
| *Sonneratia alba* | *Halophila decipiens* [c] |
| *Xylocarpus granatum* | *Syringodium isoetifolium* |
| *Xylocarpus moluccensis* | *Thalassia hemprichii* |
| | *Thalassodendron ciliatum* |

[a] Several authors indicate *Halodule wrightii* does not occur in the region and has been misidentified with *Halodule uninervis*.

[b] *Halophila minor* is often considered a member of *Halophila ovalis* complex.

[c] *Halophila decipiens* was recently confirmed in the region[9], so few published records exist on its distribution. Personal communication by Jeanne A. Mortimer during the workshop 'The state of knowledge of seagrass habitats in Seychelles' in April 2020.

**Table 2.** Existing information (to the best of our knowledge) on habitat extent of blue carbon ecosystems in Seychelles. In **bold** is the information used to inform this assessment.

| Ecosystem | Area (ha) | Spatial data available? | Reference Year | Region | Study |
|---|---|---|---|---|---|
| Mangrove forests | 1,087 | Yes (UNEP) | 2000 | Global | Giri et al. (2011)[10] |
| | 104.7 | Yes (UNEP) | 2010 | Global | Bunting et al. (2018)[11] |
| | 110 | Yes (UNEP) | 2016 | Global | Bunting et al. (2018)[11] |
| | 541 | Yes (CGMFC-21) | 2014 | Global | Hamilton and Casey (2016)[12] |
| | **2,508** | **Yes (at request to the authors)** | **Collation of local maps** | **Seychelles** | **Smith et al. (2020)**[2] |
| | 1,720 | Yes (Dryad repository) | 2011 | Aldabra | Walton et al. (2019)[1] |
| | **1,221** | **No** | **2018** | **Aldabra** | **Constance et al. (2021)**[4] |
| | 26 | Yes (at request to the author) | 2013 | Port Launay | Alcindor (2015)[6] |
| Seagrass meadows | **2.1 million** | **Yes (at request to the authors)** | **Collation of local maps** | **Seychelles** | **Smith et al. (2020)**[2] |
| | **142,065** | **Unknown** | **Unknown** | **Seychelles** | **Rowlands et al. (in prep)*** |
| | 119,963 | Yes (UNEP) | Collation of available maps | Global modelled distribution | Jayathilake and Costello (2018)[13] |

* Rowlands GP, Antat S, Baez SK, Barri PM, Cupidon A, Faure A, Harlay J, Lee CB, Martin LEC, Morgan M, Mortimer JA, Traganos D (in prep) The Seychelles Seagrass Mapping and Carbon Assessment. A report to be submitted to the Ministry of Agriculture, Climate Change and Environment (MACCE).

**Table 3.** Existing information on mean carbon stocks (tonnes $C_{org}$ $ha^{-1}$) for seagrasses and mangroves in Seychelles*. In **bold** is the best mean carbon data available for each carbon pool and ecosystem in Seychelles, which was used to inform this assessment.

| Ecosystem | Carbon pool | Mean carbon stock (tonnes $C_{org}$ $ha^{-1}$) | Region | Study |
|---|---|---|---|---|
| Mangrove Forests | AGC | 59.3 | WIO | Palacios et al. (2021)[3] |
| | BGC | 46.3 | WIO | Palacios et al. (2021)[3] |
| | **AGC + BGC** | *A. marina*: 103<br>*C. tagal*: 45.8<br>*R. mucronata*: 88.9<br>**Mixed forests: 109.1** | **Aldabra Atoll (Seychelles)** | **Palacios et al. (2021)[7] based on data from Constance (2016)[14]** |
| | | 92 | Seychelles | Macreadie et al. (2021)[15] based on data from Simard et al. (2019)[17], which used the mangrove extent developed by Hamilton & Casey (2016)[12] |
| | SOC | 644 | Seychelles | Macreadie et al. (2021)[15] based on data from Sanderman et al. (2018)[18], which used the mangrove extent developed by Giri et al. (2011)[10] |
| | | 386 | Global (IPCC default value for aggregated organic and mineral soils) | IPCC (2014)[19] |
| | | **369** | **WIO** | **Palacios et al. (2021)[3]** |
| | Mangrove total stocks (AGC + BGC + SOC) | 462 | Aldabra Atoll | UNESCO (2020)[20] based on AGC+BGC data from Sllimard et al. (2019)[17], SOC data from Sanderman et al. (2018)[18] and mangrove extent from Giri et al. (2011)[10] |
| Seagrass meadows | AGC | **0.76** | **WIO** | **Palacios et al. (2021)[3]** |
| | BGC | **2.21** | **WIO** | **Palacios et al. (2021)[3]** |
| | SOC | **116** | **WIO** | **Palacios et al. (2021)[3]** |
| | | 144 | Seychelles | Macreadie et al. (2021)[15] based on the modelled seagrass extent[13] and SOC predictions from Atwood et al. (2020)[21]. |
| | | 34 | Aldabra | UNESCO (2020)[20] based on carbon data from Tanzania [22] |

* Local on-ground measures of mangrove carbon stocks (Wartman et al. in prep) and seagrass carbon stocks (Rowlands et al. in prep) are currently being generated to improve the accuracy of Seychelles' blue carbon estimates.

-Wartman M, Costa MDP, Palacios MM, Nourice B, Macreadie PI. (in prep) Blue carbon assessment for mangrove systems in Seychelles. A report to be submitted to the Seychelles' Department of Blue Economy. Deakin University, Australia.

-Rowlands GP, Antat S, Baez SK, Barri PM, Cupidon A, Faure A, Harlay J, Lee CB, Martin LEC, Morgan M, Mortimer JA, Traganos D (in prep) The Seychelles Seagrass Mapping and Carbon Assessment. A report to be submitted to the Ministry of Agriculture, Climate Change and Environment (MACCE).

**Table 4.** Estimated blue carbon stocks for each blue carbon ecosystem in Seychelles.

| Ecosystem | Carbon pool | Mean carbon stock (tonnes $C_{org}$ $ha^{-1}$) | Estimated carbon stocks (tonnes $C_{org}$) |
|---|---|---|---|
| Mangrove forests | AGC + BGC | 109.1 (mixed forests)[7] | 185,034 |
| | SOC | 369 [3] | 625,824 |
| Seagrass meadows | AGC | 0.76 [3] | 107,969 - 1,596,000* |
| | BGC | 2.21 [3] | 313,964 - 4,641,000* |
| | SOC | 116 [3] | 16,479,540 - 243,600,000* |

*For seagrass meadows, we calculated both the upper and lower bound to account for existing uncertainties in the seagrass distribution extent. The upper bound assumes a seagrass extent of 2.1 million ha [2], while the lower bound 143,000 ha (Rowlands et al. in prep*).

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## APPENDIX B

### Species-specific carbon stocks for mangroves in Port Launay in Seychelles

Using spatial data from Alcindor (2015)[6] for Port Launay, this example illustrates how the species-specific distribution of mangroves can be combined with carbon stock data to improve blue carbon estimates in Seychelles' mangrove forests.

| Mangrove species | Code | Mangrove Area (ha) | Plant carbon (tonnes C $ha^{-1}$) | Soil carbon (tonnes C $ha^{-1}$) | Total blue carbon stocks (tonnes C ) |
|---|---|---|---|---|---|
| *Avicennia marina* | | 1.45 | 103 | 369 | 684.40 |
| *Bruguiera gymnorhiza* | | 0.84 | 109* | 369 | 425.42 |
| *Ceriops tagal* | | 2.00 | 45.8 | 369 | 829.60 |
| *Lumnitzera racemosa* | | 0.80 | 109* | 369 | 382.4 |
| *Rhizophora mucronata* | | 5.72 | 88.9 | 369 | 2,620.51 |
| *Sonneratia alba* | | 6.99 | 109* | 369 | 3,341 |
| *Xylocarpus granatum* | | 3.45 | 109* | 369 | 1,649 |
| Mixed vegetation | | | | | |
| Dead mangroves | | | | | |
| River | | | | | |

**Area:** Includes species-specific mangrove cover estimated by Alcindor (2015)[6]

**Plant carbon:** Includes mean species-specific plant carbon stocks reported for Seychelles[7]. Values with asterisk (*) are mean mangrove plant carbon stocks within the WIO[3] due to lack of species-specific data for Seychelles.

**Soil Carbon:** Includes mean soil organic carbon (SOC) stocks for mangroves in the WIO[3], since data is not available for Seychelles.

## APPENDIX C

### Long-term change in mangrove carbon stocks in Aldabra Atoll, Seychelles

Using spatial data from Constance et al. (2021)[4] for the Aldabra Atoll, this example demonstrates how detailed data on the change in mangrove distribution can be combined with carbon stock datasets to understand fluctuations in blue carbon through time.

| Year | Mangrove Area (ha) | Area change (ha) | Plant stocks (tonnes $ha^{-1}$) | Soil stocks (tonnes $ha^{-1}$) | Total stocks (tonnes C) |
|---|---|---|---|---|---|
| 1997 | 1161 | NA | 109 | 369 | 554,958 |
| 2004 | 1121 | - 40 | 109 | 369 | 499,978 |
| 2009 | 1552 | 431 | 109 | 369 | 547,772 |
| 2014 | 1362 | - 190 | 109 | 369 | 530,262 |
| 2018 | 1221 | - 141 | 109 | 369 | 521,897 |

Since Aldabra Atoll is a restricted marine protected area, we assumed mangrove loss within the study period was not due to human impact, but mostly related to changes in the environmental conditions that led to declines in the mangrove vegetation[4]. For this analysis, we assumed that:

1. Soil carbon stocks for 1997 were calculated by multiplying the mangrove area extent in that year by the average carbon in mixed forests for Aldabra Atoll[7] (i.e., 109 tonnes per hectare). Then, we estimated the area lost and gained between the different time steps.
2. If mangrove area was lost, we assumed that 40% of the living biomass would be lost and that soil stocks would remain the same (i.e., no alteration). However, this is still an open question in blue carbon science.
3. If the mangrove area increased between two-time steps, we assumed that the gained mangrove area accumulated soil carbon following the global average rate of 1.89 tonnes of carbon per hectare per year[23].

## REFERENCES


1. Walton, R. et al. In the land of giants: habitat use and selection of the Aldabra giant tortoise on Aldabra Atoll. Biodivers. Conserv. **28**, 3183–3198 (2019).

2. Smith, J.L. et al. Seychelles Marine Spatial Plan Atlas. Developed by The Nature Conservancy for the Seychelles MSP Initiative. (2020).

3. Palacios, M. et al. Literature Review: Blue Carbon research in the Tropical Western Indian Ocean. (2021).

4. Constance, A. et al. Extent change of protected mangrove forest and its relation to wave power exposure on Aldabra Atoll. Glob. Ecol. Conserv. **27**, e01564 (2021).

5. Senterre, B. & Wagner, M. Mapping Seychelles habitat-types on Mahé, Praslin, Silhouette, La Digue and Curieuse. (2014) doi:10.13140/RG.2.1.4558.6009.

6. Alcindor, A. Mapping the distribution and composition of mangrove species: A case study in the Seychelles. (Kingston University London, 2015).

7. Palacios, M. et al. Seychelles' mangrove research and legislation. (2021).

8. Albert, D. et al. Evaluation of ecosystem goods and services for Seychelles' existing and proposed protected area system. (2021).

9. McMahon, K.M. & Waycott, M. New record for Halophila decipiens Ostenfeld in Kenya based on morphological and molecular evidence. Aquat. Bot. **91**, 318–320 (2009).

10. Giri, C. et al. Status and distribution of mangrove forests of the world using earth observation satellite data: Status and distributions of global mangroves. Glob. Ecol. Biogeogr. **20**, 154–159 (2011).

11. Bunting, P. et al. The global mangrove watch—a new 2010 global baseline of mangrove extent. Remote Sens. **10**, 1669 (2018).

12. Hamilton, S.E. & Casey, D. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Glob. Ecol. Biogeogr. **25**, 729–738 (2016).

13. Jayathilake, D.R.M. & Costello, M.J.A modelled global distribution of the seagrass biome. Biol. Conserv. **226**, 120–126 (2018).

14. Constance, A. Mangroves on Aldabra – habitat change trends, stand structure and species composition. (University of Zurich, 2016).

15. Macreadie, P. I. et al. Blue carbon as a natural climate solution. Nat. Rev. Earth Environ. **2**, 826–839 (2021).

16. Simard, M. et al. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. Nat. Geosci. **12**, 40–45 (2018).

17. Simard, M. et al. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. Nat. Geosci. **12**, 40–45 (2019).

18. Sanderman, J. et al. A global map of mangrove forest soil carbon at 30 m spatial resolution. Environ. Res. Lett. **13**, 55002 (2018).

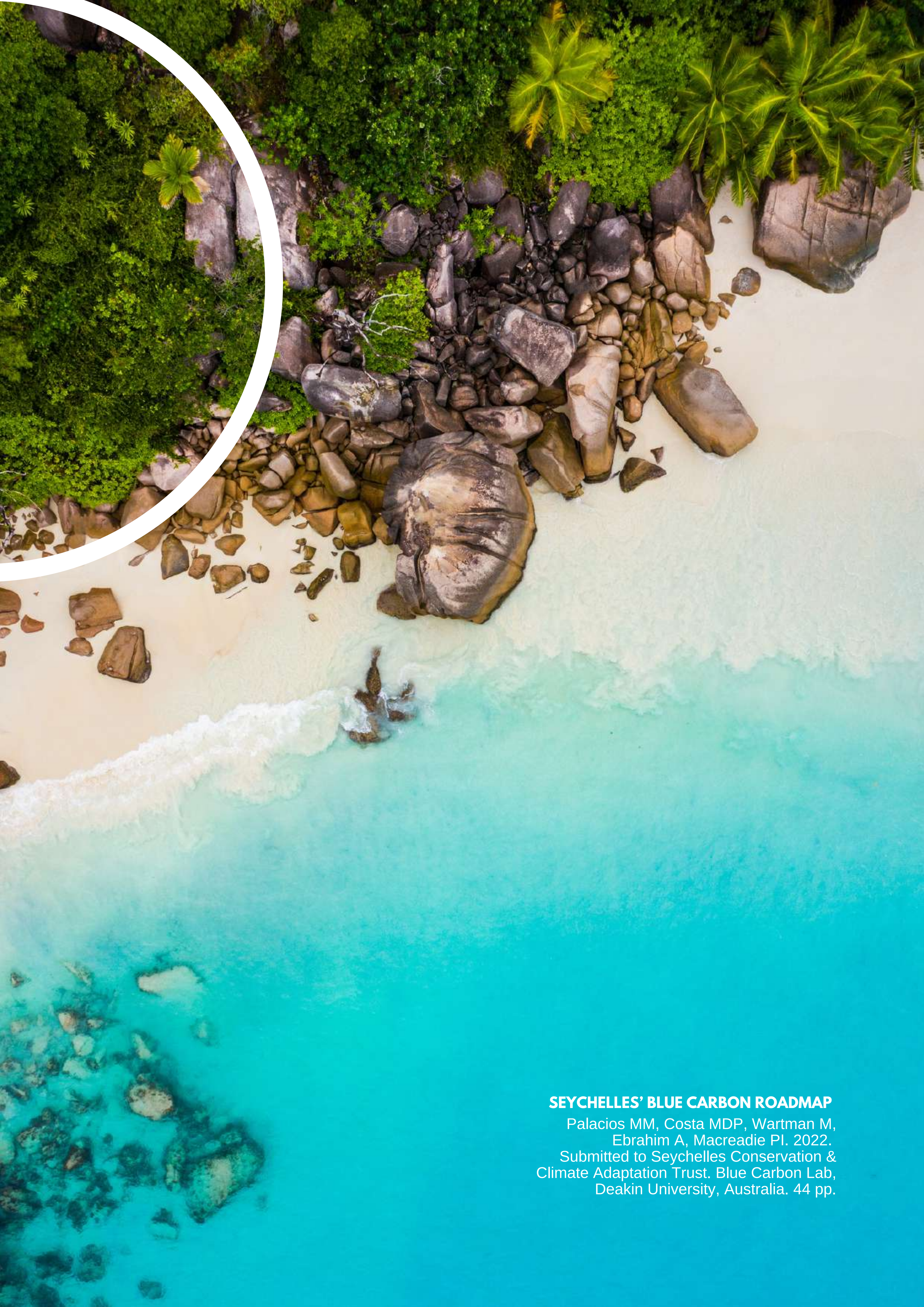
19. IPCC. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. (IPCC, 2014).

20. UNESCO. UNESCO Marine World Heritage: Custodians of the globe's blue carbon assets. (2020).

21. Atwood, T. B. et al. Global Patterns in Marine Sediment Carbon Stocks . Frontiers in Marine Science vol. 7 165 (2020).

22. Belshe, E. F., et al. Seagrass community-level controls over organic carbon storage are constrained by geophysical attributes within meadows of Zanzibar, Tanzania. Biogeosciences **15**, 4609–4626 (2018).

23. Nellemann, C. et al. Blue Carbon: A rapid response assessment. (United Nations Environment Programme, GRID-Arendal, 2009).



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