Supplementary Material

Drone-based characterization of seagrass habitats in the tropical waters of Zanzibar

Idrissa Y. Hamad[1, 2,*], Peter A. U. Staehr [1], Michael B. Rasmussen[1] and Mohammed Sheikh [2]

[1]Department of Ecoscience, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

[2]Tropical Research Center for Oceanography, Environment and Natural Resources [1], State University of Zanzibar, P, O. Box 146, Zanzibar, Tanzania

*Correspondence: iyhamad19@ecos.au.dk; or idrissa.hamad@suza.ac.tz.

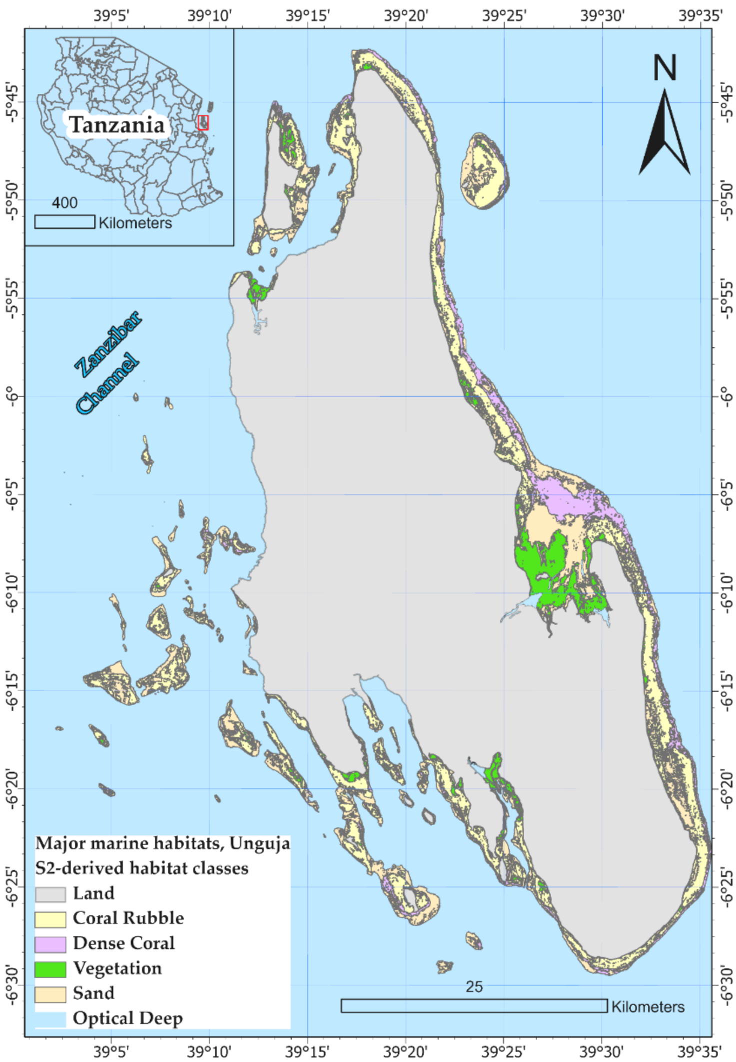
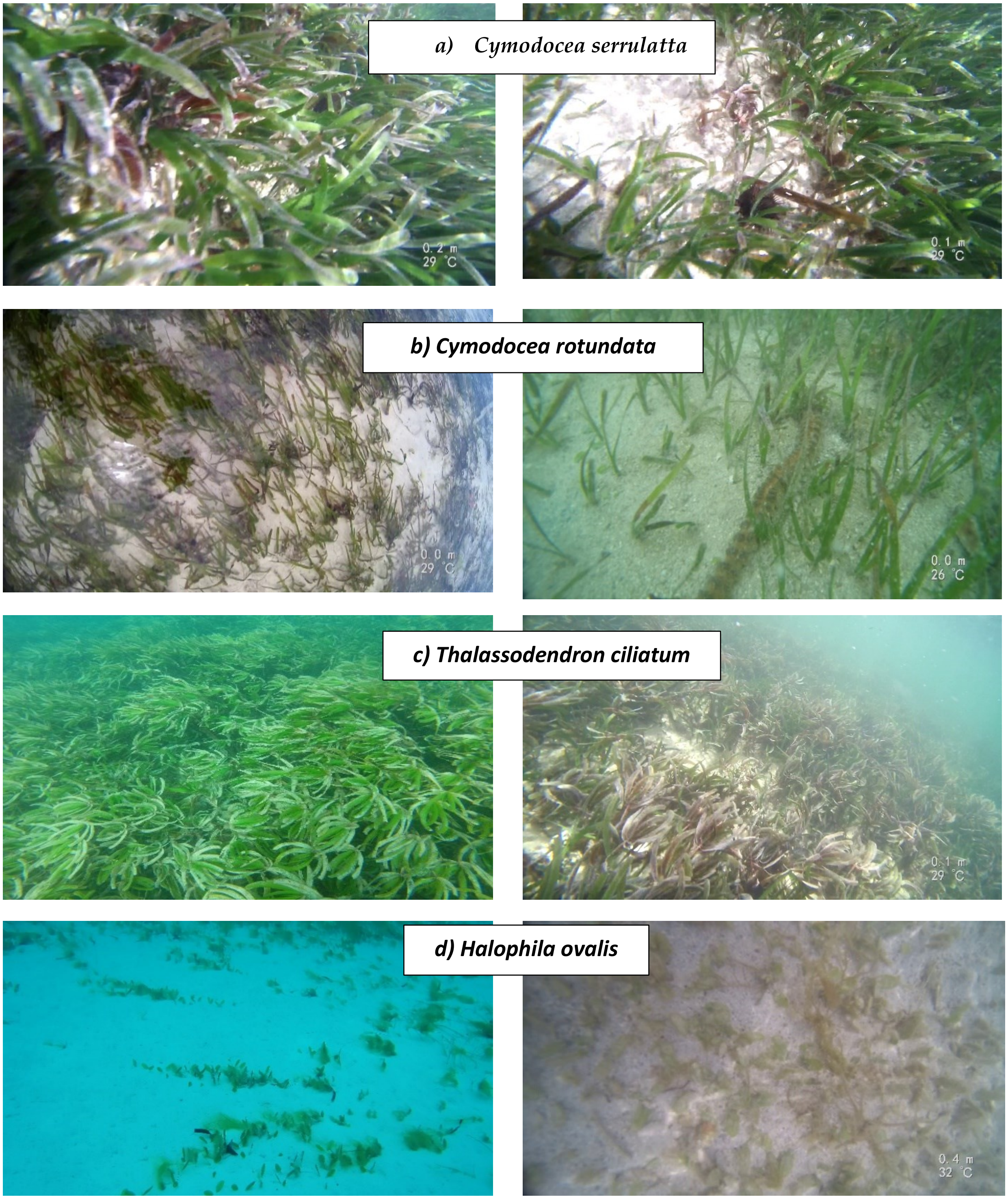


Figure S1. The Sentinel 2-derived major classes for marine habitats in Unguja, Zanzibar. We applied information acquired through this classification for the choice of detailed-local mapping of seagrass-dominated nine nearshore sites. This S2 habitat map served as first scoping map, where areas with major SAV were identified across the island so that our choice represented different angles of the island waters. We fine tune our selection with the reconnaissance survey to select nine areas s described in the Section 2.1 of the main paper. This Sentinel 2 habitat map was produced using machine-learning techniques a random forest algorithm using method presented by[1] based on the Sentinel 2 2 product of 2018 June.


a) Cymodocea serrulatta
b) Cymodocea rotundata
c) Thalassodendron ciliatum
d) Halophila ovalis

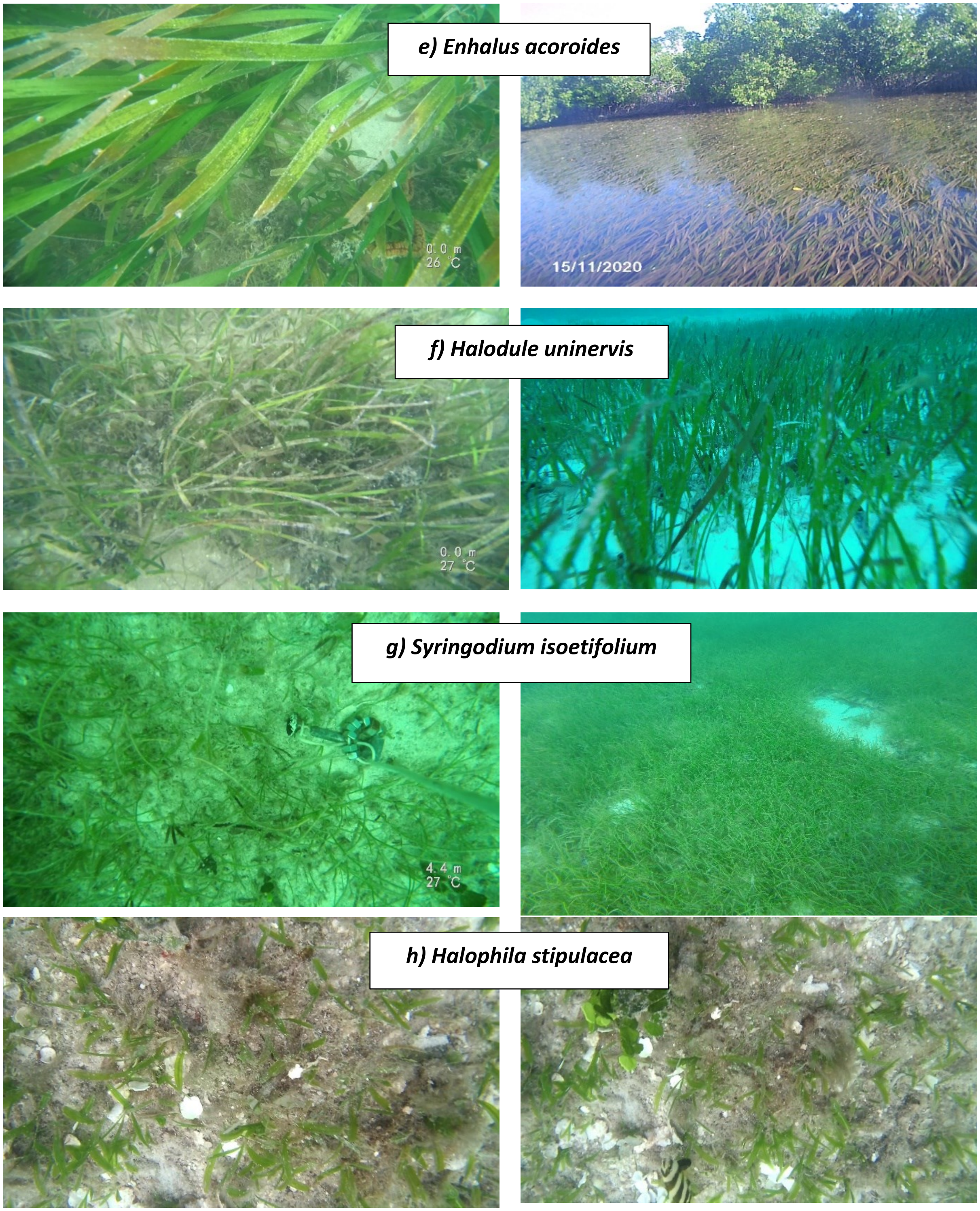
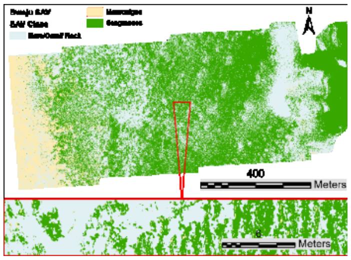
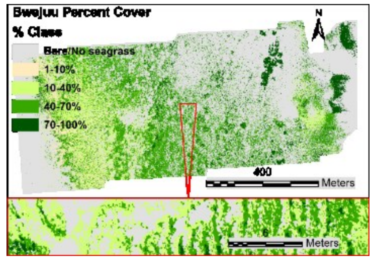

e) Enhalus acoroides
0.0 m
26 °C
15/11/2020
f) Halodule uninervis
0.0 m
27 °C
g) Syringodium isoetifolium
4.4 m
27 °C
h) Halophila stipulacea

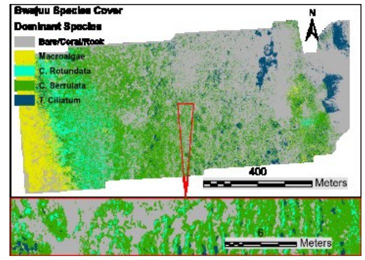
Figure S2. Seagrass species that were observed during fieldwork. **(a)** CS = *Cymodcea serrulata*; **(b)**CR = *Cymodocea rotundata*; **(c)** TC = *Thalassodendron ciliatum*; **(d)** HO= *Halophila Ovalis*; **(e)** EA = *Enhalus acoroides*; **(f)** HU = *Halodule uninervis*; **(g)** SI = *Syringodium isoetifolium*; ***(h)*** HS = *Halophila stipulacea*a; **(i)** TH = *Thalassia Hemprichii*. The most common species that we observed were CS, CR, TC, SI, and EH.

Site name	Benthic classes	Seagrass total cover	Seagrass species cover

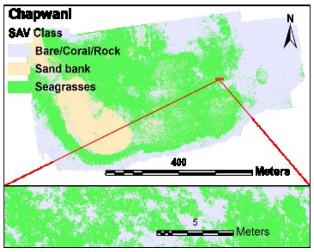
Bwejuu

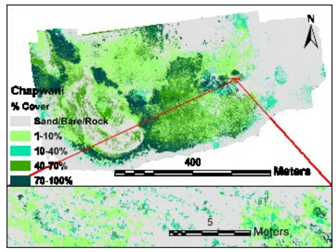


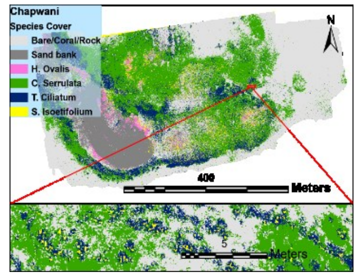




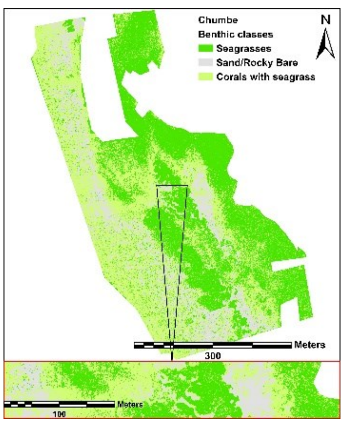
Chapwani

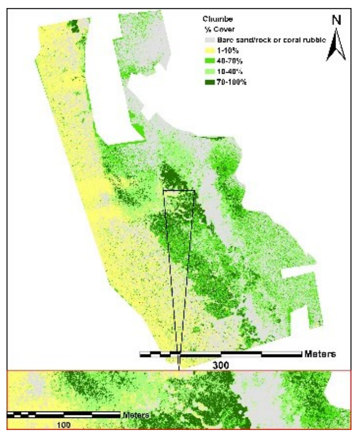


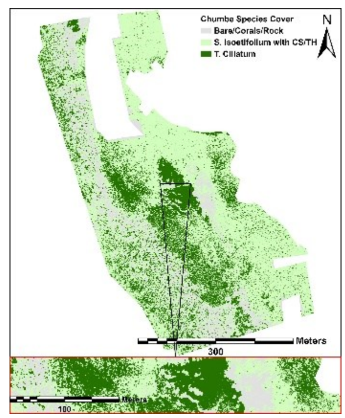




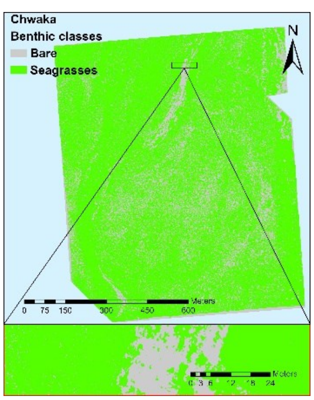
Chumbe

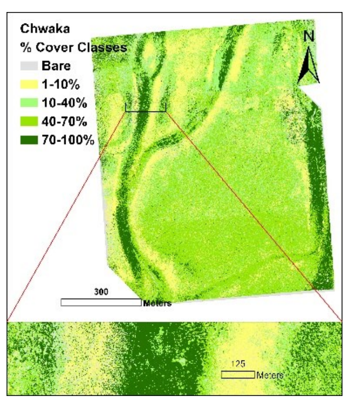


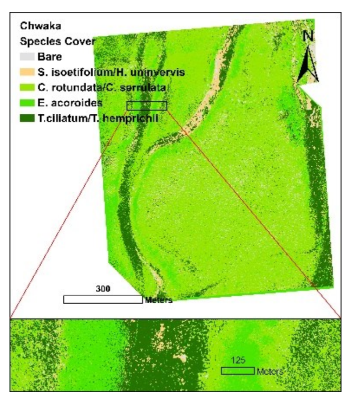




Chwaka



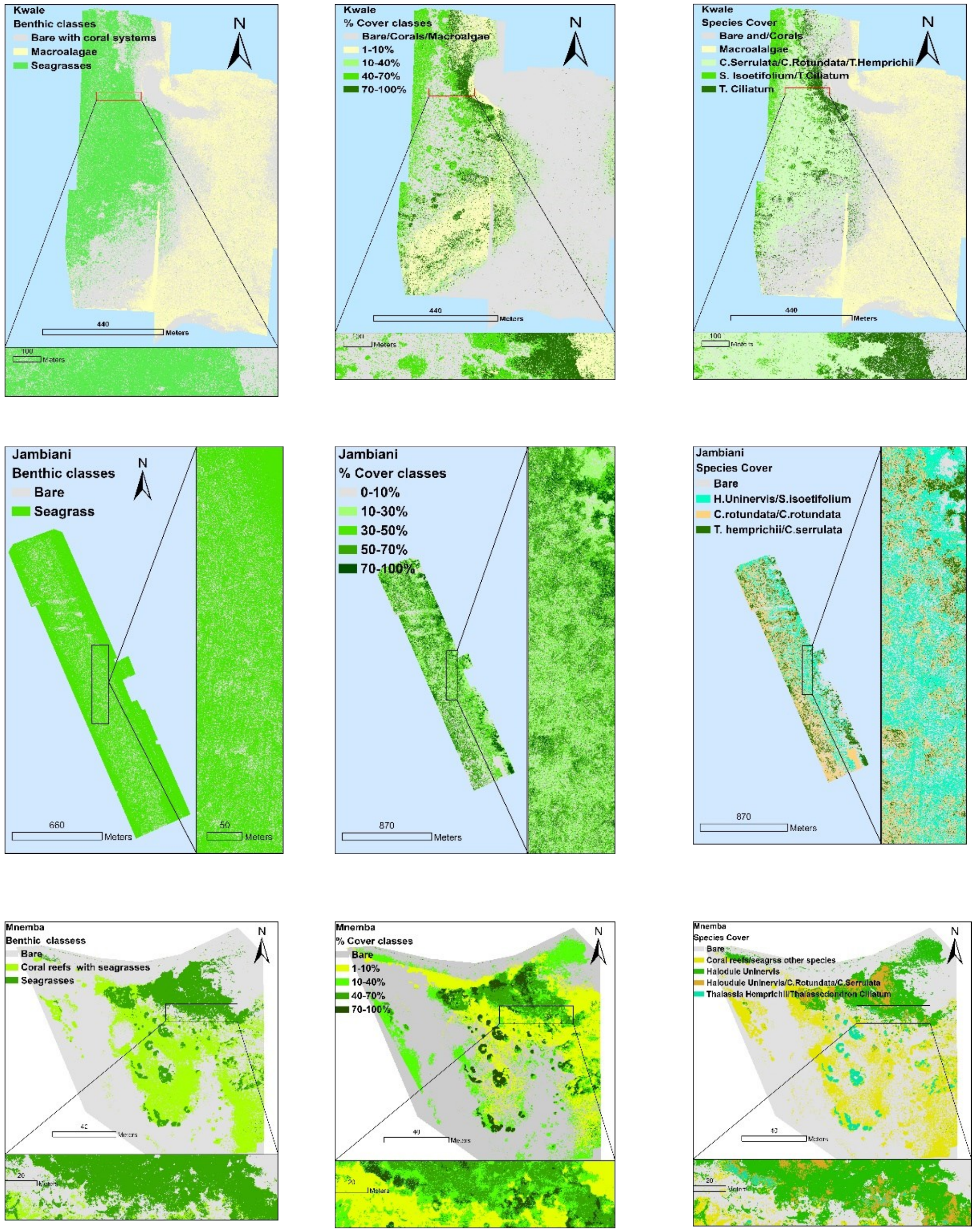




Kwale

Jambiani

Mnemba



Tumbatu

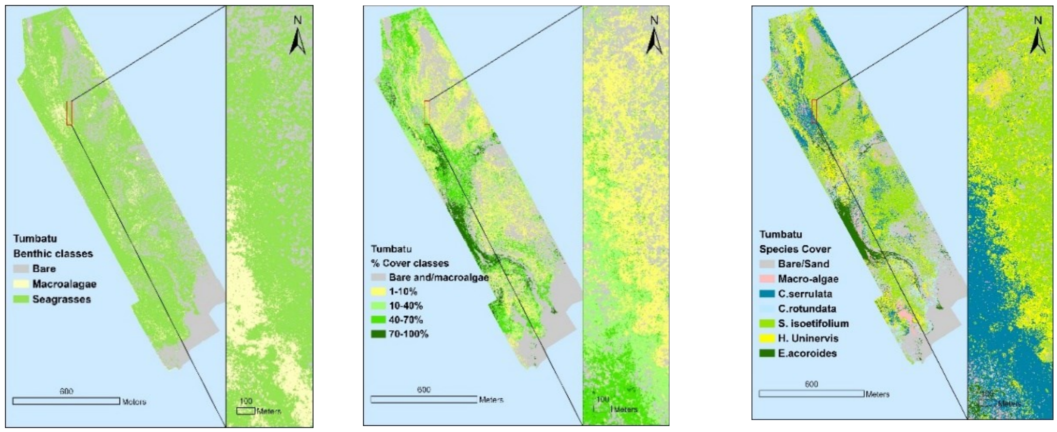


Figure S3. Classified cover maps of eight nearshore sites. We classified four benthic classes *(if all)* present (bare; seagrasses, corals, and macroalgae); seagrass cover was based on *the bare*, *low cover* (1-10%), *moderate cover* (10-40%) *dense cover* (40-70%), and *continuous cover* (70-100%). Species presented varied depending on the site. If more than one species was significantly co-existed, a common group was generated and shown on a map and the group name followed the order of their cover contribution. We observed nine, and eight of these species were possible to be shown on drone maps: *Cymodocea Serrulata, Cymodocea Rotundata, Syringodium Isoetifolium; Thalassodendron Ciliatum; Thalassia Hemprichii; Enhalus Acoroides; Haloldule Uniniervis and Halophila Ovalis.* On other hand, *Halophila Stipulacae was only found in small patches and not shown in these maps.*

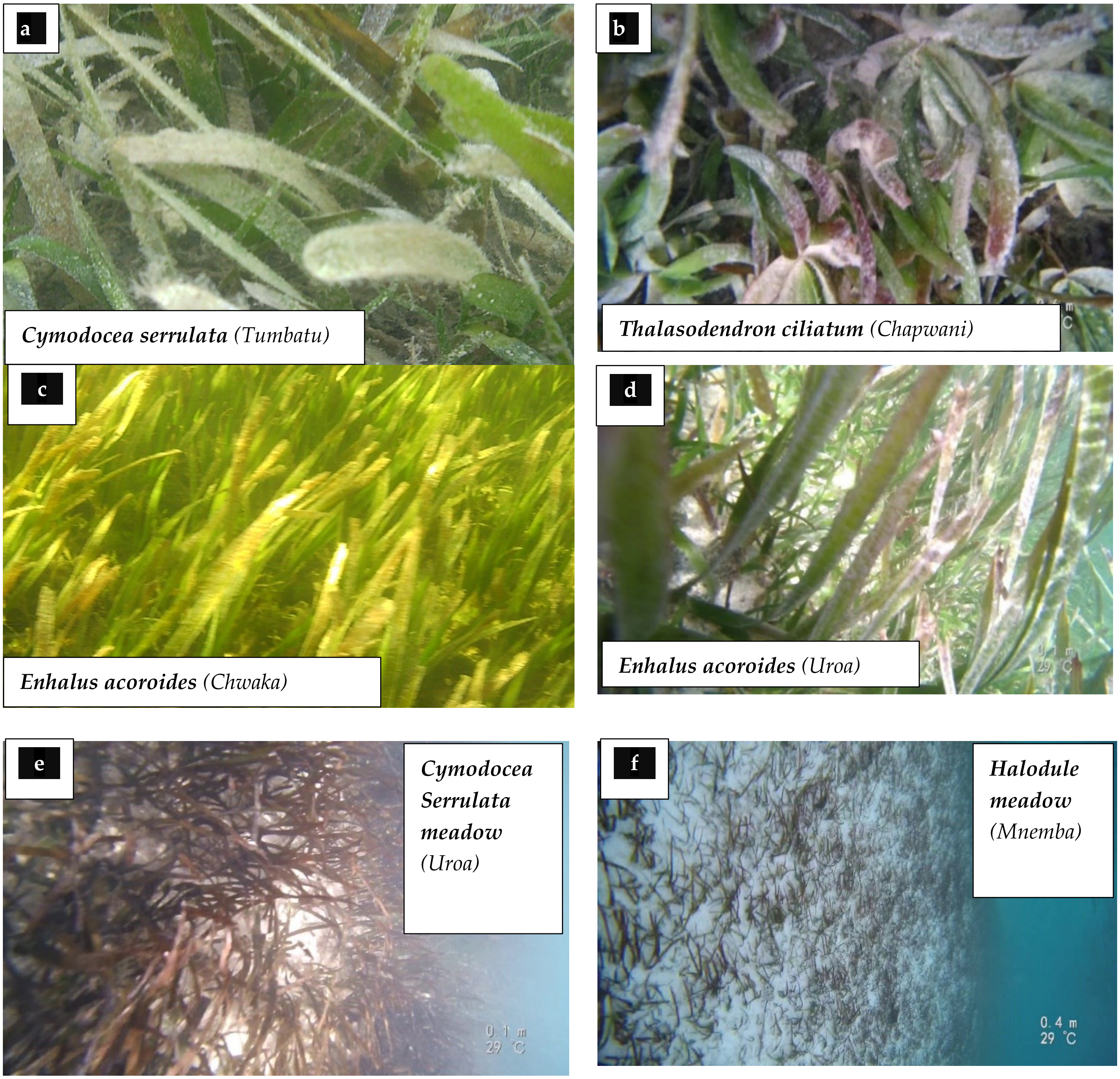


Figure S4. Species recorded a higher mean percent of epiphytic loadings & dead leaves. From top **(a-d)** are snapshots of different species levels of epiphytic cover on seagrass leaves and the last row **(e-f)** shows signs of desiccation **(e and f)** on leaves.

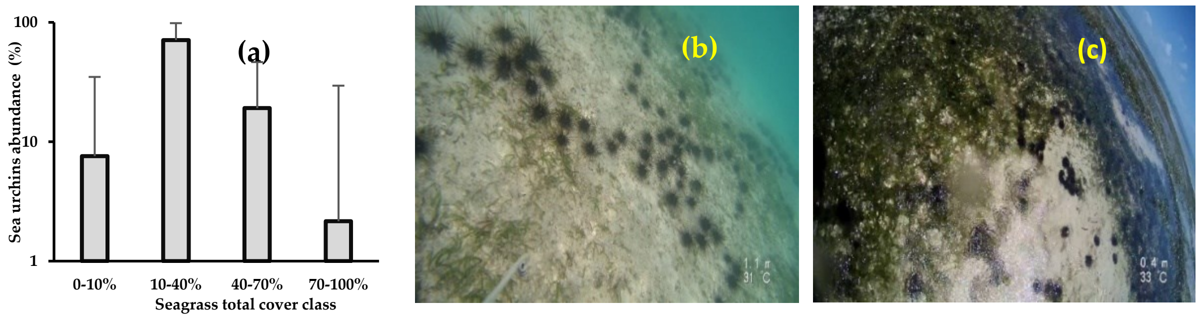


Figure S5. Observed patchiness in sea urchin abundant sites. **(a)** Sea urchin abundance in four seagrass cover classes. **(b)** An extended seagrass seascape with a high frequency of sea urchins associated with low percent cover and herbivory action by sea urchins (Chapwani) and patterns of extremely degraded seagrass shoots; **(c)** bare and low percent cover (10-40%) in Jambiani with high sea urchin density.

Table S1. Selected metrics for fragmentation analysis. All computations, equations, and metric naming were based on[2] *landscapementrics* R package.

Metric (Abbrv)	Full name	Metric type	Unit	Level	Equation	Current use
NP	Number of patches	Aggregation	None	P,C	$NP = ni$	Describes fragmentation of a class without indicating configuration or composition
PD	Patch density	Aggregation	Number per 100 hectares	Class	$PD = \frac{N}{A} * 10000 * 100$	Describes fragmentation; higher number as the landscape becomes more patchy.
AREA_MN	Mean of Patch Area	Area and Edge	Hectares	Class	$AREAMN = mean(AREA[patchij])$	Describe landscape composition and can indicate the structure. Summarizes the class as a means of all patch areas belonging to that class.
LPI	Largest Patch Index	Area and Edge	Percentage	Class	$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A} * 100$	Used to measure dominance effect by describing the percentage of the landscape covered by a corresponding largest patch of a particular class.
PLAND	Percent of a class in a landscape	Area and Edge	Percentage	Class	$PLAND = \frac{\sum_{j=1}^{n} a_{ij}}{A} * 100$	Describe landscape composition by computing percentage of the landscape benging to a class i.
GYRATE_MN	Mean radius of gyration	Area and Edge	Meters	Class	$GYRATEMN = mean(GYRATE[patchij])$	It measures the distance from each cell to the patch centroid. It characterize both the pathc area and compactness.
SPLIT INDEX		Area and Edge		Class	$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$	The measure patch aggregation. It describes the number of patches if all patches of class i would be divided into equally sized patches.
LD	Landscape Division Index	Aggregation	Proportion	Class	$DIVISON = (1 - \sum_{j=1}^{n} (\frac{a_{ij}}{A})^2)$	It describe fragmentation; it can be given as the probability that two randomly selected cells are not located in the same patch of class i.
PARA_MN	Mean Perimeter Area Ratio	Shape	None	Class	$PARA_{MN} = mean(PARA[patch_{ij}]$	The perimeter-area ratio describes the patch complexity in a straightforward way
TCA	Total Core Area	Core Area	Hectares	Class	$TCA = \sum_{j=1}^{n} a_{ij}^{core} * (\frac{1}{10000})$	It characterizes patch areas and shapes of patches belonging to class i simultaneously. It is also a measure of landscape configuration.
ED	Edge Density	Area and Edge	Meters per Hectares	Class	$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A} * 10000$	The metric describes the configuration of the landscape and it is standardized to the total landscape area, thus comparisons among landscapes with different total areas are possible.

Table S2. Summary description of the nine studied nearshore study sites around Unguja Island, Zanzibar.

Site Name & Coordinates	Coastal Type	Major habitat types and seagrass species	Substrate characteristics	Bathymetry
Bwejuu *39.5393980°E* *6.2409516°S*	Main-coastline; large intertidal area.	Seagrasses, macroalgae, and green algae in a shallow zone; intermittent coral rag systems.	Mainly of sand; soft substrate, fine sand to mud, and coral rubble.	Shallow, max. depth of 5 m.
Chapwani *39.1962128°E* *6.1275935°S*	An islet coast; the map covers an area close to a sandbank, which can be fully submerged.	Seagrasses occur intermittently with corals and coral rubble; it borders extensive rocky pavement with macroalgae towards islet (not mapped). The high density of sea urchins.	Mainly of sand, sandy coral in the seagrass meadows, significant accumulations of dead shelves, and deposited sediments of pebble size from the recently-developed marina.	Covers area up to 7 m depth. The seagrass is within 5 m and bathymetry is deep close to the ship channel.
Chumbe *39.1757430°E* *6.2824003°S*	A coral islet and MPA – Chumbe Island Coral Park.	Seagrasses; sand bare and hard pavement (often with algae). It has complex coral reef systems intermingle with seagrass spots.	Sand substrates form most of the seagrass-dominated beds. Hard bare in the pavement areas, especially bordering cliff coast	The mapped areas cover the area to the max. 10 m.
Chwaka *39.4449548°E* *6.1640658°S*	Main-coastline bay, with a very extensive intertidal area.	Rich in seagrass meadows and diversity often with macroalgae. *Enhalus acoroides* dominate in narrow pools with high epiphytic loadings.	Mainly of sand, fine sandy to mud substrates with spots of hard bottom. The exposed part to the coast also has bare hard substrata.	A shallow bay with an average of 3 m. Narrow strip pools with a max of 5 m.
Jambiani *39.5539270°E* *6.3179724°S*	Main-coastline; large intertidal area. Reef borders the coast from the open sea.	Seagrasses; bare sands; green and macro-algae. A high number of sea urchins and seaweed farms in the 1-2 m zone. Many seaweed farms intermittently co-exist with seagrass. Extensive seaweed detritus are evident occupying barren substrates.	Sand substrates; several bare hard/rocky beds alternate. The littoral beds consist of several small pools of sand beds with raised hard substrates. Erosion features are common within seaweed farms and in the pools.	Maximum area mapped falls with 5 m the area falling before the major reef.
Kwale *39.2921213°E* *6.3786193°S*	An islet coast; covers an area close to the sandbank. Part of Menai Bay Conservation Area.	Seagrasses heavily fused with coral reefs, bordering extensive rocky bear with macroalgae. *Thalassodendron ciliatum* meadows occupy deeper depth, and their canopies rise so high with shots about 85 cm high and hosting fish assemblage.	Sand substrates and rocky substrates; corals rubble, and sand bare in areas with seagrasses.	Maximum 10 m. The zone close to the islet and the sandbank is shallow.
Mnemba	An atoll and a marine conservation	Seagrasses; Coral reefs systems; very clear sand bares. What appeared to be wave-configured	Mainly of very fine and clear sand. Coral reefs systems.	The mapped area reaches a 5 m zone.

39.3976185°E *5.8036087°S*	area, no significant intertidal zone.	shapes define the seagrass here; pioneer species such as *Halophila ovalis* are evident in barren bottoms.		
Tumbatu *39.2353184°E* *5.8304471°S*	An island and a population center. The coast has a very extensive intertidal area. Untreated sewage effects and solid waste are evident near the island coast.	Seagrasses; macroalgae and green algae at the pavement area; aquatic weeds intermix with seagrasses. Signs of wasting diseases and pollution from solid waste are evident. Seagrass and weeds are competing in what appear to be highly nutrient-rich mud substrates.	Mainly of sand, hard pavement close to the land. Mud substrates; also sand-dominated by seagrasses.	Shallow 3 m. areas with deep strips and pools exist, which are used for boat navigation to the island during low tide.
Uroa *39.4293399°E* *6.0945890°S*	Main-coastline and a bay with a very extensive intertidal area.	Seagrass meadows; coral and rock systems, dunes submerged. Extensive areas of the dead and uprooted leaves are evident.	Mainly of sand; coral rubbles substrates: Very fine sand to mud beds are common close to the shoreline.	A shallow area with an average of 3 m and a max. of 5 m within the mapped area.

Table S4. Seagrass total cover share by site and depth.

Site	0-1 m	1-2 m	2-3 m	3-4 m	4-5 m	SD
Bwejuu	31.9	12.2	0.3	0.0	0.0	13.0
Chapwani	8.9	25.0	11.5	1.6	0.7	8.5
Chumbe	20.7	23.2	1.8	0.7	1.0	10.4
Chwaka	66.2	4.0	11.1	0.0	0.0	26.8
Jambiani	2.5	34.1	25.1	10.4	0.2	12.3
Kwale	0.9	8.3	2.8	6.5	8.0	2.9
Mnemba	3.0	32.3	1.8	0.0	0.0	13.4
Tumbatu	58.0	1.0	0.4	1.7	1.9	24.7
Uroa	37.3	40.8	0.3	0.0	0.0	19.5

Table S5. Additional metrics describing the degree of patchiness in seagrass meadows in nine nearshore sites.

Site	GYRATE_MN1 (m)	LPI1 (Percentage)	LD1 (Proportion)	TCA1 (Hectare)	PLAND1 (Percentage)
Bwejuu	0.61	14.50	0.79	5.80	9.86
Chapwani	0.42	43.60	0.81	6.58	28.20
Chumbe	0.40	43.40	0.81	5.86	32.30
Chwaka	0.92	79.10	0.38	39.50	46.10
Jambiani	14.70	0.15	1.00	0.27	0.28
Kwale	0.36	30.50	0.91	7.64	9.32
Mnemba	0.71	7.79	0.99	2.02	8.63
Tumbatu	0.60	60.80	0.63	31.90	35.40
Uroa	0.50	74.30	0.45	17.20	53.20
SD	**4.71**	**28.56**	**0.22**	**13.84**	**18.59**

[1]Largest patch index (LPI); Mean radius of gyration (GYRATE_MN); Landscape division index (LD); Total core area (TCA); and Percent of a class in a landscape i.e. PLAND. See (Table ST2, supplementary material) for details of each metric. Units are used based on the original computation in the landscapemetrics.

References:

1. Huber, S., et al., *Novel approach to large-scale monitoring of submerged aquatic vegetation: A nationwide example from Sweden.* Integrated Environmental Assessment and Management, 2021(2021:1-12): p. 1-12.
2. Hesselbarth, M.H.K., et al., *landscapemetrics: an open-source R tool to calculate landscape metrics.* Ecography, 2019. **42**(10): p. 1648-1657.