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Broad-scale benthic habitat classification of the South Atlantic

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Supplementary Material

R scripts for all analyses and links to download the final non-hierarchical and hierarchical habitat classifications are available at: https://github.com/DeepSeaCRU/South-Atlantic-Benthic-Habitat-Classification.

Table S1. Summary of global-, regional-, national- and finer-scale habitat classifications relevant to the South Atlantic.

Extent	Environment	Methods/Approach	Data	Reference
Global and regional classifications				
Global	Benthic and pelagic	Expert derived, hierarchical approach. Global Open Oceans and Deep Seabed (GOODS) biogeographic classification	Temperature, salinity, dissolved oxygen, organic matter flux.	UNESCO (2009)
Global	Benthic	Statistical, non-hierarchical approach based on ISO clustering	Depth, seabed slope, sediment thickness, primary production, bottom water dissolved oxygen, bottom temperature.	Harris & Whiteway (2009)
Global	Benthic	Mixed manual and statistical hierarchical approach	Bathymetry and topographic derivatives.	Harris et al. (2014)
Global	Benthic	Expert derived, non-hierarchical approach. Built on GOODs classification, with a focus on bathyal and abyssal zones	Depth, temperature, salinity, dissolved oxygen, particulate organic carbon flux.	Watling et al. (2013)
Global	Benthic and pelagic	Statistical, hierarchical approach based on *k*-means clustering	Temperature, salinity, dissolved oxygen, nitrate, phosphate, silicate.	Sayre et al. (2017)
Global	Pelagic	Mixed thematic and statistical hierarchical approach	Mixed layer depth, solar irradiance penetration, chlorophyll concentrations, biological data.	Longhurst (2007)
Global	Mesopelagic	Mixed expert derived and statistical non-hierarchical approach, based on expert knowledge supported by ISO clustering	Temperature, salinity, dissolved oxygen.	Sutton et al. (2017)
Global seamounts	Benthic	Thematic, hierarchical approach	Biogeography (based on goods), export production, summit depth, oxygen, seamount proximity.	Clark et al. (2011)

Global coastal and shelf areas (EEZs)	Benthic and pelagic	Expert derived, hierarchical approach	Biological data (e.g. species composition, endemism).	Spalding et al. (2007)
Global coastal and shelf areas (EEZs)	Benthic	Expert derived, non-hierarchical approach	Topography, hydrography, productivity, trophic relationships.	Sherman (1986)
Global	Benthic and pelagic	Thematic, hierarchical approach based on ecological function and biota. IUCN Global Ecosystem Typology	Depth, topography, ecosystem function, biological data (e.g. biogenic reefs).	Keith et al. (2020)
Global	Benthic and pelagic	Statistical, hierarchical approach based on clustering, SIMPER and ANOSIM	Distribution records of marine plant and animal species.	Costello et al. (2017)
Atlantic	Benthic	Statistical, non-hierarchical approach based on clustering by Gaussian mixture models	Bathymetry, slope, terrain ruggedness index, topographic position index, sediment thickness, POC flux, salinity, dissolved oxygen, temperature, current velocity, phytoplankton abundance in surface waters.	Schumacher et al. (2022)
National and finer-scale classifications				
South Africa: EEZ	Benthic and pelagic	Thematic, hierarchical approach	Bathymetry, sediments, oceanography, benthic biological data (grab, trawl, rov and other image data).	Sink et al. (2019)
South Africa: Coastal waters	Benthic	Statistical, hierarchical approach based on conditional inference trees	Aerial imagery, surf zone width, exposure, number of waves and bores, surf zone type, beach width, beach slope.	Harris et al. (2011); Harris et al. (2019)
South Africa: EEZ	Pelagic	Statistical, hierarchical approach based on clustering	Depth, slope, sea surface temperature, chlorophyll-*a*, net primary productivity, mean sea level anomalies.	Roberson et al. (2017)
South Africa: East coast	Benthic and pelagic (inshore), and pelagic (offshore)	Statistical, hierarchical approach based on *k*-means clustering	Sea surface and bottom temperature, chlorophyll-*a*, turbidity, bathymetry, sediments, seabed oxygen.	Livingstone et al. (2018)
South Africa:	Benthic	Statistical, non-hierarchical approach based on clustering, PCO and SIMPER	Sediment grain size, depth, slope, maximum surface chlorophyll concentration, austral summer bottom temperature, austral summer	Karenyi et al. (2016)

West coast continental shelf			bottom oxygen concentration, sediment organic carbon content.	
Namibia: EEZ	Benthic and pelagic	Mixed thematic and statistical, hierarchical approach. Coastal areas mapped by Harris et al. 2013; offshore (>30m) benthos mapped through thematic, hierarchical approach; offshore (>30m) pelagic mapped through ISO clustering	Coastal: - Grain size and wave exposure. Benthic: - Depth, slope and topography, geology, biozones. Pelagic: - Sea surface temperature, net primary productivity, chlorophyll-*a*, depth, turbidity, frequency of eddies, distribution of temperature, chlorophyll fronts.	Holness et al. (2014); Harris et al. (2013)
Namibia: Coastal waters	Benthic	Statistical, hierarchical approach based on conditional inference trees	Aerial imagery.	Harris et al. (2013)
Angola: EEZ	Benthic and pelagic	Mixed thematic and statistical, hierarchical approach. Coastal areas mapped by Harris et al. 2013; offshore (>30m) benthos mapped through thematic, hierarchical approach; offshore (>30m) pelagic mapped through ISO clustering	Coastal: - Grain size and wave exposure. Benthic: - Depth, slope and topography, geology, biozones. Pelagic: - Sea surface temperature, net primary productivity, chlorophyll-*a*, depth, turbidity, frequency of eddies, distribution of temperature, chlorophyll fronts.	Holness et al. (2014); Harris et al. (2013)
Angola: Coastal waters	Benthic	Statistical, hierarchical approach based on conditional inference trees	Aerial imagery.	Harris et al. (2013)
South Georgia	Benthic	Statistical, hierarchical approach based on PCA and *k*-means clustering	Bathymetry and derivatives (slope angle, rugosity, bathymetric position index, aspect, curvature), salinity, temperature, current magnitude and direction, net primary productivity.	Hogg et al. (2016)
South Georgia:	Benthic	Statistical, non-hierarchical approach based on object-based random forest classification	Drone imagery.	Golding & Black (2020)

Coastal margins				
Falkland Islands: Coastal margins	Benthic	Statistical, non-hierarchical approach based on object-based random forest classification	Aerial, satellite and drone imagery.	Golding & Black (2020)
Falkland Islands: Deep-sea	Benthic	Statistical, non-hierarchical approach based on PCA and *k*-means classification	Bathymetry and derivatives (slope angle, rugosity, bathymetric position index, aspect, curvature), sediment composition, bottom current, bottom temperature, surface dissolved oxygen, surface chlorophyll, surface ph, bottom ph, bottom phosphate, surface phosphate, bottom silicate, aragonite saturation state, dissolved inorganic carbon, calcite saturation state, nitrate, total alkalinity.	Pearman (2021)
St Helena: Intertidal	Benthic	Thematic, hierarchical approach based on IUCN classification	Aerial imagery and field survey (no specific details given).	Pike et al. (2018)
Southern Brazil	Benthic and pelagic	Statistical, non-hierarchical approach based on PCA and *k*-means classification	Benthic: - Bathymetry and derivatives (slope angle, rugosity, bathymetric position index), sediment composition, bottom current, bottom temperature, bottom dissolved oxygen, bottom chlorophyll, total suspended matter, nitrate, phosphate, silicate, light penetration. Pelagic: - Bathymetry, coast distance, salinity, sea surface temperature, surface current, surface chlorophyll, surface dissolved oxygen, surface nitrate, phosphate and silicate, mixed layer depth, euphotic zone depth, photosynthetic active radiation.	Gandra (2020); Gandra et al. (2020)
Brazil: EEZ	Benthic and pelagic	Mixed thematic hierarchical approach for benthic and non-hierarchical ISO clustering approach for pelagics.	Benthic:	Magris et al. (2020)

			- Ecoregions (from Spalding et al., 2007), depth, substrate type, habitat forming species, geomorphological structures. Pelagic: - Salinity, sea surface temperature, dissolved molecular oxygen, chlorophyll-*a*, nitrate, phosphate, silicate.	

Table S2. Environmental properties (mean ± standard deviation) of clusters selected for the non-hierarchical classification approach in the South Atlantic study area, produced through CLARA clustering of environmental surrogates. "NA" indicates classes not occurring within the study area. Units as follows: FBPI = NA; BBPI = NA; slope = degrees; salinity = PSS; temperature = °C; POC = mmol C m^{-2} d^{-1}.

Variable class	Cluster	Variable	Mean (stdev)	Description
Topography	1	FBPI	29.62 (193.88)	Hills & ridges
		BBPI	90.27 (411.05)	
		Slope	1.36 (0.48)	
	2	FBPI	-6.99 (70.65)	Plains & shallow slopes
		BBPI	-38.79 (200.87)	
		Slope	0.37 (0.23)	
	3	FBPI	-59.76 (381.22)	Seamounts & complex features
		BBPI	23.59 (776.35)	
		Slope	3.75 (1.44)	
Water Mass Structure	1	Salinity	34.65 (0.01)	Offshore
		Temperature	-0.66 (0.07)	
	2	Salinity	34.67 (0.01)	
		Temperature	-0.07 (0.21)	
	3	Salinity	34.72 (0.03)	
		Temperature	0.57 (0.2)	
	4	Salinity	NA	
		Temperature	NA	
	5	Salinity	34.74 (0.4)	
		Temperature	1.6 (3.38)	
	6	Salinity	34.86 (0.05)	
		Temperature	2.03 (0.18)	
	7	Salinity	34.67 (0.31)	
		Temperature	3.4 (0.76)	
	8	Salinity	33.91 (0.49)	Inshore
		Temperature	6.67 (1.02)	
	9	Salinity	34.19 (0.74)	
		Temperature	10.67 (1.13)	
	10	Salinity	35.16 (1.4)	
		Temperature	16.24 (2.17)	
	11	Salinity	35.09 (3.18)	
		Temperature	26.01 (2.59)	
	12	Salinity	36.73 (0.46)	
		Temperature	27.35 (0.76)	
Productivity	1	POC	0.07 (0.06)	Lowest
	2	POC	0.48 (0.26)	Low
	3	POC	5.24 (1.79)	Medium
	4	POC	11.16 (1.59)	High
	5	POC	27.27 (8.96)	Highest

Table S3. Results of hierarchical approach level 2 clustering within the South Atlantic study area, giving number of Principal Components with eigenvalues < 1 selected for clustering, total cumulative variance explained by PCs, Average Silhouette Width of CLARA clustering of PCs, and key variables driving divisions between classes. Drivers are the top four environmental variables (where > 4) with the highest correlations (< -0.6 or > 0.6, in decreasing order of importance) to the first PC (i.e. those variables explaining the greatest proportion of variation in the data), with "+" indicating a positive correlation and "-" a negative correlation.

Class clustered	No. PCs	Variance (%)	ASW	No. clusters	Drivers
Class 1	3	70	0.59	4	-Nit, -Phos, +DissOx, -Sil
Class 2	4	73	0.48	11	+DissOx, -Temp, -BBPI, -Slope
Class 3	4	70	0.33	7	-DissOx, +Temp, +BBPI
Class 4	4	72	0.32	7	+Phos, -DissOx, +Nit

Table S4. Results of hierarchical approach level 3 clustering within the South Atlantic study area, giving number of Principal Components with eigenvalues < 1 selected for clustering, total cumulative variance explained by PCs, Average Silhouette Width of CLARA clustering of PCs, and key variables driving divisions between classes. Drivers are the four environmental variables with the highest correlations (< -0.6 or > 0.6, in decreasing order of importance) to the first PC (i.e. those variables explaining the greatest proportion of variation in the data), with "+" indicating a positive correlation and "-" a negative correlation. "NA" indicates classes not occurring within the study area.

Class clustered	No. PCs	Variance (%)	ASW	No. clusters	Drivers
Class 1					
Class 1.1	NA	NA	NA	NA	NA
Class 1.2	NA	NA	NA	NA	NA
Class 1.3	4	70%	0.29	5	+Phos, +Sil, +Nit, +POC
Class 1.4	4	74%	0.37	7	+Temp, -Sil, +BBPI, -Dissox
Class 2					
Class 2.1	5	81%	0.27	8	-Nit, -Phos, +FBPI, +BBPI
Class 2.2	4	79%	0.33	8	-Nit, +DissOx, -Temp, -Phos
Class 2.3	NA	NA	NA	NA	NA
Class 2.4	4	72%	0.47	8	-Nit, -Sil, -Phos
Class 2.5	4	69%	0.47	6	+Temp, -DissOx, +Sal
Class 2.6	NA	NA	NA	NA	NA
Class 2.7	4	69%	0.33	6	+DissOx, -Temp
Class 2.8	4	74%	0.58	4	-Slope, -Temp, +DissOx, -FBPI
Class 2.9	4	72%	0.43	8	-FBPI, -Temp, -Slope, +DissOx
Class 2.10	4	72%	0.30	7	+Nit, +Phos, -Temp, +Sil
Class 2.11	4	77%	0.40	5	-FBPI, -Slope, -BBPI, -CurrVel
Class 3					
Class 3.1	4	70%	0.38	7	+Phos, +Nit, -Sal, +BBPI
Class 3.2	4	72%	0.52	6	+BBPI, +FBPI, +Phos
Class 3.3	4	78%	0.34	10	-DissOx, +Temp, +Phos, -Sal
Class 3.4	4	71%	0.35	4	-Nit, +DissOx

Class 3.5	4	64%	0.34	6	-Temp, +DissOx, -Phos
Class 3.6	5	76%	0.30	2	DissOx, -Nit, -Temp
Class 3.7	4	79%	0.48	7	-DissOx, +Temp, +Sal, +Currvel
Class 4					
Class 4.1	NA	NA	NA	NA	NA
Class 4.2	NA	NA	NA	NA	NA
Class 4.3	NA	NA	NA	NA	NA
Class 4.4	NA	NA	NA	NA	NA
Class 4.5	3	64	0.35	8	-Phos, +Dissox, - Nit
Class 4.6	NA	NA	NA	NA	NA
Class 4.7	NA	NA	NA	NA	NA

Table S5. Environmental properties (mean ± standard deviation) of habitat classes occurring in the South Atlantic study area at level 1 and level 2 of the hierarchical approach.

Habitat class	BBPI	FBPI	Slope (°)	Salinity (PSS)	Temper-ature (°)	POC (mmol C m^{-2} d^{-1})	Dissolved oxygen (mmol m^{-3})	Nitrate (mmol m^{-3})	Silicate (mmol m^{-3})	Phosphate (mmol m^{-3})	Current velocity (m s^{-1})
Class 1	25.33 (329.4)	11.58 (160.61)	0.89 (1)	34.86 (0.12)	2.18 (0.65)	0.41 (0.8)	241.82 (11.11)	23.6 (1.13)	50.88 (9)	1.59 (0.09)	0.07 (0.04)
Class 1.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 1.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 1.3	118.41 (608.68)	15.03 (228.82)	1.16 (1.6)	34.59 (0.42)	3.73 (1.13)	2.79 (3.43)	273.48 (19.47)	21.07 (1.23)	25.8 (3.93)	1.45 (0.15)	0.05 (0.03)
Class 1.4	23.84 (322.76)	11.52 (159.28)	0.89 (0.98)	34.86 (0.11)	2.16 (0.6)	0.37 (0.6)	241.31 (10.15)	23.64 (1.08)	51.28 (8.48)	1.59 (0.08)	0.07 (0.04)
Class 2	211.25 (389.58)	20.26 (78.7)	0.23 (0.59)	34.56 (1.48)	13.37 (7.41)	19 (12.24)	225.12 (67.05)	12.37 (8.66)	15.4 (10.22)	1.14 (0.63)	0.09 (0.09)
Class 2.1	909.75 (485.61)	143.7 (117.47)	1.41 (1.05)	35.79 (0.63)	17.27 (5.38)	4.86 (5.03)	195.78 (23.14)	10.13 (6.19)	6.64 (3.51)	0.81 (0.41)	0.23 (0.14)
Class 2.2	53.68 (286.54)	-34.23 (74.03)	0.65 (0.52)	35.33 (0.17)	12.05 (2.94)	0.74 (0.26)	212.01 (14.95)	14.75 (2.02)	8.17 (4.33)	1.1 (0.1)	0.11 (0.06)
Class 2.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 2.4	172.12 (63.15)	5.14 (8.93)	0.1 (0.1)	36.21 (0.12)	17.8 (0.33)	2.45 (0.9)	207.7 (1.31)	5.73 (0.45)	2.5 (0.14)	0.56 (0.03)	0.11 (0.01)
Class 2.5	37.65 (113.11)	1.35 (8.39)	0.06 (0.06)	33.73 (0.7)	9.41 (2.59)	25.44 (8.5)	255.79 (32.82)	11.2 (3.56)	15.98 (4.01)	1.27 (0.17)	0.05 (0.03)
Class 2.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 2.7	188.28 (238.62)	6.84 (16.08)	0.11 (0.12)	35.42 (1.11)	16.19 (3.64)	17.42 (9.81)	213.05 (36.67)	6.64 (2.95)	6.33 (2.99)	0.74 (0.19)	0.1 (0.05)
Class 2.8	171.26 (320.13)	14.36 (50.61)	0.22 (0.49)	34.27 (0.62)	8.21 (3.47)	20.19 (9.75)	221.95 (93.05)	20.78 (3.49)	23.02 (6.7)	1.71 (0.2)	0.07 (0.07)
Class 2.9	347.84 (415.58)	12.33 (35.2)	0.09 (0.2)	36.15 (0.97)	26.83 (1.78)	4.73 (2.87)	204.52 (5.35)	0.38 (0.78)	4.18 (3.57)	0.12 (0.07)	0.19 (0.08)
Class 2.10	2037.94 (600.4)	618.51 (306.56)	3.74 (1.25)	35.94 (0.83)	18.74 (5.78)	2.98 (3.85)	202.01 (23.02)	7.8 (7.42)	6.05 (4.66)	0.66 (0.48)	0.41 (0.27)
Class 2.11	82.87 (252.04)	3.25 (13.77)	0.05 (0.07)	33.63 (2.75)	18.86 (5.68)	29.95 (14.98)	243.27 (29.4)	2.34 (1.81)	11.64 (14.04)	0.47 (0.27)	0.09 (0.07)

Class 3	-18.51 (320.28)	-3.97 (145.51)	0.86 (0.95)	34.7 (0.06)	0.51 (0.9)	0.23 (0.48)	226.76 (15.97)	31.63 (1.96)	110.97 (21.21)	2.17 (0.15)	0.09 (0.06)
Class 3.1	0.63 (328.05)	-4.82 (141.5)	0.92 (0.99)	34.76 (0.08)	1.41 (0.63)	0.3 (0.32)	227.37 (12.89)	28.54 (1.88)	81.64 (13.92)	1.93 (0.13)	0.07 (0.04)
Class 3.2	415.65 (479.48)	43.89 (152.2)	1.85 (1.38)	34.69 (0.2)	5.45 (2.34)	2.79 (3.68)	153.07 (54.8)	30.88 (2.93)	31.22 (8.74)	2.06 (0.18)	0.1 (0.07)
Class 3.3	1061.09 (583.91)	492.48 (331.97)	3.36 (1.88)	34.66 (0.07)	1.33 (1.57)	0.38 (0.71)	210.01 (36.96)	32.66 (1.41)	98.13 (28.33)	2.25 (0.09)	0.08 (0.05)
Class 3.4	-66.64 (245.57)	-25.21 (119.48)	0.73 (0.79)	34.71 (0.02)	0.6 (0.33)	0.21 (0.19)	221.16 (7.61)	31.71 (0.64)	109.55 (8.8)	2.16 (0.06)	0.08 (0.05)
Class 3.5	-71.85 (74.45)	-22.22 (22.75)	0.29 (0.15)	34.64 (0.02)	3.6 (0.21)	0.19 (0)	148.68 (3.57)	33.87 (0.15)	78.37 (3.18)	2.41 (0.02)	0.1 (0.02)
Class 3.6	156.58 (276.7)	70.63 (132.61)	1.24 (1.08)	34.68 (0.02)	0.23 (0.23)	0.18 (0.14)	224.24 (7.28)	32.73 (0.3)	121.8 (4.24)	2.26 (0.02)	0.07 (0.04)
Class 3.7	-95.11 (265.58)	-28.07 (119.94)	0.71 (0.75)	34.66 (0.01)	-0.21 (0.28)	0.16 (0.17)	235.25 (14.2)	33.07 (0.41)	129.46 (5.04)	2.29 (0.02)	0.1 (0.07)
Class 4	-1513.77 (493)	-692.86 (402.33)	3.04 (1.87)	34.67 (0.02)	-0.17 (0.32)	0.09 (0.06)	232.54 (14.9)	33.12 (0.47)	129.86 (5.45)	2.28 (0.03)	0.13 (0.1)
Class 4.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 4.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 4.3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 4.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 4.5	-1513.77 (493)	-692.86 (402.33)	3.04 (1.87)	34.67 (0.02)	-0.17 (0.32)	0.09 (0.06)	232.54 (14.9)	33.12 (0.47)	129.86 (5.45)	2.28 (0.03)	0.13 (0.1)
Class 4.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Class 4.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA