



Supplementary Materials

Table S1. Benthic cover types and their codes in field data of Ningaloo Reef [52].

Name	Code
Branching <i>Acropora</i>	ACB
Branching <i>Acropora</i> “blue tip”	ACBT
Digitate <i>Acropora</i>	ACD
Encrusting <i>Acropora</i>	ACE
Submassive <i>Acropora</i>	ACS
Tabulate <i>Acropora</i>	ACT
Bottlebrush <i>Acropora</i>	ACX
Coralline Algae	CA
Branching non- <i>Acropora</i>	CB
Digitate non- <i>Acropora</i>	CD
Encrusting non- <i>Acropora</i>	CE
Foliaceous non- <i>Acropora</i>	CF
Massive coral	CM
Mushroom coral	CMR
Submassive coral	CS
Recently dead coral	DC
<i>Dictyota</i>	DY
<i>Halimeda</i> spp.	HA
Intact Dead Coral	IDC
Branching IDC	IDC-B
Tabulate IDC	IDC-T
Digitate IDC	IDC-D
Massive IDC	IDC-M
Limestone pavement	LP
Macroalgae	MA
<i>Padina</i>	PA
Rubble	R
Sand	S
Sand and Microalgae	SA
Soft Coral	SC
Seagrass	SG
<i>Sargassum</i>	SR
Sponge	Sp
Turf Algae	TA
<i>Ulva</i>	UL

Table S2. Definition of the ruleset and the class ranges using bathymetry data of Ningaloo Reef at the 9 × 9 pixel majority kernel scale. (Slope (degrees), aspect (0-360 degrees) and bathymetry (cm). Variable names are indicated in caps, Avg= average.

Rule definition
1 If Avg_SLOPE > 30.0 AND Avg_ASPECT [225.0, 315.0] AND Avg_DEPTH < -50.0, then assign to "W_steep_deep"
2 If Avg_SLOPE < 30.0 AND Avg_ASPECT [45.0, 135.0] AND Avg_DEPTH > -50.0, then assign to "E_flat_shallow"
3 If Avg_ASPECT > 315.0 AND Avg_SLOPE < 30.0 AND Avg_DEPTH > -50.0, then assign to "N_flat_shallow"
4 If Avg_SLOPE < 30.0 AND Avg_DEPTH > -50.0 AND Avg_ASPECT [0.0, 45.0], then assign to "N_flat_shallow"

- 5 If Avg_SLOPE > 30.0 AND Avg_ASPECT [135.0, 225.0] AND Avg_DEPTH < -50.0, then assign to "S_steep_deep"
- 6 If Avg_SLOPE < 30.0 AND Avg_ASPECT [225.0, 315.0] AND Avg_DEPTH > -50.0, then assign to "W_flat_shallow"
- 7 If Avg_SLOPE [30.0, 89.9598] AND Avg_ASPECT [45.0, 135.0] AND Avg_DEPTH < -50.0, then assign to "E_steep_deep"
- 8 If Avg_SLOPE [30.0, 89.9598] AND Avg_ASPECT > 315.0 AND Avg_DEPTH < -50.0, then assign to "N_steep_deep"
- 9 If Avg_SLOPE [30.0, 89.9598] AND Avg_ASPECT [0.0, 45.0] AND Avg_DEPTH < -50.0, then assign to "N_steep_deep"
- 10 If Avg_SLOPE < 30.0 AND Avg_ASPECT [135.0, 225.0] AND Avg_DEPTH > -50.0, then assign to "S_flat_shallow"
- 11 If Avg_SLOPE > 30.0 AND Avg_ASPECT [225.0, 315.0] AND Avg_DEPTH > -50.0, then assign to "W_steep_shallow"
- 12 If Avg_SLOPE < 30.0 AND Avg_ASPECT [225.0, 315.0] AND Avg_DEPTH < -50.0, then assign to "W_flat_deep"
- 13 If Avg_SLOPE > 30.0 AND Avg_ASPECT [45.0, 135.0] AND Avg_DEPTH > -50.0, then assign to "E_steep_shallow"
- 14 If Avg_SLOPE < 30.0 AND Avg_ASPECT [45.0, 135.0] AND Avg_DEPTH < -50.0, then assign to "E_flat_deep"
- 15 If Avg_SLOPE > 30.0 AND Avg_ASPECT > 315.0 AND Avg_DEPTH > -50.0, then assign to "N_steep_shallow"
- 16 If Avg_SLOPE > 30.0 AND Avg_ASPECT [0.0, 45.0] AND Avg_DEPTH > -50.0, then assign to "N_steep_shallow"
- 17 If Avg_SLOPE < 30.0 AND Avg_ASPECT > 315.0 AND Avg_DEPTH < -50.0, then assign to "N_flat_deep"
- 18 If Avg_SLOPE < 30.0 AND Avg_ASPECT [0.0, 45.0] AND Avg_DEPTH < -50.0, then assign to "N_flat_deep"
- 19 If Avg_SLOPE > 30.0 AND Avg_ASPECT [135.0, 225.0] AND Avg_DEPTH > -50.0, then assign to "S_steep_shallow"
- 20 If Avg_SLOPE < 30.0 AND Avg_ASPECT [135.0, 225.0] AND Avg_DEPTH < -50.0, then assign to "S_flat_deep"
- 21 If Avg_ASPECT < 0.0 AND Avg_DEPTH [-50.0, -1.0], then assign to "Noaspect_flat_shallow"
- 22 If Avg_ASPECT < 0.0 AND Avg_DEPTH < -50.0, then assign to "Noaspect_flat_deep"

Table S3. The ruleset for geomorphic classes developed using topographic and habitat classes for the Ningaloo Reef. Area = the object area; tx_variance = the texture variance of the object; tx_entropy = the object's entropy; max, min, std prefixes indicate minimum, maximum and standard deviation of slope and depth. Other parameters specified below are related to the object shape, such as length, area, convexity and the length of the major and minor axes. Thresholds for the area are in m² and depth in cm.

Class name	Details of the ruleset
Sand (flat, lagoonal)	Area > 8000.0 AND tx_variance < 9.0 AND tx_entropy > 0.1858 AND maxslope < 40.0 AND mindepth > -100.0 AND avgBenthic_Class [20.0, 29.0] AND stdBenthicClass < 10.0 AND stdslope < 10.0
Sand (lagoonal slopes)	If area [600.0, 1500.0] AND length [20.0, 1000.0] AND convexity < 1.2 AND roundness < 0.5483 AND majaxislen > 54.7999 AND minaxislen < 40.0 AND tx_range < 15.6671 AND avgSLOE_1 > 15.0 AND avgBenthicClass [29.0, 29.0] OR avgband_4 [19.0, 19.0].
Sand (lagoonal slopes)	Elongation > 4.0 AND majaxislen > 100.0 AND minaxislen < 38.0000
Forereef and deep lagoonal	maxdepth < -55.0
Backreef and shallow lagoonal	maxdepth [-70.0, -10.0] AND mindepth [-150.0, -20.0] AND avgBenthicClass NOT [28.5, 29.5] AND area > 50.0
Reef flat and very shallow lagoonal	maxdepth > -20.0 AND mindepth > -50.0 AND avgBenthicClass NOT [28.5, 29.5] AND tx_range NOT [8.1237, 12.7657]

Table S4. Results of the validation of the pixel-based classification against the field data.

Classification labels*	HC	HC and MA with LP	HC with LP	HC with S	HC with TA- or MA-	HC with TA- or MA-	HC, MA and TA	LP dark	LP light	LP with S	LP, R and S	MA	MA with LP	MA with LP and S	MA with R	MA with S	S	SC	SC, HC and MA with	SC, HC with LP	TA with LP	Total	Producer's accuracy
HC	10	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	80.6
HC and MA with LP and S	1	9	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	76.6
HC with LP	1	1	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	73.7
HC with S	1	1	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	64.7
HC with TA- or MA-covered IDC or R	1	0	0	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	67.7
HC with TA- or MA-covered IDC or R and S	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	50.0
HC, MA and TA with LP	0	0	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	79.4
LP dark	0	0	0	0	0	0	1	5	0	1	1	0	0	0	0	0	0	0	0	0	0	7	77.8
LP light	0	0	0	0	0	0	0	1	5	2	0	0	0	0	0	0	0	0	0	0	0	7	64.3
LP with S	0	0	0	0	0	0	0	1	1	10	0	0	0	0	0	0	1	0	0	0	0	12	81.6
LP, R and S	0	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0	1	0	0	0	0	6	72.0
MA	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	1	0	0	0	0	0	11	93.2
MA with LP	0	0	0	0	0	0	0	1	0	0	0	1	7	1	0	1	0	0	0	0	0	12	63.1
MA with LP and S	0	0	0	0	0	0	0	0	1	0	0	1	1	7	1	1	0	0	0	0	0	11	60.0
MA with R	0	0	0	0	0	0	0	0	0	0	0	2	0	1	5	1	0	0	0	0	0	9	58.3

MA with S	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	6	0	0	0	0	1	10	63.2
S	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	12	0	0	0	0	13	90.4
SC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	2	0	9	58.3
SC, HC and MA with LP	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	4	1	0	7	57.7
SC, HC with LP	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	0	7	55.6
TA with LP	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	4	64.3
Total	14	12	11	7	7	3	11	7	7	13	7	15	10	10	7	9	13	8	6	7	3	185	
User's accuracy (%)	69.1	78.3	66.7	78.6	77.8	66.7	61.4	72.4	64.3	75.5	66.7	68.3	74.4	65.9	77.8	66.7	90.4	67.8	60.0	57.7	75.0		
Overall agreement (%)	71.08																						

*Abbreviations used: HC hard coral, MA macro algae, LP limestone pavement, S sand, IDC intact dead coral, R rubble (coral rubble), SC soft coral, TA turfing algae

Table S5 Results of the validation of the geomorphic classification against field data.

Validation of the geomorphic classification	Geomorphic class name							
	Coral and algal back and shallow forereef	Coral and algal deep forereef	Coral and algal reef flat and shallow	Sand and limestone pavement flat lagoonal	Sand and limestone pavement lagoonal slopes	Grand Total		Producer's accuracy (%)
Field validation								
Hard coral	5					5		100.0
Hard coral with limestone pavement			2			2		100.0
Hard coral with macro algae	22	6	6	1		35		97.1
Hard coral with macro algae and limestone pavement	17	10	9			36		100.0
Limestone pavement					1	1		100.0
Limestone pavement with sand	1	1	1	4	3	10		70.0
Macro algae	1		2			3		100.0
Macro algae and limestone pavement		1	1			2		100.0
Macro algae with limestone pavement and sand	1					1		100.0
Sand				12	1	13		92.3
Sand and limestone pavement					1	1		100.0
Sand				2		2		100.0
Soft coral, hard coral and limestone pavement			1	1		2		50.0
Soft coral, hard coral, macro algae and limestone pavement	5	3				8		100.0
Soft coral, hard coral and macro algae	2		1			3		100.0
Grand Total	54	21	23	20	6	124		
user's accuracy	96.3	90.5	91.3	90.0	100.0			
Overall accuracy= 93.5%								
Green shading indicates classes belonging to the coral dominated geomorphic classes								
Yellow shading indicates classes belonging to the sand and limestone dominated geomorphic classes								

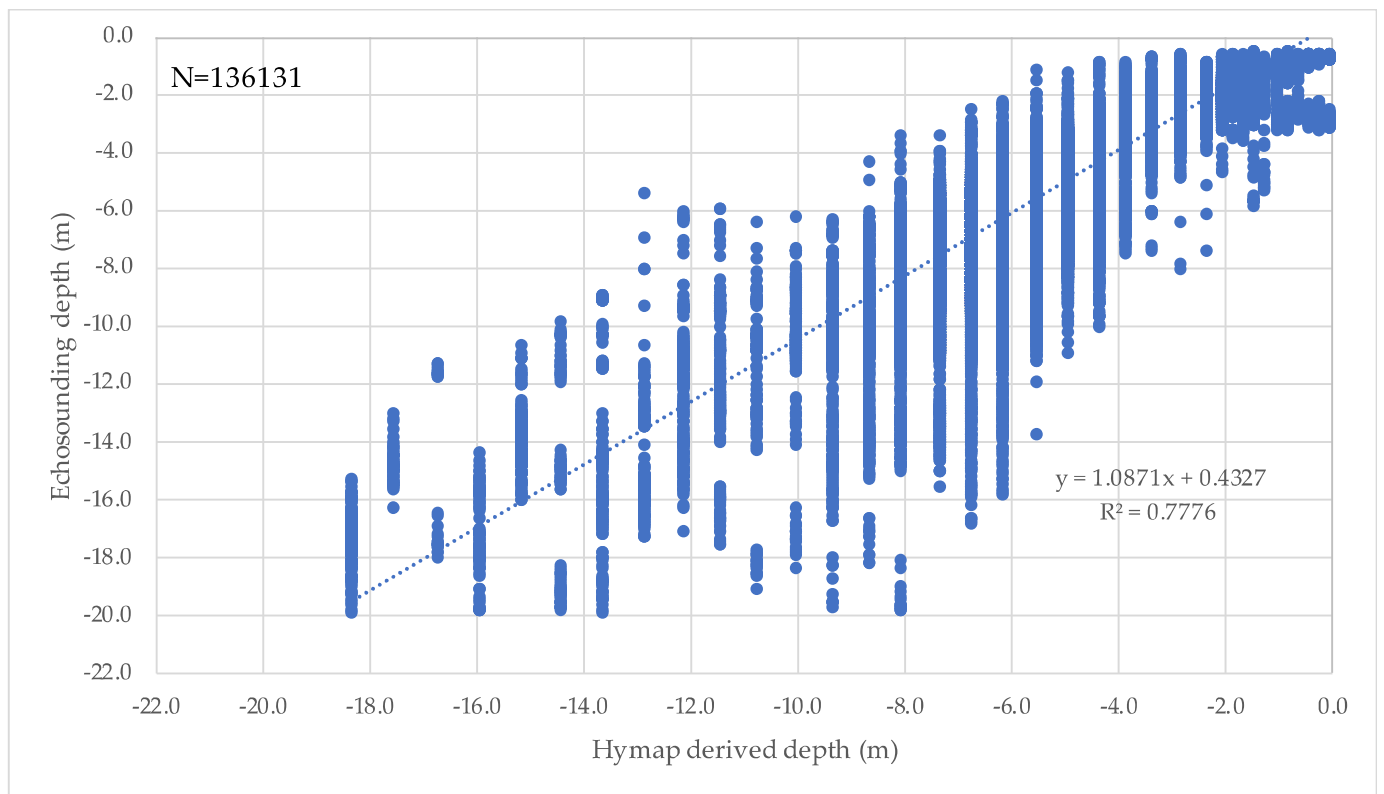


Figure S1. Validation of the bathymetry data derived from the HyMap sensor against echosounder data (WA Dept of Transport).