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Coastal Zone Management in Response to Sea Level Rise in the 21st Century: A Study from Hurst Spit to Lymington, South England

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Abstract:- This study examines the coastal region spanning from Hurst Spit to the mouth of the Lymington River along the Western Solent coast in Hampshire, South England. The area comprises critical habitats for international bird species on the seaward side and is protected by a seawall on the landward side. Rising sea levels pose a significant threat to this area, including habitat loss and potential seawall breaches.

To address the uncertainty in sea level rise projections for the 21st century, this study utilises data processing in ArcGIS, including LiDAR data, tidal data, and sea level rise projections. It adopts contingency allowances for sea level rise, resulting in a projected 0.89 metre by 2100.

Analysis reveals a significant transformation in habitat distribution, with standing water and mudflats expanding while salt marshes and dry land areas diminish. Salt marsh areas are projected to contract by 64.6%, with the pioneer salt marsh facing the greatest loss.

The report recommends a proactive approach, including realigning the seawall in vulnerable areas, allowing for the creation of new salt marshes. This managed intervention strategy can reduce habitat loss to approximately 17.43%, mitigating the potential ecological and human habitat impacts of rising sea levels in that region.

Keywords:- *Arcgis, Coastal Squeeze, Digital Terrain Map (DTM), Lidar, Sea Level Rise, Salt Marshes, Mudflats, Highest Astronomical Tide (HAT), Mean High Water Spring (MHWS), Mean High Water (MHW), Mean High Water Neap (MHWN), Lowest Astronomical Tide (LAT), Ordnance Datum (OD), Chart Datum (CD)*

I. INTRODUCTION AND BACKGROUND

The study area stretches from Hurst Spit to the mouth of the Lymington River, nine km along the coast of the Western Solent in the County of Hampshire. On the seaward side, salt marshes and mudflats form habitats for internationally significant bird species. On the landward side are pools of brackish water, grazing lands, and built-up and habited areas, the notable towns being Keyhaven, Pennington, and Lymington (UNEP-WCMC, 2024; National Coastal Monitoring, 2024). Protecting the landward side from the waters of the Solent on the south is a seawall stretching 8.3 km from Hurst Spit to the town of Lymington (red line in Figure 1). The mudflats and salt marshes in front of the sea wall attenuate wave action during high tides and offer some degree of protection to the seawall which is at a height of +2.5 m OD or + 4.48 CD (Annual Tide Report, 2022).

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Fig 1: Google Earth Pro Image of Study Area (2024)

It is well-documented that sea level rise is happening and it is caused by human-induced climate change (Trujillo & Thurman, 2014). During the 21st century, sea level rise is expected to put pressure on the study area, reducing the areas of mudflats and salt marshes and, possibly, overtopping or breaching the present sea wall. If the present line of sea defence is maintained by raising the sea wall and extending its base, the mudflats, and salt marshes will experience coastal squeeze, that is, the reduction of their area between the rising sea and the fixed sea wall and very likely, their destruction in the long-term and loss of wildlife habitats (What is Coastal Squeeze? 2021). Also, overtopping or breaching the sea wall will result in degrading the grazing areas and habitats on the landward side. It is therefore imperative that the appropriate coastal zone management measures be developed and implemented to protect the habitats in the study area (Holland & Pugh, 2010).

- *Aims and Rationale*

Estimates for the global sea level rise by the end of the 21st century range from 0.49 metre to 2.0 metres (Wind, 1987; Field et al, 2002). This uncertainty in our knowledge of future sea level rise makes it crucial that we decide now on the appropriate measures to manage the study area so that wildlife habitats on both sides of the sea wall and human habitations can be best protected. This study aims to investigate how the study site can be managed during the 21st century, given the large uncertainty associated with sea level rise projections.

- *Data Processing*

The data for this project were processed using ArcGIS software, namely ArcCatalogue and ArcMap. The data used included Topographical LiDAR data of Hurst Spit to Lymington (2009), Tidal Data for Hurst Point & Lymington (2006), and net sea level rise projections for the 21st century.

Given the uncertainty in sea level rise projections, it was decided to use the Planning Policy Statement 25 (2006) recommended contingency allowances for net sea level rise in South England, where the study site is located. The following are the projections:

2000 – 2025: 3.5 mm/yr (25 yrs) = 8.75 cm
2025 – 2055: 8.0 mm/yr (30 yrs) = 24.0 cm
2055 – 2085: 11.5 mm/yr (30 yrs) = 34.5 cm
2085 – 2100: 14.5 mm/yr (15 yrs) = 21.75 cm

Total sea level rise from 2000 – 2100 = 89.0 cm = 0.89 m.

Vertical movement of the land is considered for the above figures.

(Planning Policy Statement 25, p. 15)

First, the present-day scenario for the distribution of habitats in the study site was obtained as outlined in the flow diagram below (Chart 1).

Next, the projected end-of-century sea level rise of 0.89 m was used to obtain the 2100 projected scenario distribution of habitats at the site.

Then the two scenarios were compared to note the differences and changes predicted by the ArcGIS programme. MS Excel was used to calculate the predicted changes in salt marsh distribution from the present day to 2100.

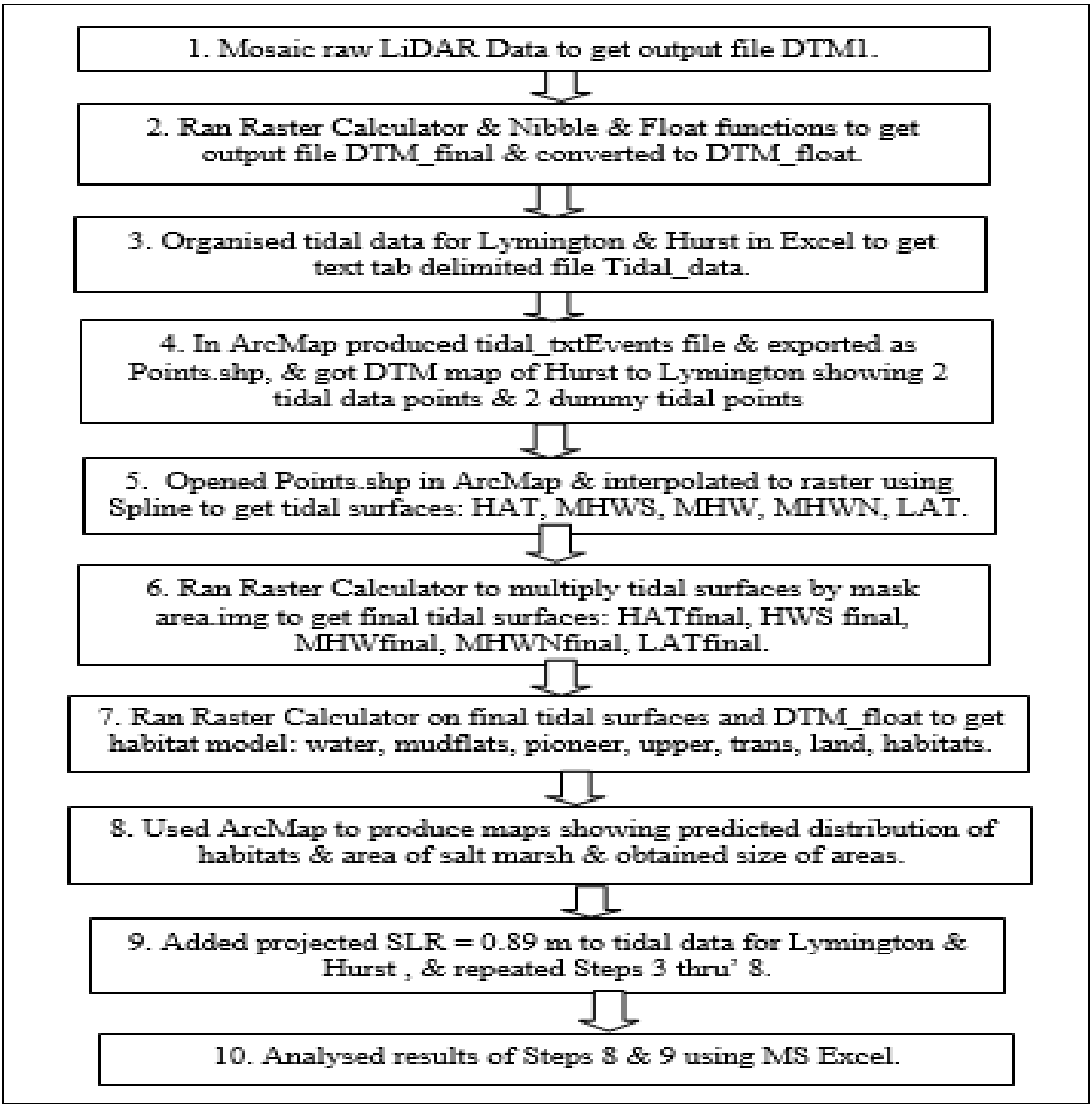

Chart 1: Flow Diagram Outlining the ArcGIS Operations for the Study

II. RESULTS

The results are displayed in Tables 1 – 7 below, followed by spatial representations in the maps of Figures 2 – 8.

Table 1: Present-Day Distribution of Habitats in the Study Site

Zone	**Area/km^2**	**Area/ha**
Standing water	8.3851	838.51
Mudflats	7.0496	704.96
Pioneer salt marsh	1.4164	141.64
Upper/mid salt marsh	1.1926	119.26
Transitional salt marsh	0.4310	43.10
Land	17.0878	1,708.78
Total	**35.5625**	**3,556.25**

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Table 2: 2100 Projected Distribution of Habitats in the Study Site

Zone	Area/km^2	Area/ha
Standing water	10.3403	1,034.03
Mudflats	8.5152	851.52
Pioneer salt marsh	0.3576	35.76
Upper/mid salt marsh	0.3800	38.00
Transitional salt marsh	0.3386	33.86
Land	15.6622	1,566.22
Total	**35.5939**	**3,559.39**

Table 3: Present-Day Distribution of Saltmarsh

Zone	Area/km^2	Area/ha
Pioneer salt marsh	1.4164	141.64
Upper/mid salt marsh	1.1926	119.26
Transitional salt marsh	0.4310	43.10
Totals	3.0400	304.00

Table 4: 2100 Projected Distribution of Saltmarsh

Zone	Area/km^2	Area/ha
Pioneer salt marsh	0.3576	35.76
Upper/mid salt marsh	0.3800	38.00
Transitional salt marsh	0.3386	33.86
Totals	1.0762	107.62

Table 5: Predicted Changes in the Area of Saltmarsh from Present-Day to 2100

Zone	Area/km^2	Area/ha	%
Pioneer salt marsh	-1.0588	-105.88	-74.7529
Upper/mid salt marsh	-0.8126	-81.26	-68.1368
Transitional salt marsh	-0.0924	-9.24	-21.4385
Totals	-1.9638	-196.38	-64.5987

Table 6: Results of Interpolation & Raster Calculations for final tidal surfaces (2006)

Tidal Elevation	DATA INPUT		FINAL TIDAL SURFACES	
	Lymington/m	Hurst/m	High/m	Low/m
HAT	1.3	1.04	1.44921	1.03365
MHWS	1.08	0.87	1.20052	0.864868
MHW	0.84	0.67	0.937561	0.665846
MHWN	0.6	0.47	0.674605	0.466823
LAT	-1.84	-1.54	-1.53267	-2.01217

Table 7: Results of Interpolation & Raster Calculations for Final Tidal Surfaces (2100 Projected SLR = 0.89 m)

Tidal Elevation	DATA INPUT		FINAL TIDAL SURFACES	
	Lymington/m	Hurst/m	High/m	Low/m
HAT	2.19	1.93	2.33921	1.92365
MHWS	1.97	1.76	2.09052	1.75487
MHW	1.73	1.56	1.82756	1.55585
MHWN	1.49	1.36	1.56461	1.35682
LAT	-0.95	-0.65	-0.642669	-1.12217

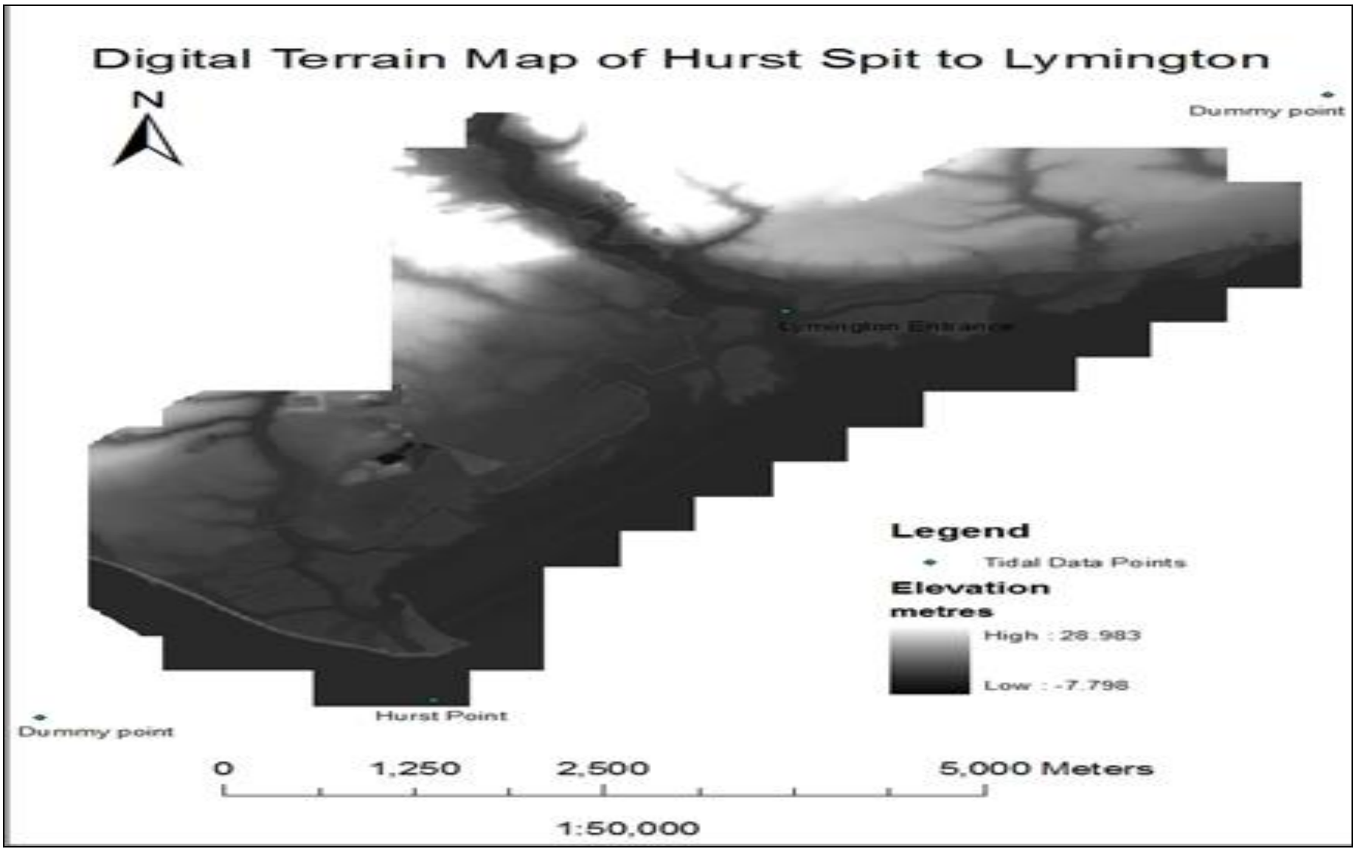

Fig 2: Final DTM of Hurst Spit to Lymington Produced in ArcMap

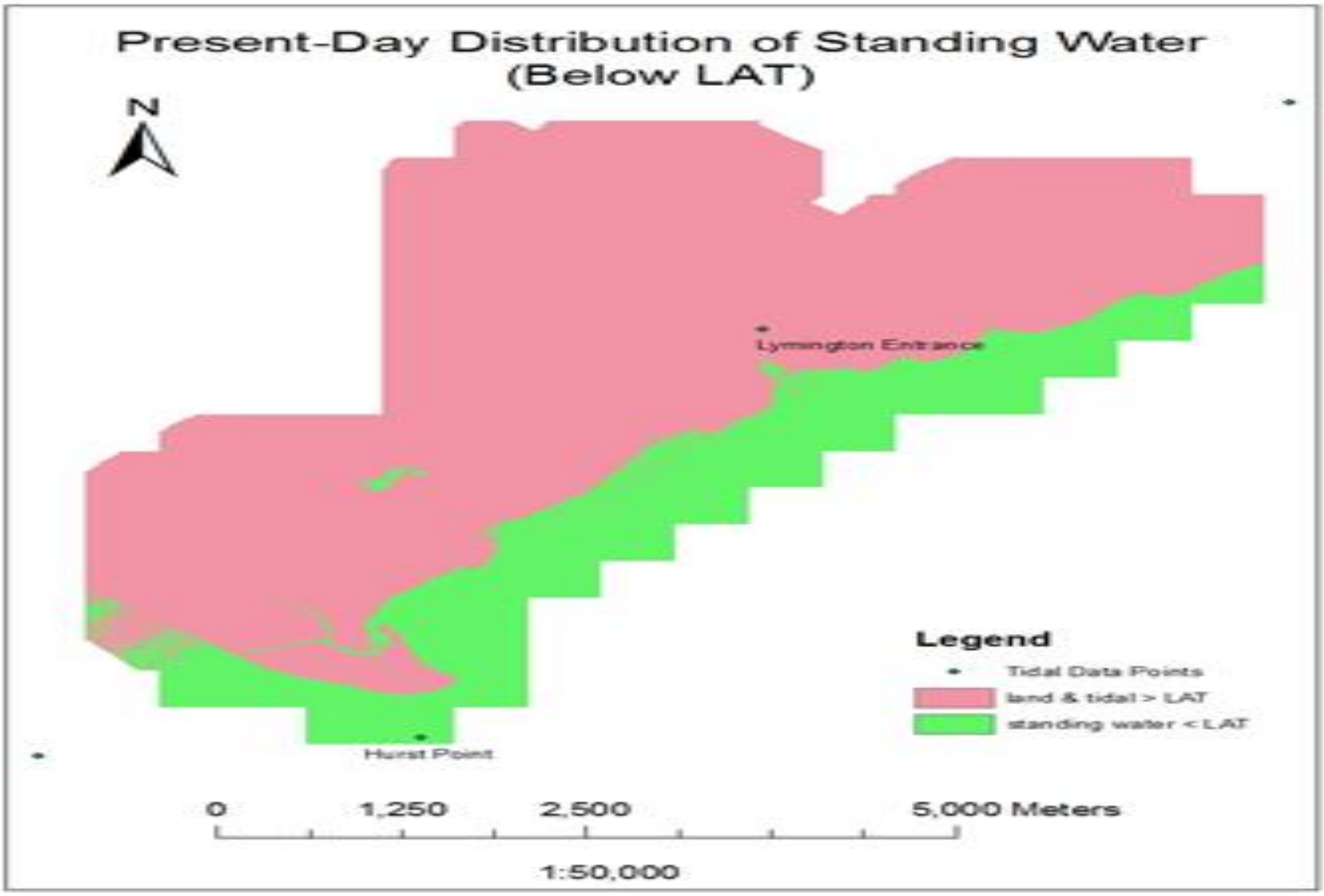

Fig 3: Present-Day Scenario of the Distribution of Standing Water Below LAT & the Land & Inter-Tidal Zone Above LAT

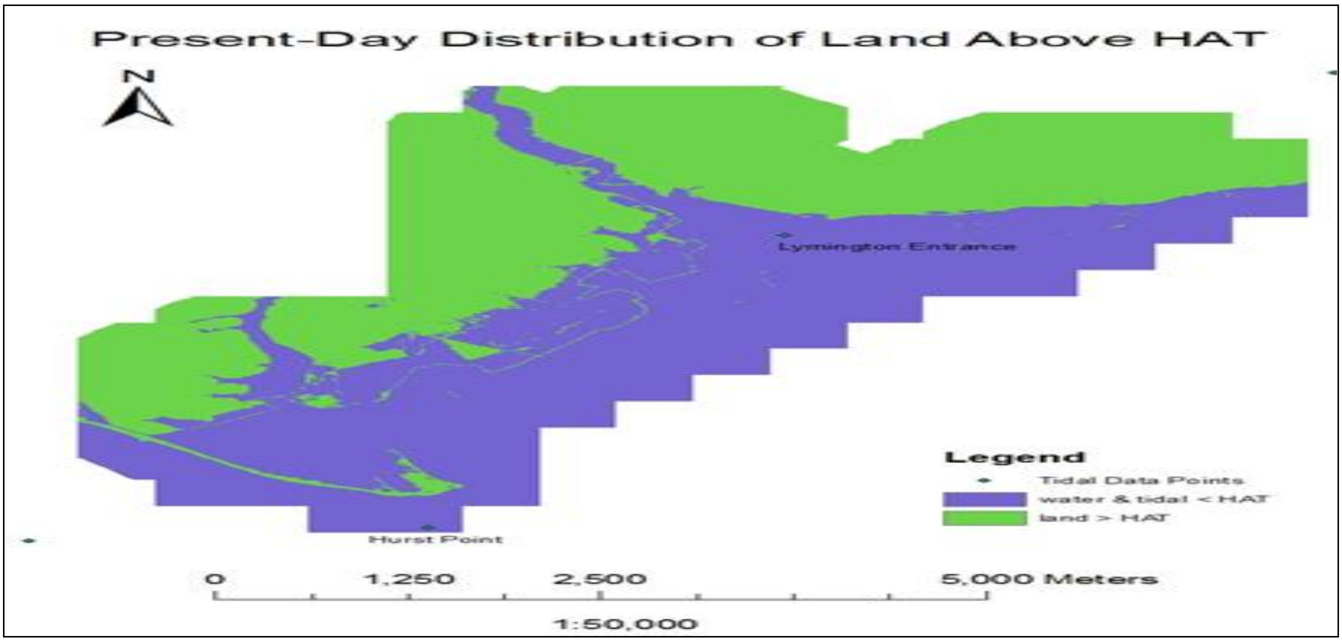

Fig 4: Present-Day Scenario of the Distribution of Supra-Tidal Land Above HAT and the Water & Inter-Tidal Zone Below HAT

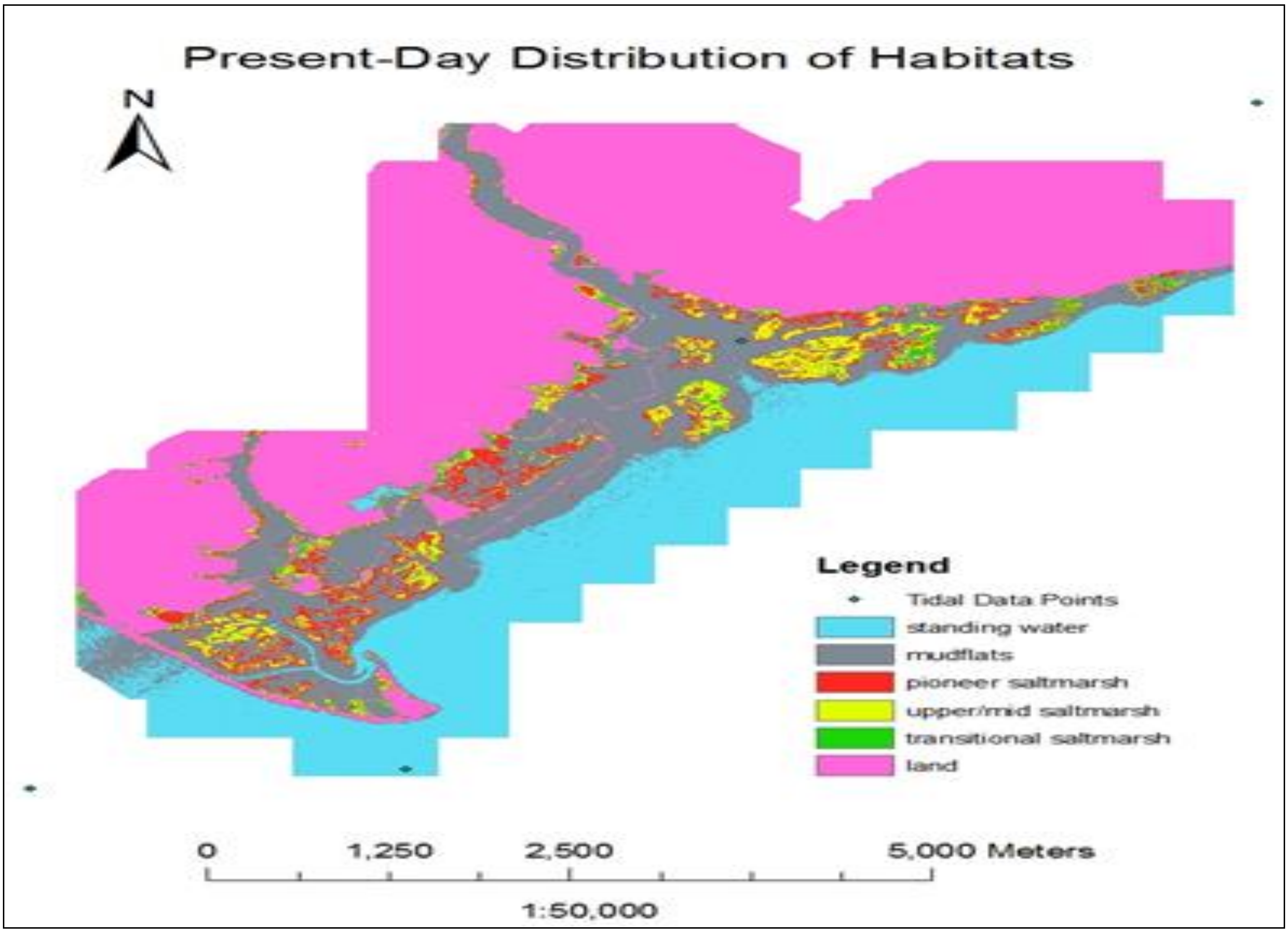

Fig 5: Present-Day Scenario of the Distribution of Habitats at the Study Site.

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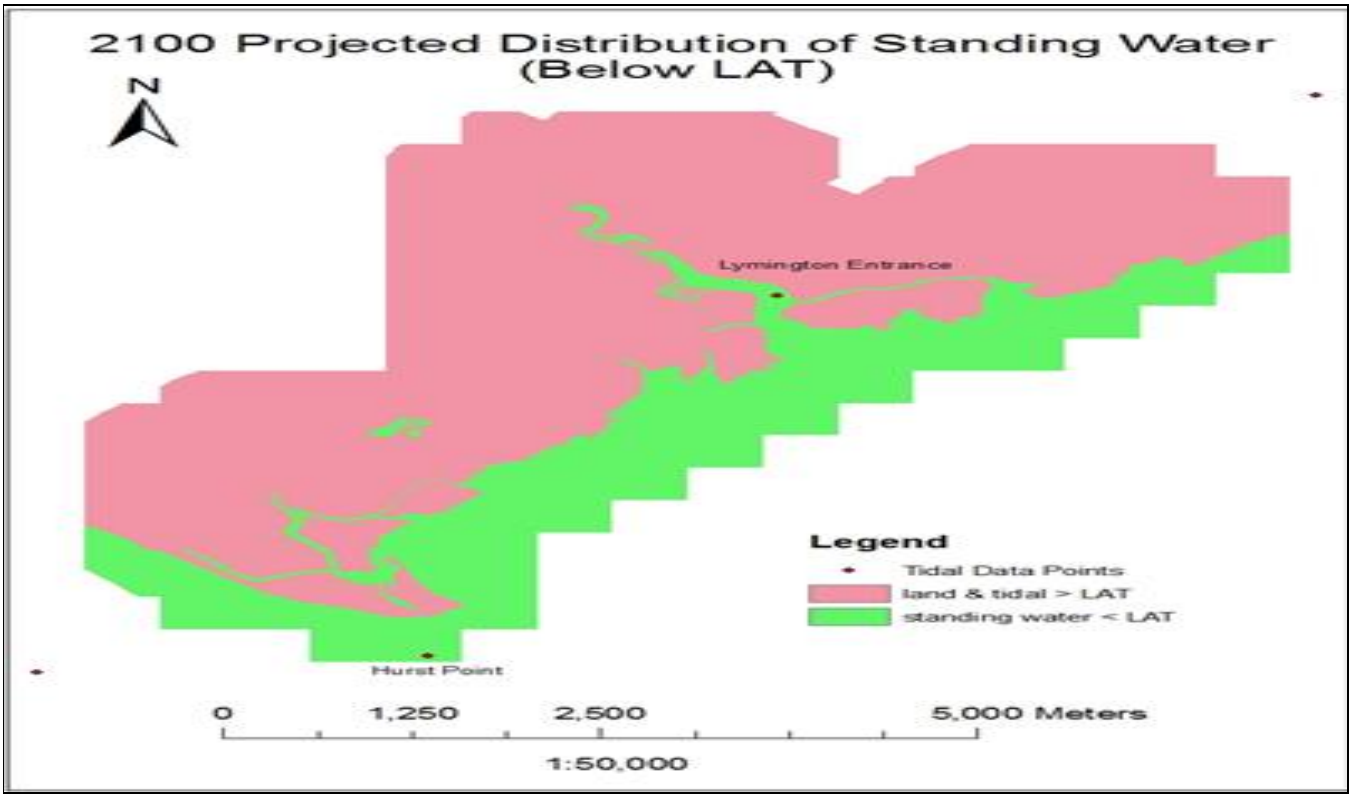

Fig 6: 2100 Projected Scenario of the Distribution of Standing Water below LAT & the Land & Inter-Tidal Zone Above LAT

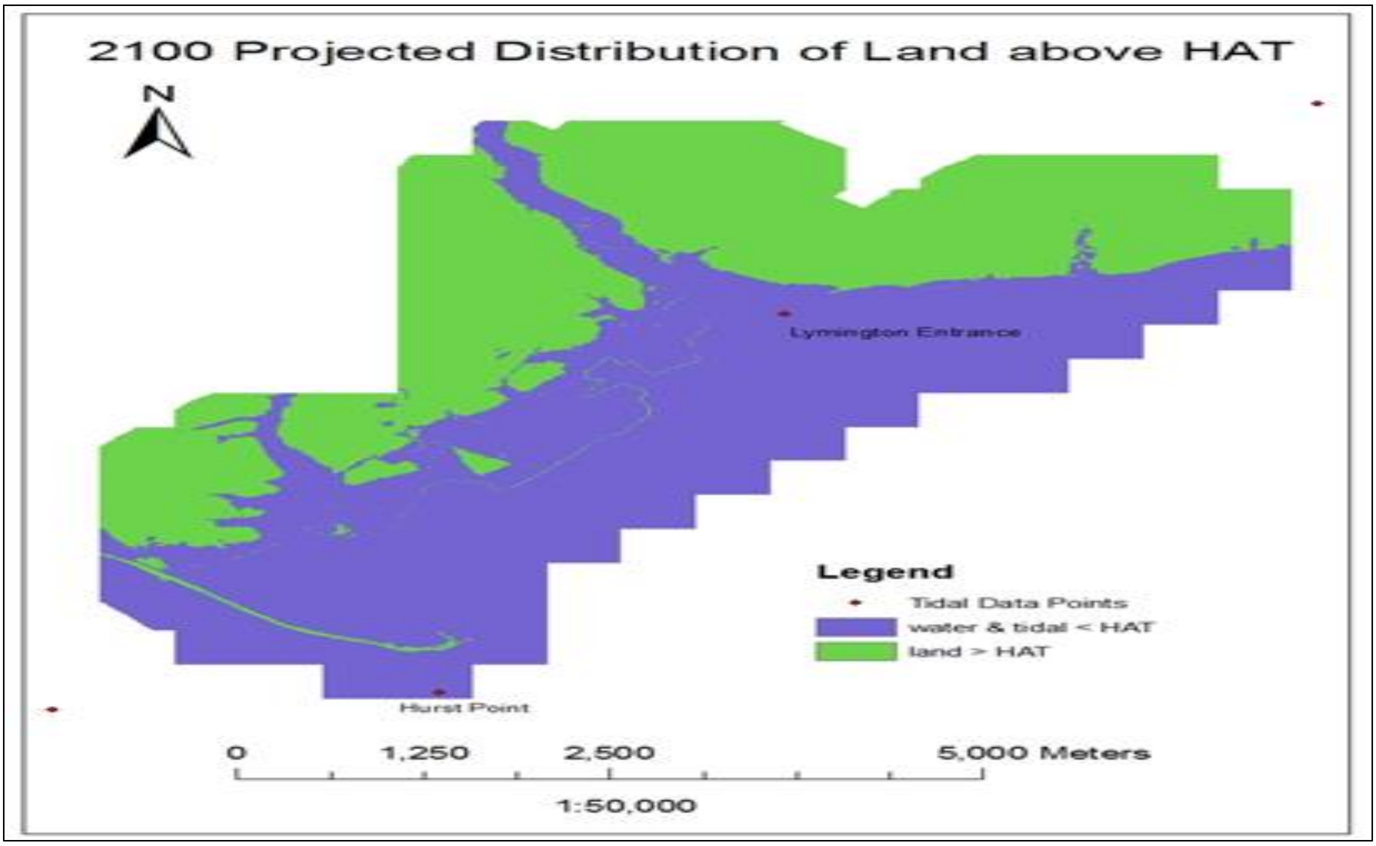

Fig 7: 2100 Projected Scenario of the Distribution of Supra-Tidal Land above HAT and the Water & Inter-Tidal Zone Below HAT

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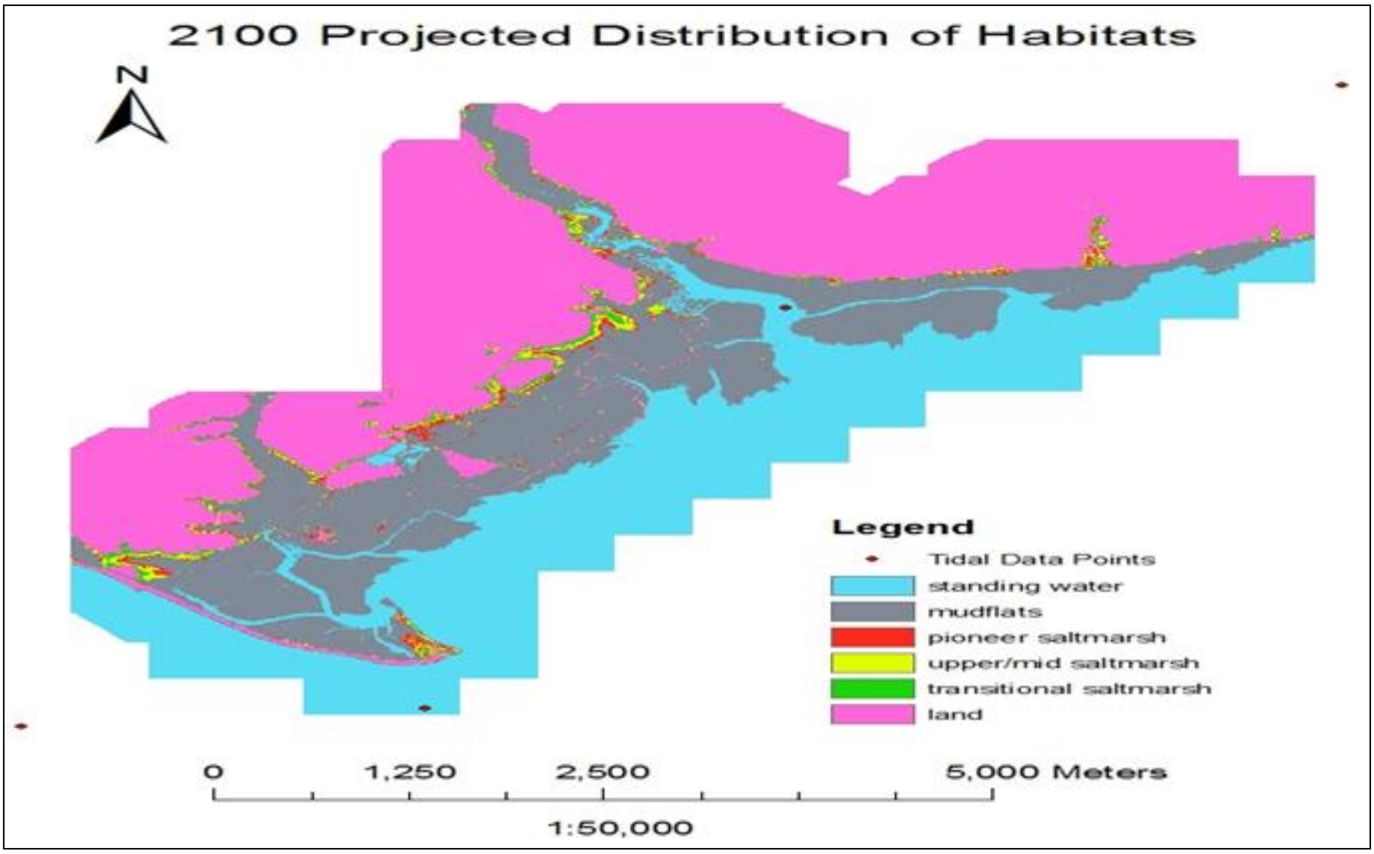

Fig 8: 2100 Projected Scenario of the Distribution of Habitats at the Study Site.

III. SUMMARY

A comparison of Tables 1 and 2 shows that, under the projected sea level rise of 0.89 m, the extent of the areas of standing water and mudflats would increase, while the salt marshes and dry land areas would decrease. The maps in Figures 3 and 6 also indicate that the extent of standing water might increase at the expense of salt marshes and land. Tables 3 and 4 show that each of the three zones of salt marshes would contract, with Table 5 giving the actual areas and percentage of contraction as negative values.

A predicted rise in overall tidal surface elevations is seen in Tables 6 and 7. At present, the Pennington seawall, at a height of +2.5 m OD, can defend against the highest astronomical tide of 1.45 m with the help of the marshes, which aid in dissipating wave energy. However, by 2100, the highest predicted astronomical tide will reach 2.34 m. With a projected reduction of the area of the salt marshes, the seawall will be subjected to greater loadings from the higher tides, wind-induced waves, and storm surges. It could suffer overtopping and breaching. This is also indicated in the map of Figure 7. If there is no human protective intervention, this scenario will likely happen with consequential loss of lands on the landward side of the seawall.

IV. KEY FINDINGS

From Table 5, the predicted total percentage loss of saltmarsh area by 2100 is -64.6 %, with the pioneer saltmarsh suffering the greatest loss of -74.8 % and the transitional saltmarsh losing the least of -21.4%.

From Tables 5 and 6, the tidal elevation at the highest astronomical tide is projected to rise from 1.45 m to 2.34 m by 2100, a rise of +61.4 %. The mean high water is projected to rise from 0.94 m to 1.83 m by 2100, a rise of +94.7%.

V. RECOMMENDATIONS

The present seawall should be realigned in those areas where overtopping or breaching is most likely to occur. If the seawalls are raised higher in their present locations, the result will be a coastal squeeze of the salt marshes with the destruction of habitats. Realignment will help create space for the creation of new salt marshes up to the points where the seawall will be realigned.

As far as practical, the realigned seawall should follow the line of the highest astronomical tide shown in Figure 7. This will provide an additional area of 143 hectares for the creation of new salt marshes (obtained by subtracting the two land area figures in Tables 1 & 2, thus: 1708.78 – 1566.22 = 142.56 ha), so that the total area for salt marshes would be 251 hectares. Although this is less than the present-day area of saltmarsh, the percentage loss is not as

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great; the loss in this case would be just about -17.43 %, instead of the projected -64.6%

So, with human intervention and a managed realignment of the seawall, the loss of salt marshes and habitats would not be as great without human intervention.

Continuous GIS monitoring and analysis should be done to identify specific areas along the coastline that are particularly vulnerable to erosion and inundation under projected sea level rise scenarios. This could help prioritize adaptation measures and coastal protection strategies in areas where the risk is highest.

The local district authorities should support capacity-building initiatives and educational programmes aimed at increasing awareness of climate change impacts and building adaptive capacity among local communities, policymakers, and resource managers. Coastal residents should be empowered with the knowledge and skills needed to participate in adaptation planning and implementation efforts.

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Thanks to Dr. Mustafa Mokrech of the University of Southampton, School of Civil Engineering and the Environment, for advice and guidance.

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APPENDIX

Technical Details

Table 8: Tidal Data (2006) used to Produce the Excel Text Tab-Delimited File

	Latitude	Longitude	Easting	Northing	HAT	MHWS	MHW	MHWN	LAT
Lymington	50º 45' N	1º 31' W	434094	94663	1.30	1.08	0.84	0.60	-1.84
Hurst	50º 42' N	1º 33' W	431776	89089	1.04	0.87	0.67	0.47	-1.54
Lymington	Dummy	Dummy	437660	97755	1.30	1.08	0.84	0.60	-1.84
Hurst	Dummy	Dummy	429181	88846	1.04	0.87	0.67	0.47	-1.54

Table 9: Tidal Data (2100 projected SLR = 0.89 m) used to Produce the Excel Text Tab-Delimited File

	Latitude	Longitude	Easting	Northing	HAT	MHWS	MHW	MHWN	LAT
Lymington	50º 45' N	1º 31' W	434094	94663	2.19	1.97	1.73	1.49	-0.95
Hurst	50º 42' N	1º 33' W	431776	89089	1.93	1.76	1.56	1.36	-0.65
Lymington	Dummy	Dummy	437660	97755	2.19	1.97	1.73	1.49	-0.95
Hurst	Dummy	Dummy	429181	88846	1.93	1.76	1.56	1.36	-0.65

Table 10: Results of Raster Calculations for Final Tidal Surfaces (Present-Day 2006)

Tidal Elevation	DATA INPUT			RASTER CALCULATION	
	Lymington/m	Hurst/m	Layer	High/m	Low/m
HAT	1.3	1.04	HATfinal	1.44921	1.03365
MHWS	1.08	0.87	MHWSfinal	1.20052	0.864868
MHW	0.84	0.67	MHWfinal	0.937561	0.665846
MHWN	0.6	0.47	MHWNfinal	0.674605	0.466823
LAT	-1.84	-1.54	LATfinal	-1.53267	-2.01217

Table 11: Results of Raster Calculations for Final Tidal Surfaces (2100 Projected SLR = 0.89 m)

Tidal Elevation	DATA INPUT			RASTER CALCULATION	
	Lymington/m	Hurst/m	Layer	High/m	Low/m
HAT	2.19	1.93	HATfinal	2.33921	1.92365
MHWS	1.97	1.76	MHWSfinal	2.09052	1.75487
MHW	1.73	1.56	MHWfinal	1.82756	1.55585
MHWN	1.49	1.36	MHWNfinal	1.56461	1.35682
LAT	-0.95	-0.65	LATfinal	-0.642669	-1.12217

Table 12: Data from Statistics of Attributes of Present-Day Distribution of Habitats Map

Row ID	Value	Zone	Cell Count	Area/m^2	Area/km^2	Area/ha
0	**1**	Standing water < LAT	83,851	8,385,100	8.3851	838.51
1	**2**	LAT > Mudflats > MHWN	70,496	7,049,600	7.0496	704.96
2	**3**	MHW > Pioneer > MHWN	14,164	1,416,400	1.4164	141.64
3	**4**	MHWS > Upper/Mid > MHW	11,926	1,192,600	1.1926	119.26
4	**5**	HAT > Transitional > MHWS	4,310	431,000	0.4310	43.10
5	**6**	land > HAT	170,878	17,087,800	17.0878	1,708.78
		Total	**355,625**	**35,562,500**	**35.5625**	**3,556.25**

(Cell size = 10 m; Cell area = 100 m^2)

Table 13: Data from Statistics of Attributes of 2100 Projected Distribution of Habitats Map

Row ID	Value	Zone	Cell Count	Area/m^2	Area/km^2	Area/ha
0	**1**	Standing water < LAT	103,403	10,340,300	10.3403	1,034.03
1	**2**	LAT > Mudflats > MHWN	85,152	8,515,200	8.5152	851.52
2	**3**	MHW > Pioneer > MHWN	3,576	357,600	0.3576	35.76
3	**4**	MHWS > Upper/Mid > MHW	3,800	380,000	0.3800	38.00
4	**5**	HAT > Transitional > MHWS	3,386	338,600	0.3386	33.86
5	**6**	land > HAT	156,622	15,662,200	15.6622	1,566.22
		Total	**355,939**	**35,593,900**	**35.5939**	**3,559.39**

(Cell size = 10 m; Cell area = 100 m2)

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➢ *The Spline Interpolation Method used to Create the Tidal Surfaces:*

- Input: Points
- Z-fields: HAT, MHWS, MHW, MHWN, LAT
- Spline type: Regularized
- Weight: 0.1
- Number of points: 12
- Output cell size: 10 m ($\Rightarrow$ Cell area = 100 m^2)

➢ *Expressions used in the Raster Calculator to Obtain Final Tidal Surfaces for the Required Extent of the Study Area:*

- HATfinal= [HAT]*[area.img]
- MHWSfinal= [MHWS]*[area.img]
- MHWfinal= [MHW]*[area.img]
- MHWNfinal= [MHWN]*[area.img]
- LATfinal= [LAT]*[area.img]

➢ *Expressions used in the Raster Calculator to Build the Habitat Model:*

- water= ([dtm_float] < [LATfinal]) * 1
- mudflats= ([dtm_float] >= [LATfinal] & [dtm_float]) * 2
- pioneer= ([dtm_float] >= [MHWNfinal] & [dtm_float] < [MHWfinal]) * 3
- upper= ([dtm_float] >= [MHWfinal] & [dtm_float] < [MHWSfinal]) * 4
- trans= ([dtm_float] >= [MHWSfinal] & [dtm_float] < [HATfinal]) * 5
- land= ([dtm_float] >= [HATfinal]) * 6
- habitats=[water] + [mudflats] + [pioneer] + [upper] + [trans] + [land]