Dudgeon and Sheringham Shoal Offshore Wind Farm Extensions

Preliminary Environmental Information Report

Volume 3

Appendix 10.3 - DEP and SEP Benthic Habitat Mapping

April 2021

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Benthic Habitat Mapping for Dudgeon and Sheringham Extension Projects

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Geophysical Data Interpretation & Habitat Mapping

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1 Executive Summary

EQUINOR propose to develop extension projects for Sheringham Shoal and Dudgeon Offshore Windfarms with Dudgeon Extension Project (DEP), located to the north and southeast of the existing Dudgeon Offshore Wind Farm, and Sheringham Extension Project (SEP), located to the north and east of the existing Sheringham Shoal Offshore Wind Farm. The proposed export cable corridor intersects with Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ) that has several designated features which have been assessed.

Benthic habitat maps have been produced for the project area using geophysical data sets along with benthic sample data including grab and drop video imagery. The overarching strategy for the interpretation of the data is to combine information from the geophysical data with the benthic sample data using geostatistical processing and spatial statistical analysis.

A stratified sampling program was designed to be used for the interpretation of acoustic remote sensing datasets, habitat mapping, and baseline characterisation of benthic habitats. Sample data from stations within the project area include samples collected as part of the characterisation surveys, full particle size analysis (PSA) data, with habitats and biotopes attributed to each sample following analysis (Fugro, 2020a,b). Multibeam echosounder (MBES) data and side scan sonar (SSS) data have been collected for the project area. These data have been incorporated within a geographic information system and processed to predict benthic habitat distributions.

The machine learning tool 'Random forest classification' within 'Vision using Generic Algorithms'[1] (VIGRA), was selected to produce the habitat maps. Habitat maps were produced at two levels of the EUNIS hierarchy, Levels 2-3 and Levels 2-5.

The Level 2-3 habitat maps have a high confidence and accuracy assessment supports this. Mapping extents of habitats/biotopes at level 2-5 decreases the accuracy of the maps but this reduction is often due to confusion between biotopes which occupy similar habitats i.e., Sublittoral sands (A5.2) being mapped as Infralittoral sands (A5.23).

The boundaries between the sediment habitats of mixed or coarse are notoriously difficult to delineate and this is the case within the habitat maps produced. There are physical mismatches between mapped classes and sample data and between sample data at coincident locations, which is often due to the assignment of biological habitats which override the physical habitat present. These physical mismatches should be considered when reviewing or examining the habitat maps for decision making purposes and areas of mixed and coarse sediments should be considered 'fluid' in their boundaries.

Distributions of herring spawning habitat and sandeel habitat preference have also been produced to show parts of the project development area which may be utilised by these fish. Additionally, several habitats of conservation interest are mapped within the project development area, namely infralittoral and circalittoral rock in the near shore area of the export cable corridor, and mixed and coarse sediments which occur

[1] *VIGRA - Vision with Generic Algorithms Version 1.11.1 by Ullrich Köthe*

in the cable corridor within the MCZ and also throughout the project area. No biogenic reefs were found to occur within the project area.

2 Introduction

EQUINOR propose to develop extension projects for Sheringham Shoal and Dudgeon Offshore Windfarms with Dudgeon Extension Project (DEP), located to the north and southeast of the existing Dudgeon Offshore Wind Farm, and Sheringham Extension Project (SEP), located to the north and east of the existing Sheringham Shoal Offshore Wind Farm. Both DEP and SEP share borders with the existing operational wind farms (Figure 1).

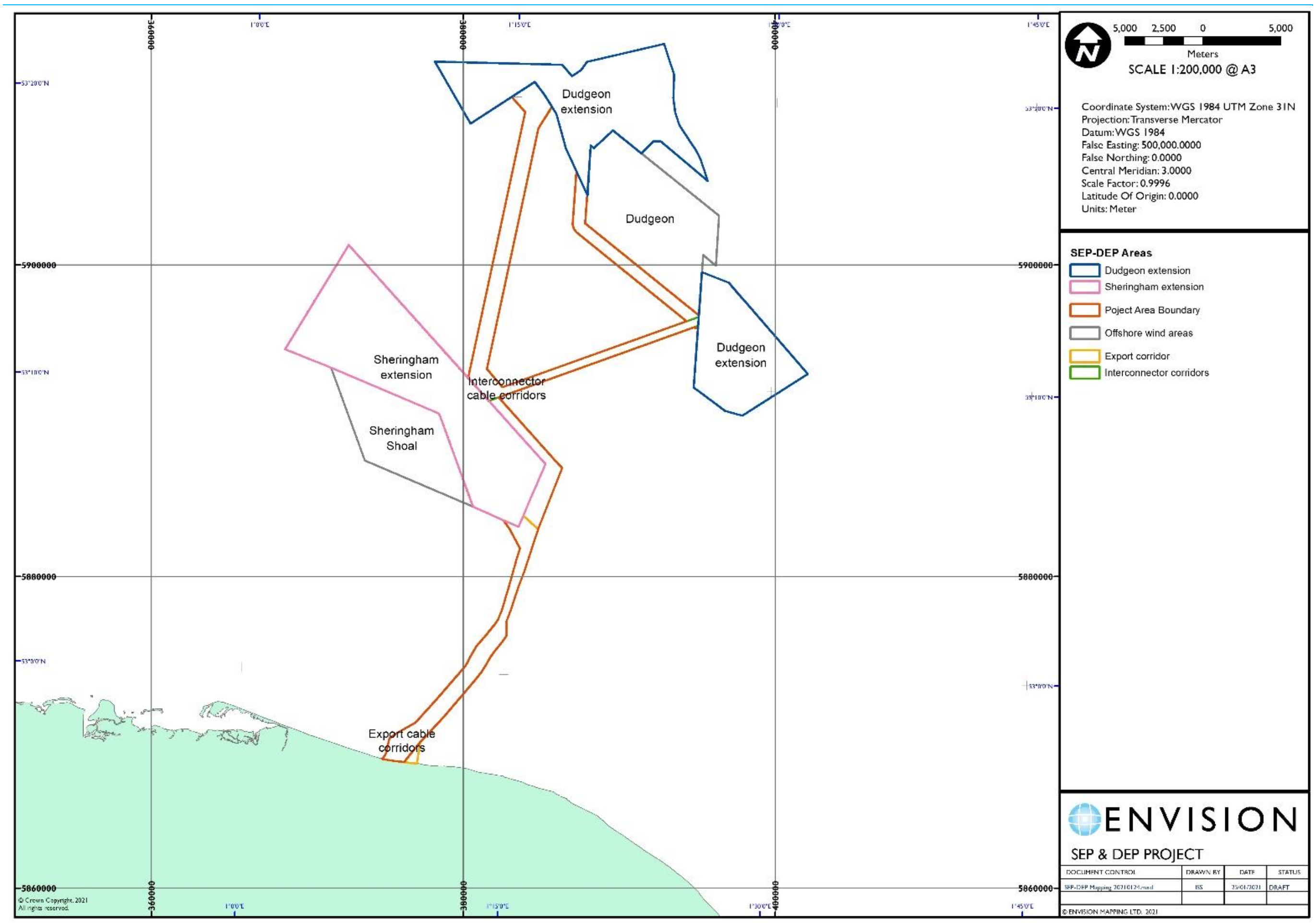

Figure 1.

Sheringham and Dudgeon extension project boundaries and existing offshore wind boundaries.

2.1 Marine Protected Areas

Of relevance to the proposed projects is the conservation area of Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ) (Figure 2).

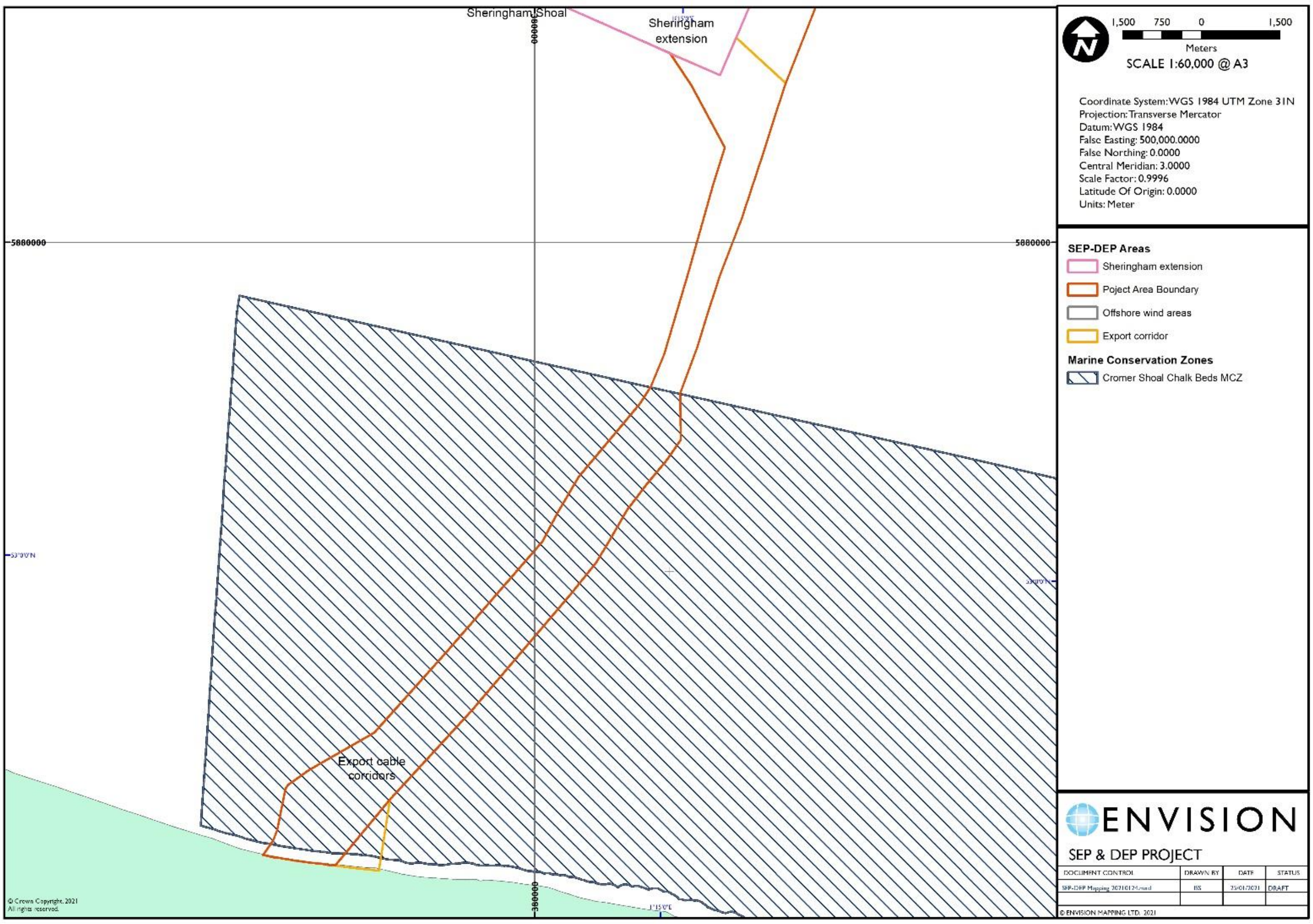

Figure 2.

Cable corridor for SEP and DEP in relation to Cromer Shoal Chalk Beds MCZ boundary

Cromer Shoal Chalk Beds MCZ is designated for several benthic habitats (Table 1).

Table 1.

Designated features which occur within Cromer Shoal Chalk Beds MCZ

Moderate energy infralittoral and circalittoral rock
High energy infralittoral and circalittoral rock
Subtidal chalk
Subtidal coarse sediment
Subtidal mixed sediments
Subtidal sand
Peat and clay exposures

Other habitats which could be environmentally significant are potential herring spawning habitat, potential sand eel habitat and biogenic reefs (*Sabellaria spinulosa* reef) which are known to occur in the North Norfolk region.

2.2 Sample Planning

A stratified sampling program was designed to be used for the interpretation of acoustic remote sensing datasets, habitat mapping, and baseline characterisation of benthic habitats. The program was systematically structured and justified and was agreed with regulatory authorities.

The sample design ensured representative sampling of the range of potential habitat types and were geographically spread throughout the area of interest and also targeted specific areas of interest which were relatively small but potentially significant habitats.

Existing maps and sample data were reviewed to identify areas where any conservation features are known to occur to allow any sample plan to consider these locations.

The sample planning methodology is detailed in Envision (2020).

3 Habitat Mapping

The overarching strategy for the interpretation of the available data is to combine information from geophysical data with the benthic sample data using geostatistical processing and spatial statistical analysis. This process uses the sample data to 'ground truth' geophysical data, a strategy which is described in the Mapping European Seabed Habitats (MESH) documentation from which Figure 3 is taken (MESH, 2008). Existing geophysical data require processing prior to integration so that the data are spatially coincident, at identical spatial resolutions and in a suitable format for the mathematical analyses. The main outputs are descriptions of habitats and distribution maps.

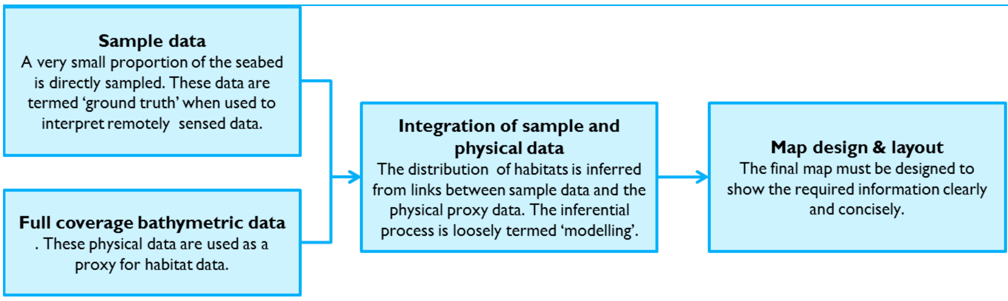

Figure 3. *A flow chart of the main stages in making a habitat map by integrating sample data and full coverage physical data*

Several approaches have been used to map the area, and the resultant maps from each approach assessed to determine which habitat map best represents the distribution of habitats from sample data.

3.1 Data Used Within Mapping Methods

3.1.1 Geophysical Data & Derivatives

Multibeam echosounder (MBES) data and side scan sonar (SSS) data have been collected for the project areas, which are relevant to the benthic environment. The data were collected during two surveys (Gardline, 2020a; Gardline,2020b):

- Gardline September to December 2019 survey of export cable corridors options.

- Gardline March to May 2020 survey of DEP and SEP wind farm sites and interlink cable corridors options.

These data have been incorporated within a geographic information system and processed to produce derived data sets which can be used to predict benthic habitat variability or complexity within the areas surveyed.

Thus, the data inputs were:

- Bathymetry (Figure 4)
- Transformed and normalised side scan sonar (Figure 5)

Bathymetry was used as gridded data at a resolution of 5m (Figure 4). In addition to detailing the depth of the seafloor, bathymetry can be used to derive other parameters such as slope and an index of rugosity which can highlight where the seabed is variable in nature.

Seabed terrain heterogeneity can indicate the complexity of a habitat and is known to be correlated to distribution of benthic fauna (Tappin *et al*., 2010). Rugosity was calculated using a terrain ruggedness index which produces gridded data suitable for analysis. Rugosity was derived using the method from Riley *et al*., (1999) (Figure 6). Another derivative from bathymetry is slope (Figure 7), which has been demonstrated to act as a significant predictor in benthic species distribution models (Wilson *et al*., 2007). Other derivatives such as aspect and curvature were not used as these are correlated to other variables and can overly influence the mapping process.

The variability of sidescan sonar images can also indicate the heterogeneity of seabed habitats and this derivative was also incorporated into the habitat mapping process (Figure 8).

All data layers were standardised to 5m pixel raster images[2] with the same geographic bounds in order to perform mathematic and statistical calculations and classifications.

[2] *A raster image is a rectangular grid of values of a regular size (pixels) which form an image of the data.*

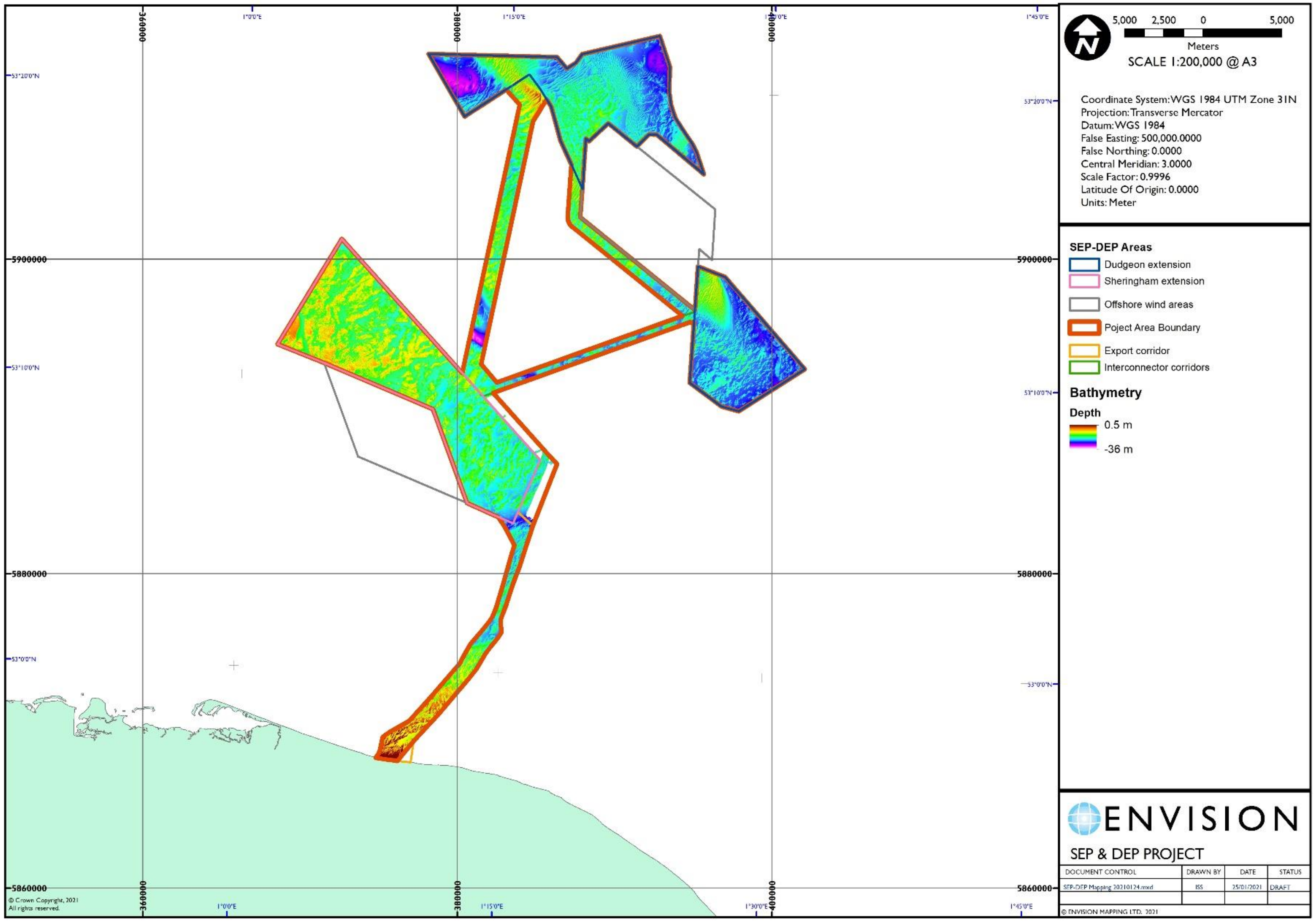

Figure 4. *Bathymetry for the SEP-DEP Project area*

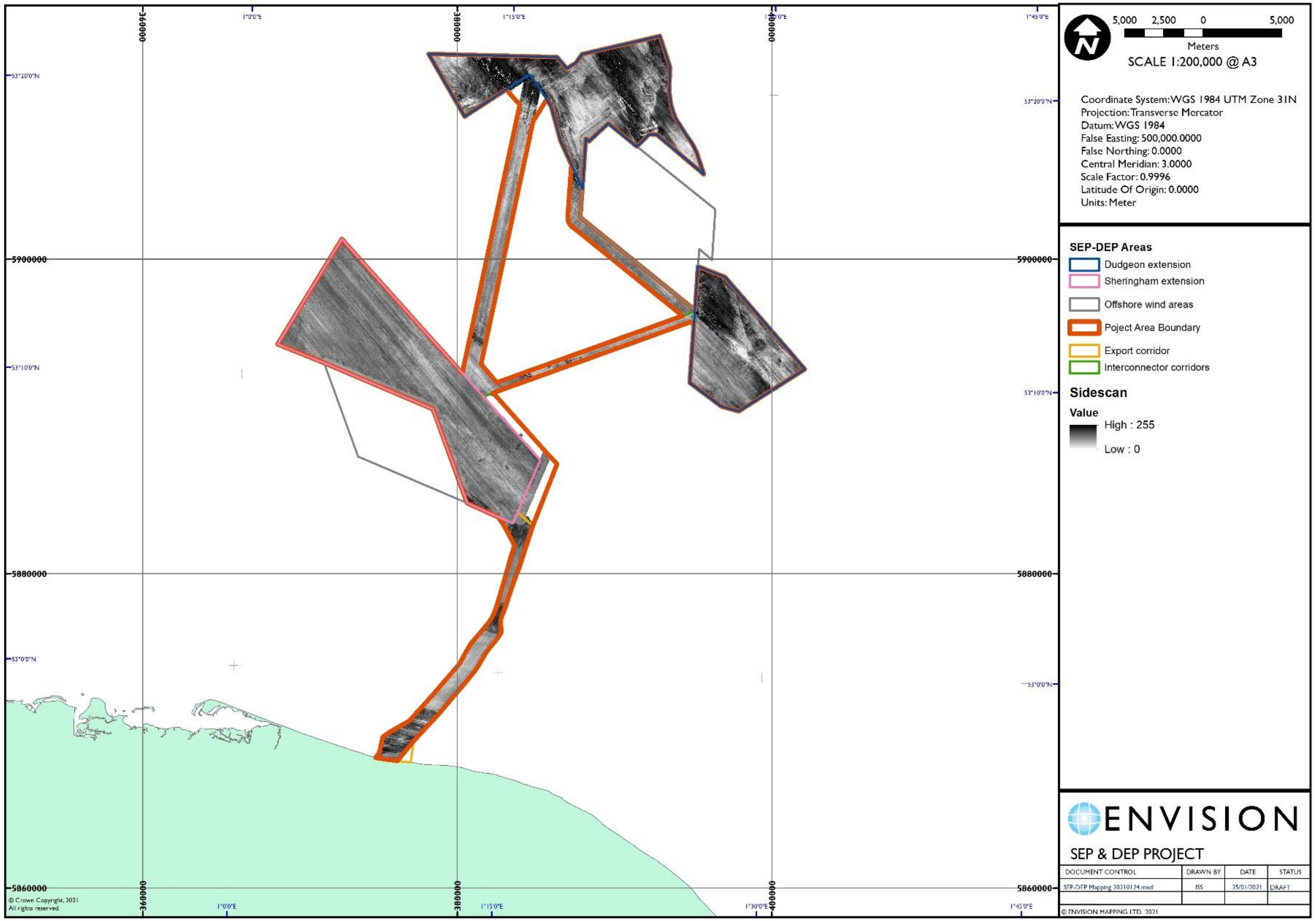

Figure 5. *Sidescan sonar data for the SEP-DEP Project area*

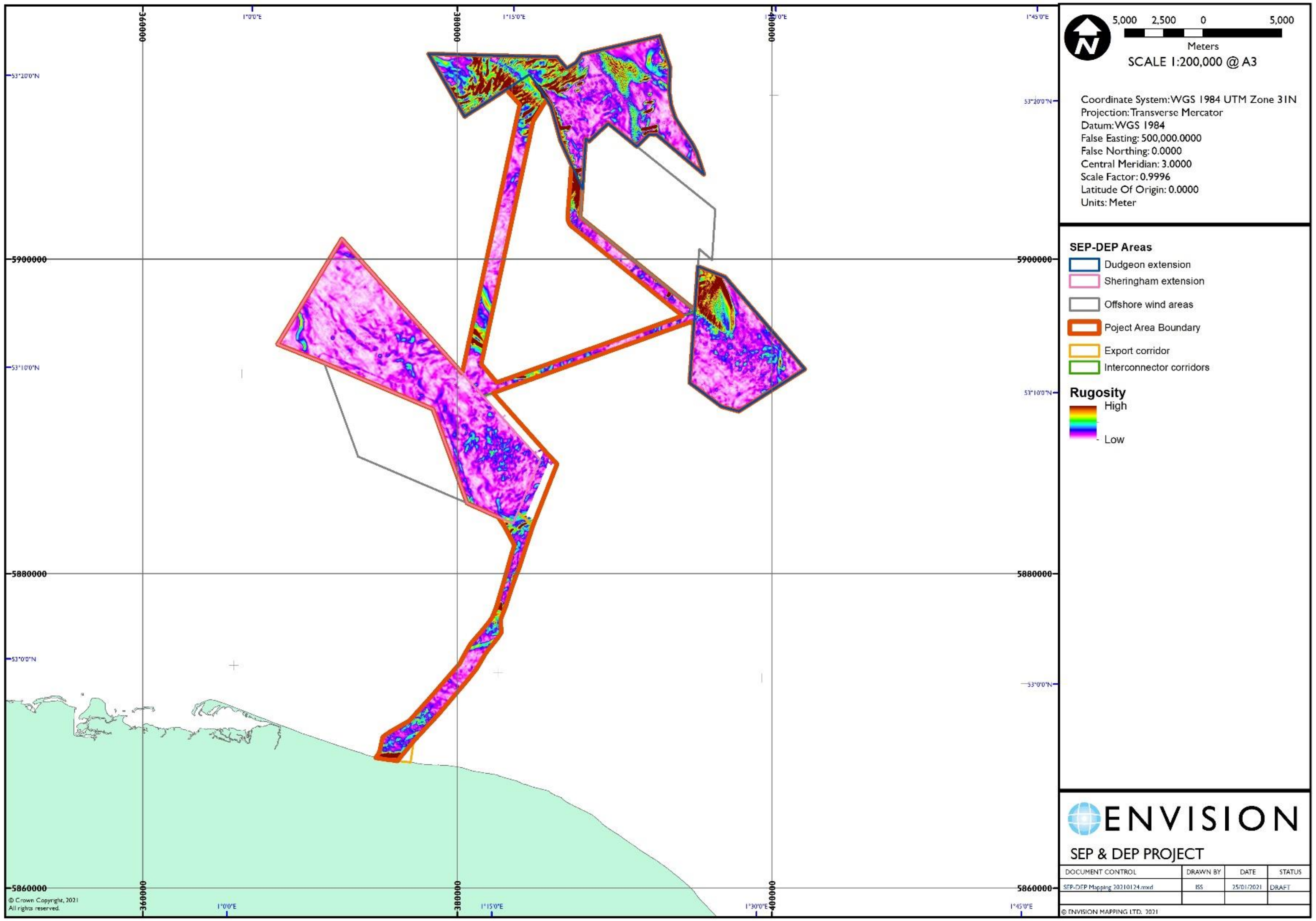

Figure 6. *Rugosity derived from bathymetric data for the SEP-DEP Project area*

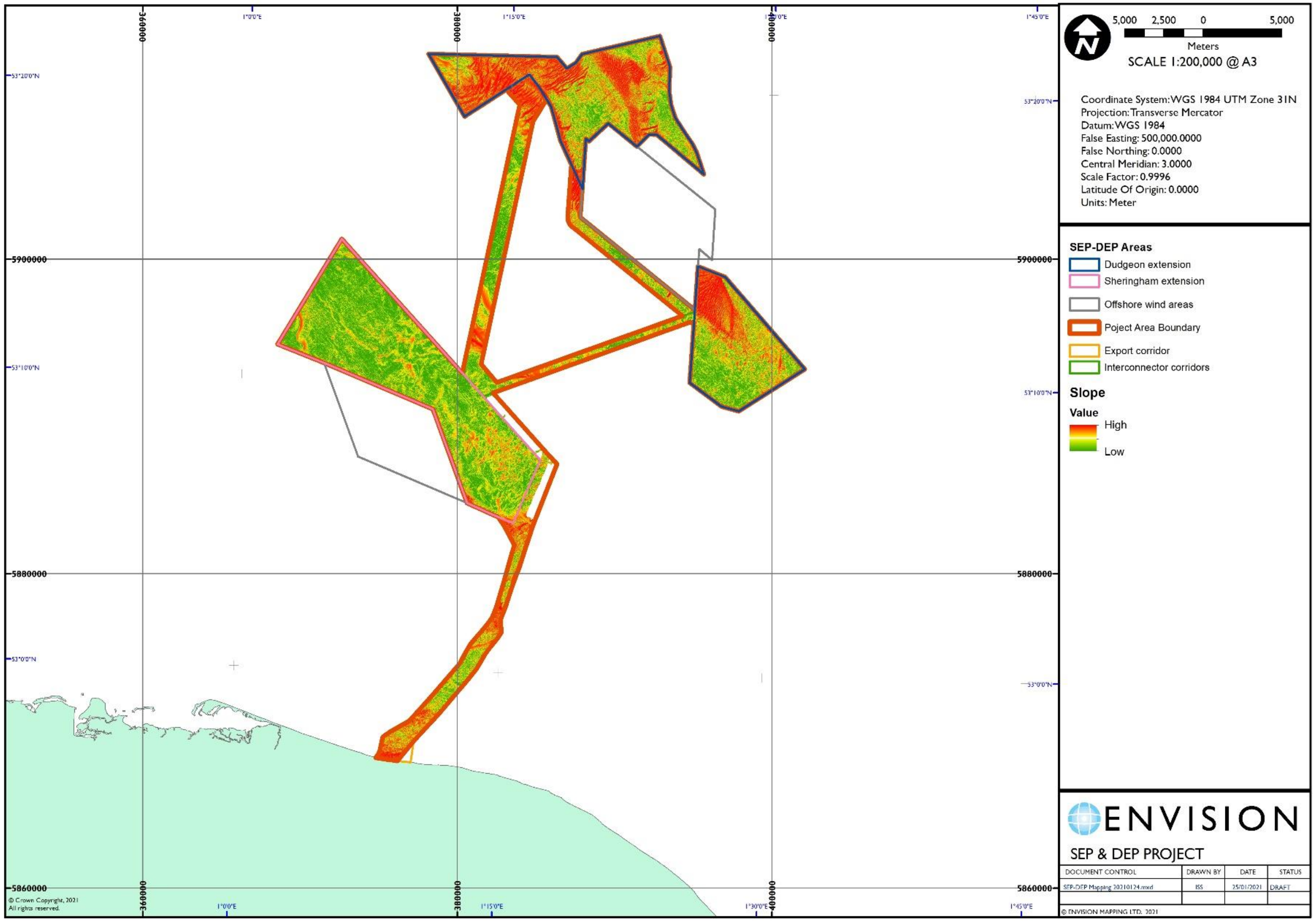

Figure 7. *Slope data derived from bathymetric data for the SEP-DEP Project area*

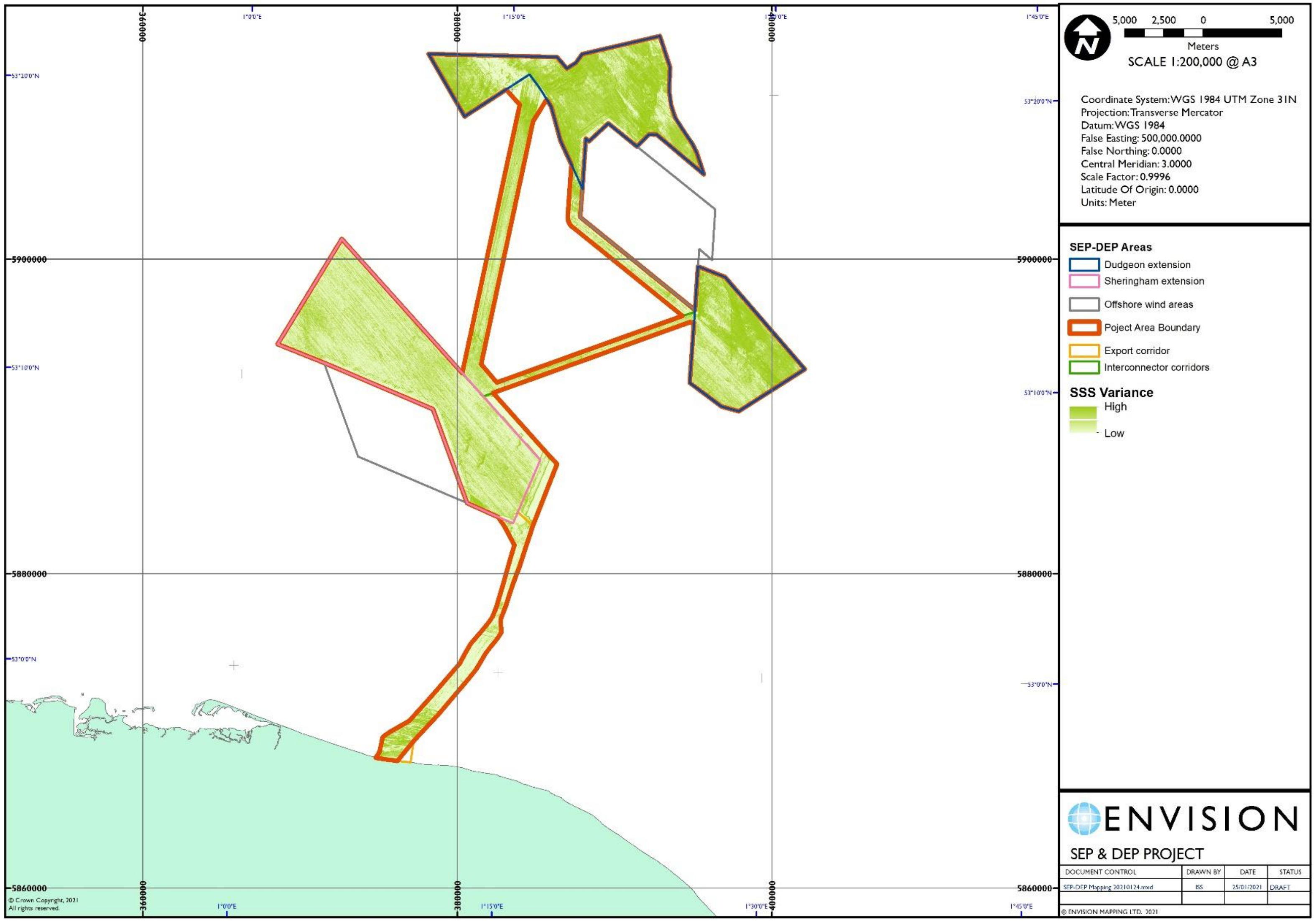

Figure 8. *Variability of sidescan sonar data for the SEP-DEP Project area*

3.1.2 Sample Data

Sample data from stations within the project area include samples collected as part of the characterisation surveys (Fugro, 2020a,b), full particle size analysis (PSA) data, with habitats and biotopes attributed to each sample following analysis.

All samples had been attributed to a European Nature Information System (EUNIS) marine habitat category or a Marine Nature Conservation Review (MNCR) habitat with the marine habitat categories used within the mapping process shown in Table 2 below, and their distribution presented in Figure 9.

Table 2.
Marine habitat categories used with the mapping process.

EUNIS Code	Name	MNCR Habitat/Biotope
A3	IR	*Infralittoral rock*
A4.231	CR.MCR.SfR.Pid	*Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay*
A5.1	SS.SCS	*Sublittoral coarse sediment (unstable cobbles and pebbles, gravels and coarse sands)*
A5.13	SS.SCS.ICS	*Infralittoral coarse sediment*
A5.2	SS.SSa	*Sublittoral sands and muddy sands*
A5.23	SS.SSa.IFiSa	*Infralittoral fine sand*
A5.233	SS.SSa.IFiSa.NcirBat	*Nephtys cirrosa and Bathyporeia spp. in infralittoral sand*
A5.4	SS.SMx	*Sublittoral mixed sediment*
A5.43	SS.SMx.IMx	*Infralittoral mixed sediment*
A5.44	SS.SMx.CMx	*Circalittoral mixed sediment*
A5.451	SS.SMx.OMx.PoVen	*Polychaete-rich deep Venus community in offshore mixed sediments*
A5.431 & A5.611	SS.SMx.IMx.CreAsAn & SS.SBR.PoR.SspiMx	*Crepidula fornicata with ascidians and anemones on infralittoral coarse mixed sediment and Sabellaria spinulosa on stable circalittoral mixed sediment*

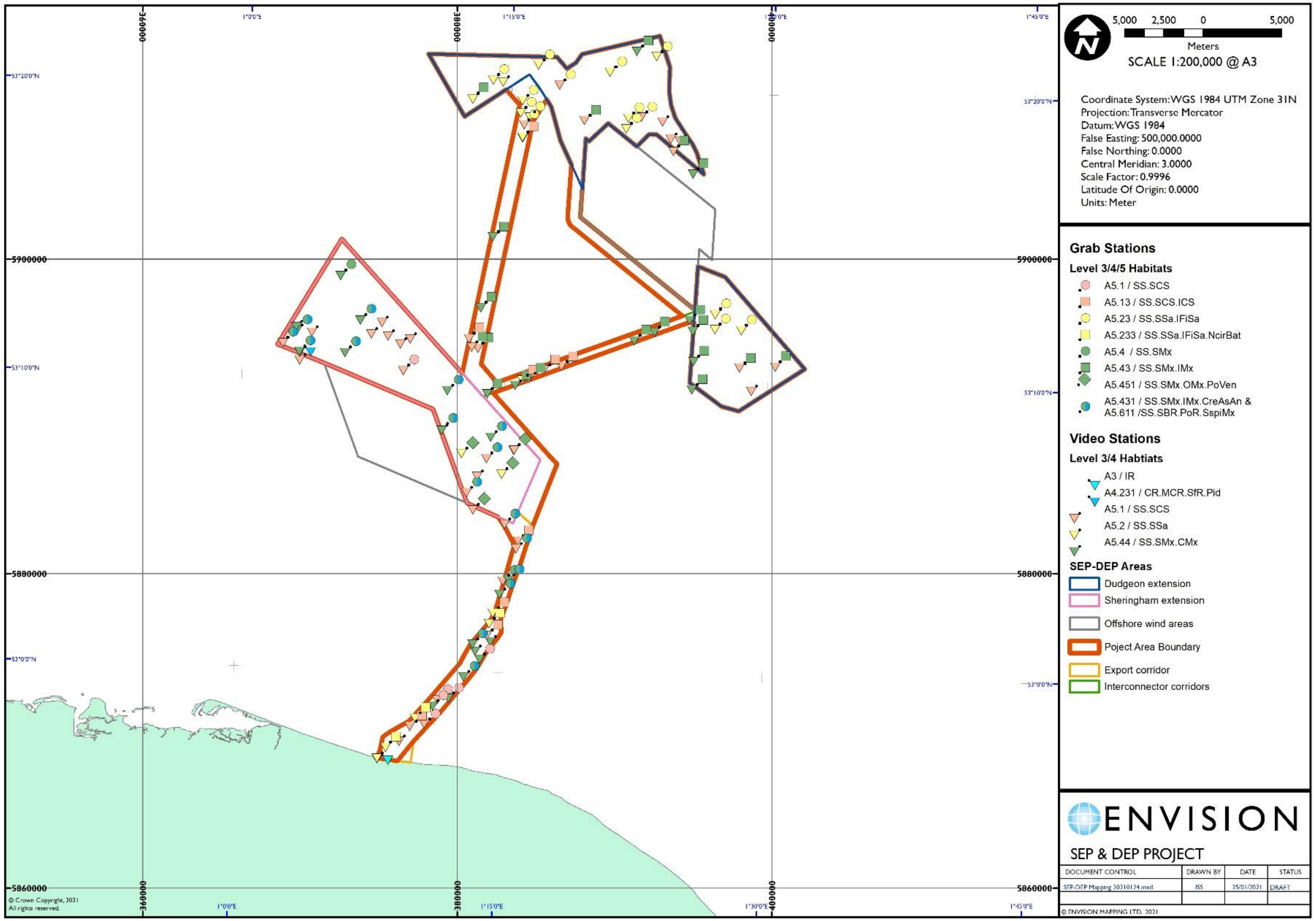

Figure 9. *Distribution of sample data collected within the SEP-DEP Project area showing EUNIS Level 3-5 habitats used for habitat mapping*

3.2 Integration of Sample and Physical Data for Mapping

Supervised or Modelled Feature Mapping uses statistical classification procedures to predict habitat distribution using ground truth datasets to interpret geophysical and other environmental coverages (usually termed "supervised classification"). The overarching strategy for this interpretation is to gather information from the physical data sets and relate these directly or statistically to the parameters which help determine the distribution and likelihood of a habitat or feature occurring. These relationships are built and investigated using spatial data analysis such as but not limited to supervised classification, cluster analysis, and segmentation classification or object-based image analysis.

The ground truth point data were buffered to create a training area of 25m radius around each point and these areas associated with the appropriate habitat category. The integration analysis was performed within the GIS and image processing software and the training areas were used to extract values from each of the geophysical layers that could be associated with the biological habitat classes. These values were used to create a statistical 'signature' for each class with these signatures then applied to the whole geophysical data set. A schematic diagram illustrating the main stages in the analytical process is shown in Figure 10.

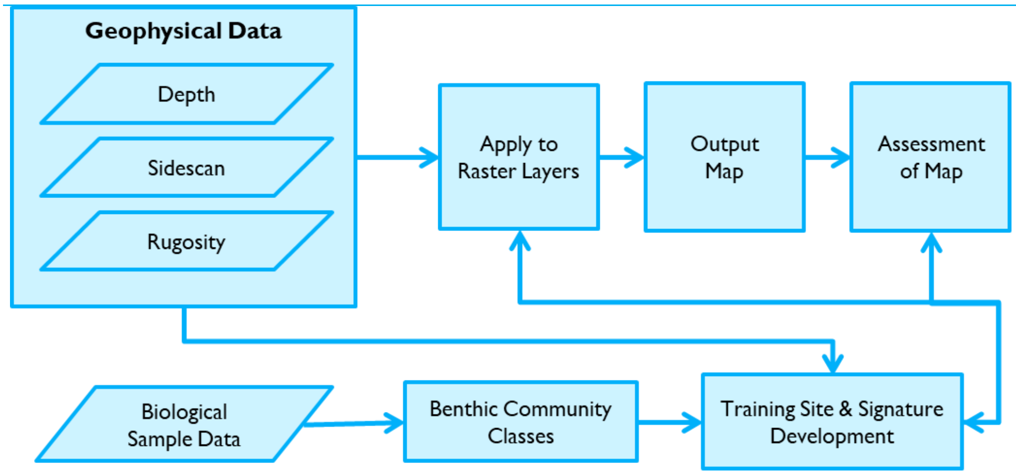

Figure 10. *Schematic diagram outlining the main stages in the modelling of the distribution of biotas classes*

3.2.1 Mapping Processes

Several mapping processes and classification techniques were investigated to produce habitat distribution maps. Maximum likelihood classification, and Maximum entropy classification processes produced outputs with low accuracy and omitted several of the mapping categories. The machine learning tool 'Random forest classification' within 'Vision using Generic Algorithms'[3] (VIGRA), was selected to produce the habitat maps as this provided a relatively high accuracy output and mapped all but one of the habitat classes (A4.231/ CR.MCR.SfR.Pid was omitted, this biotope was found at one location and it is not possible to map the extent based upon this sample). Random forest classification is an ensemble algorithm, which creates multiple decision trees from a randomly selected subset of the training areas, and the outputs from each decision

[3] *VIGRA - Vision with Generic Algorithms Version 1.11.1 by Ullrich Köthe*

tree are then evaluated to determine the final habitat class to be mapped based upon the average value or majority class from all the decision trees generated.

3.2.2 Accuracy Assessment

The habitat distribution maps were assessed using an accuracy assessment confusion matrix where the resulting maps are tested against the sample point data to assess the success of the mapping process. Ideally an independent sample data set can be used to perform an accuracy assessment, but this is not practical in all cases therefore reliance is placed on internal accuracy only.

Two measures of accuracy are produced using confusion matrices:

i. User Accuracy relates to the errors of inclusion within the map, i.e., for any habitat class, the percentage of the areas mapped that are accurately mapped.

ii. Producer Accuracy relates the errors of omission within the map, i.e., for any habitat class, the percentage of sample areas mapped that are correct.

4 Habitat Distribution

Habitat maps were produced at two levels of the EUNIS hierarchy, Level 2-3 (Figure 11) and Level 3-5 (Figure 12). Appendices 1 and 2 show the habitat maps at a variety of scales for the whole of the proposed development area.

The habitat "Piddocks with a sparse associated fauna in sublittoral very soft chalk or clay" (A4.231 / CR.MCR.SfR.Pid) was sampled only once and the mapping process does not predict this habitat to any significant extent. The habitat is identified from video footage and is shown on the habitat maps below for reference.

Only one sample recorded Infralittoral Rock (A3 - IR) and this has produced an extent of rock habitat which may be overpredicted and from existing records it is known this area contains circalittoral rock habitats also and is therefore mapped as both infralittoral and circalittoral rock (A3 - IR / A4 -CR). This has been included within the habitat maps as this is a feature of conservation importance but predicted extents should be treated with caution and this habitat has been mapped separately, see section 5.2.

4.1 EUNIS Level 2-3 Habitats

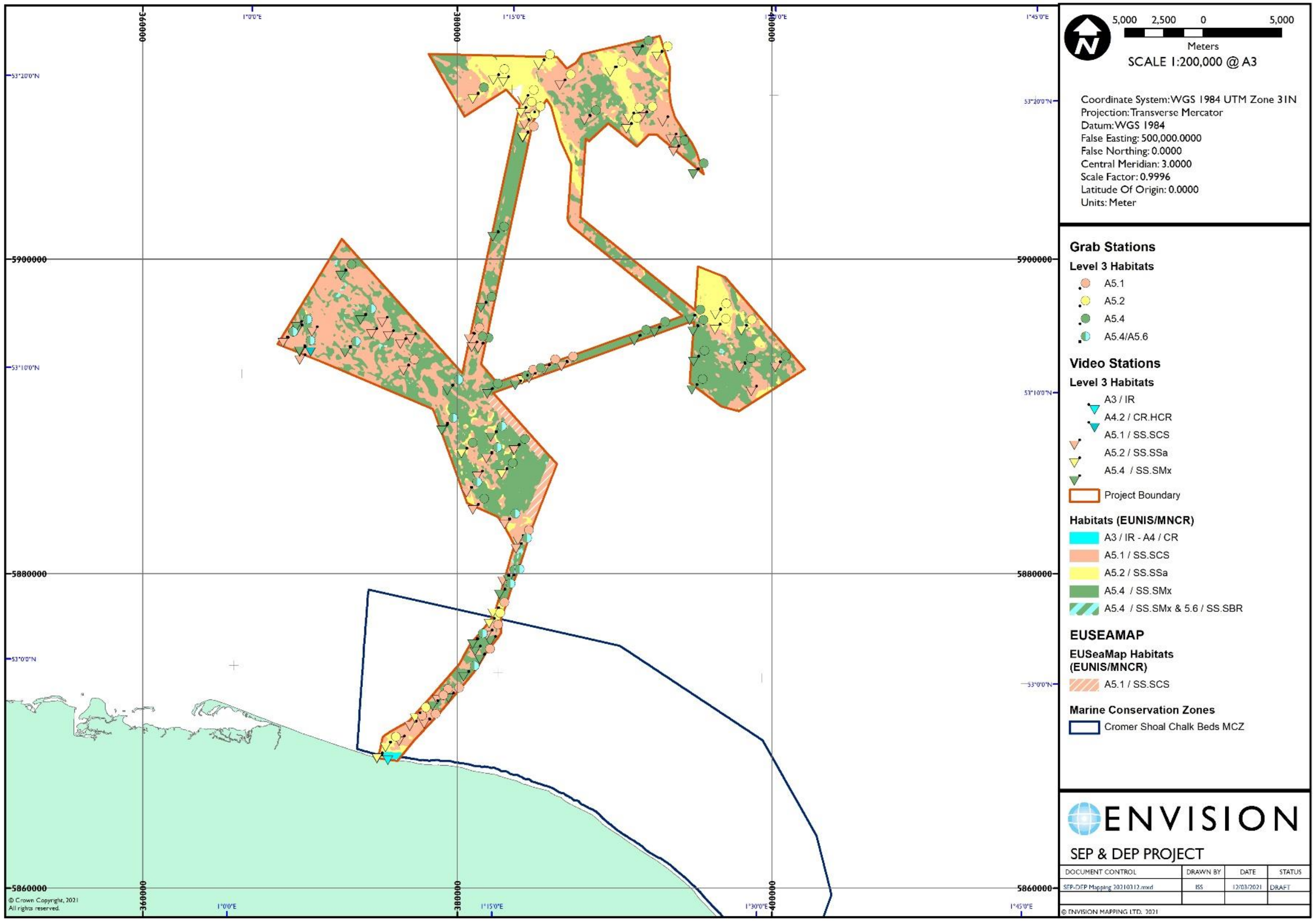

Figure 11. *Predicted distribution of EUNIS Levels 2-3 habitats for the SEP-DEP Project area*

4.2 EUNIS Level 2-5 Habitats

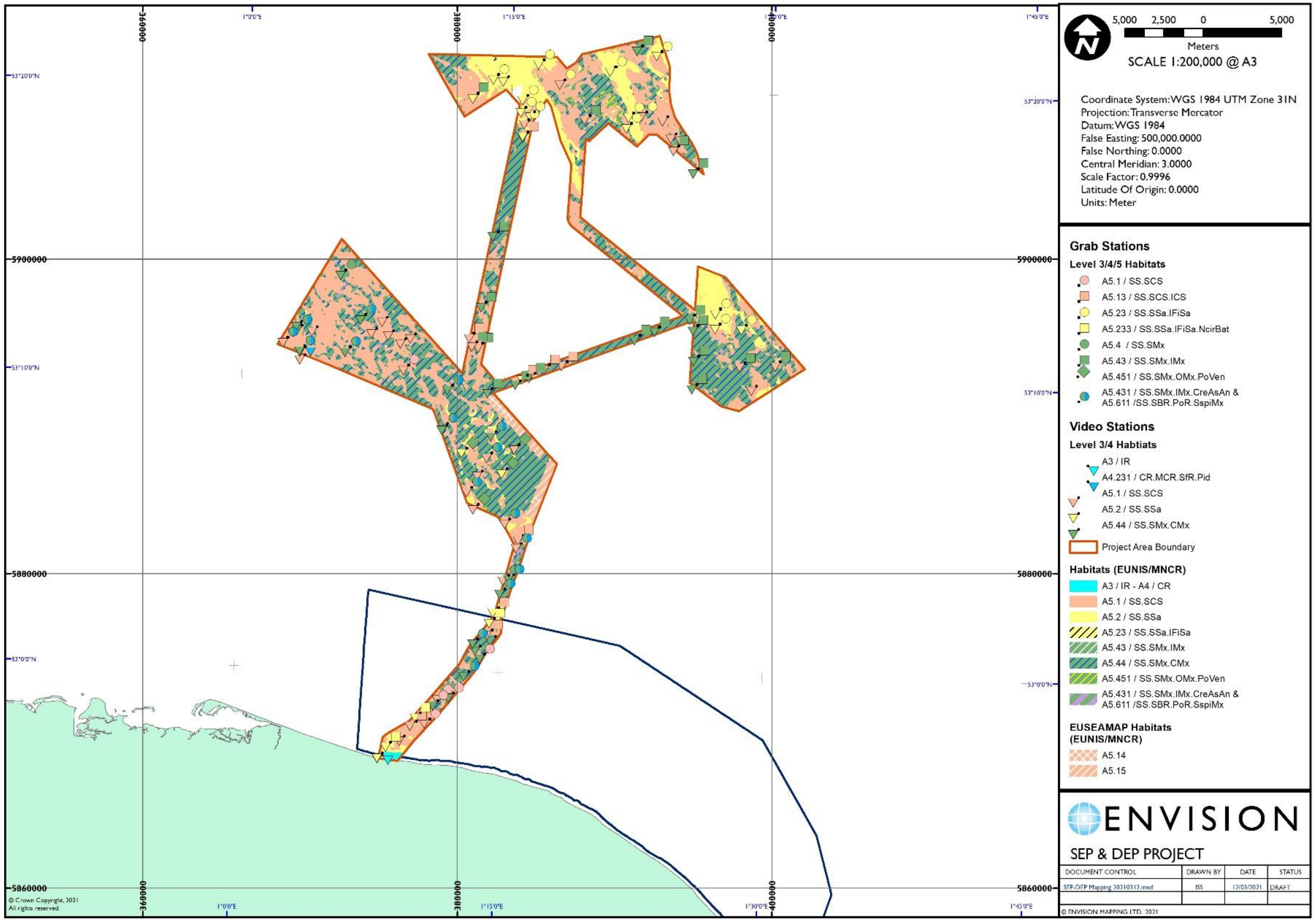

Figure 12. *Predicted distribution of EUNIS Levels 2-5 habitats for the SEP-DEP Project area*

4.3 Confidence

Confidence in the map has been assessed in several ways: a confidence score following the MESH confidence assessment method, a JNCC confidence assessment method (Lillis 2016), an accuracy assessment and the underlying distribution of probabilities for each habitat produced as part of the classification process.

Additionally, the distribution of sample points is shown on all habitat maps and the proximity of samples points to mapped areas should be taken into account when assessing any predictive map, as the mapping methodology may not consider distance from sample points in the process. When mapped areas are distant from any sample point data then these should be considered lower confidence than those areas with sample data in proximity.

4.3.1 Confidence Scores

The MESH confidence assessment scoresheet was used to determine a confidence score of 98.

Remote Technique	Remote Coverage	Remote Positioning	Remote Stds Applied	Remote Vintage	BGT Technique	PGT Technique	GT Positioning	GT Density	GT Standards Applied	GT Vintage	GT Interpretation	Remote Interpretation	Detail Level	Map Accuracy	Remote score	GT score	Interpretation score	Overall score
3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	100	95	100	**98**

The confidence of the habitat map was scored as 2.5 (out of 4) using the Lillis (2016) method.

Remote Sensing Coverage	Distinctness of class boundaries	Amount of sampling	Total Score
2	0	0.25 (0-1)*	**2.25**

*An intermediate value of 0.5 is given for the amount of sampling as the majority of habitats have ample sampling but two classes of subtidal rock have only one sample and therefore the score is reduced.

4.3.2 Accuracy Assessment

The habitat distribution maps were assessed using an accuracy assessment confusion matrix where the resulting maps are tested against the sample point data to assess the success of the mapping process. Ideally an independent sample data set can be used to perform an accuracy assessment, but this is not practical in all cases therefore reliance is placed on internal accuracy only.

Two measures of accuracy are produced using confusion matrices:

i. User Accuracy relates to the errors of inclusion within the map, i.e., for any habitat class, the percentage of the areas mapped that are accurately mapped. This represents the probability that an area classified into a given habitat actually represents that category on the ground.

ii. Producer Accuracy relates the errors of omission within the map, i.e., for any habitat class, the percentage of sample areas mapped that are correct. This value represents how well reference sites of the habitat type are classified.

Table 3
EUNIS Level 2-3 Habitat Maps

		Sample Classes					
		A3 / IR	A5.1 / SS.SCS	A5.2 / SS.SSa	A5.4 / SS.SMx	Area Sum	User Accuracy
Mapped Classes	**A3 / IR**	653	0	0	0	653	100.00%
	A5.1 / SS.SCS	0	8770	485	1347	10602	82.72%
	A5.2 / SS.SSa	0	159	5286	239	5684	93.00%
	A5.4 / SS.SMx	0	225	0	7951	8176	97.25%
	Area Sum	653	9154	5771	9537		
	Producer	100.00%	95.81%	91.60%	83.37%		

Overall User Accuracy: **93.24%**

Overall Producer Accuracy: **92.69%**

Table 4
EUNIS Level 2-5 Habitat Maps

		Sample Classes												
		A3	**A5.1**	**A5.13**	**A5.2**	**A5.23**	**A5.233**	**A5.4**	**A5.43**	**A5.431 & A5.611**	**A5.44**	**A5.451**	**Area Sum User**	**User Accuracy**
Mapped Classes	**A3**	653	0	0	0	0	0	0	0	0	0	0	653	100.00%
	A5.1	0	7641	311	0	118	0	0	220	239	94	44	8667	88.16%
	A5.13	0	190	326	50	0	0	0	0	0	0	0	566	57.60%
	A5.2	0	0	70	3810	495	117	0	43	0	0	136	4671	81.57%
	A5.23	0	89	0	323	562	0	0	0	0	0	0	974	57.70%
	A5.233	0	0	0	92	0	116	0	0	0	0	0	208	55.77%
	A5.4	0	0	0	0	0	0	35	0	0	34	0	69	50.72%
	A5.43	0	198	0	30	0	0	0	869	0	385	0	1482	58.64%
	A5.431; A5.611	0	172	0	0	0	0	0	0	663	265	0	1100	60.27%
	A5.44	0	128	0	0	0	0	44	435	434	5464	0	6505	84.00%
	A5.451	0	29	0	58	0	0	0	0	0	0	133	220	60.45%
	Area Sum Producer	653	8447	707	4363	1175	233	79	1567	1336	6242	313		
	Producer Accuracy	100.00%	90.46%	46.11%	87.33%	47.83%	49.79%	0.00%	0.00%	32.49%	6.17%	0.00%		

Overall User Accuracy: **68.63%**

Overall Producer Accuracy: **41.83%**

In summary the Level 2-3 habitat maps have a high confidence and accuracy assessment supports this. Mapping extents of habitats/biotopes at Levels 2-5 decreases the accuracy of the maps but this reduction is often due to confusion between biotopes which occupy similar habitats i.e., Sublittoral sands (A5.2) being mapped as Infralittoral sands (A5.23).

4.3.3 Underlying Probabilities

Maps of underlying probability, derived from the classification process, is available within the GIS to provide contextual data to aid in decision making processes with regards to the predicted distribution of the marine benthic habitats. The probabilities for the habitat classes in the maps for EUNIS Levels 2-3 is shown in Figure 13.

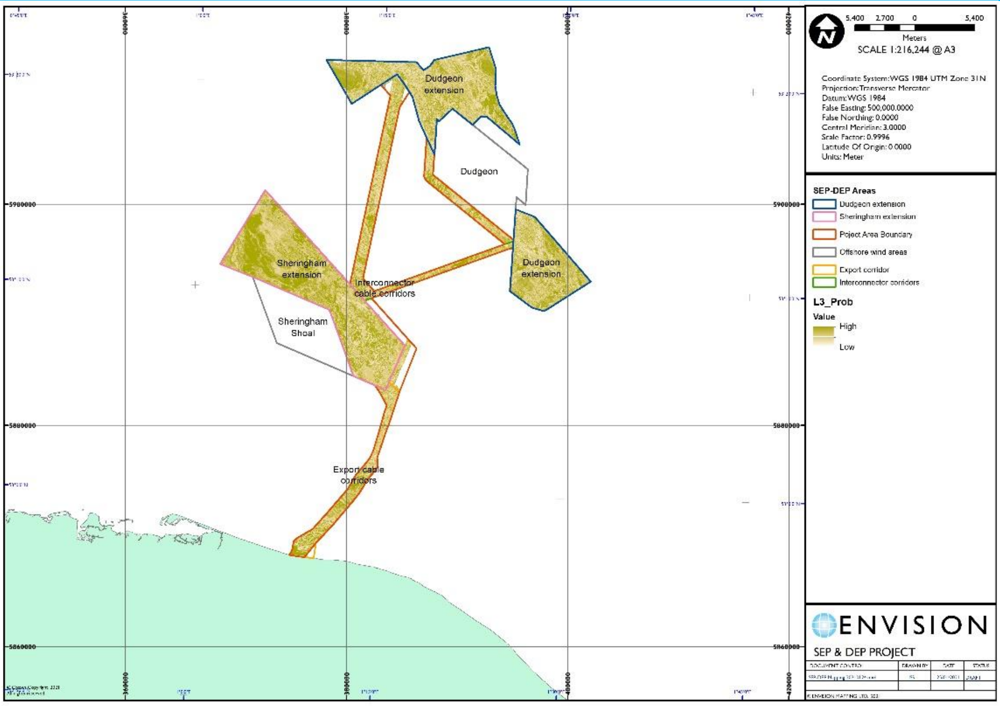

Figure 13. *Probability of the habitats mapped for the project area with a darker colour indicating a higher probability.*

These probabilities indicate where there is more or less 'confusion' in the mapped areas. Those areas with high probabilities have lower chance of being another habitat class with areas of lower probability having an increased chance. This allows confidence to be assessed spatially in addition to the above scoring mechanisms for the maps.

4.4 Habitat Maps

The habitat distribution maps are presented in Appendices 1 and 2 at a variety of scales for the whole of the proposed development area, and these are referenced in this section.

The boundaries of mixed and coarse sediments are known to be difficult to map using acoustic/geophysical data and are influenced by proportions of fine sediments which are determined by particle size analysis from grab samples. Biological groupings often do not adhere to exact sediment classes and the two habitats could be considered to be variations of each other.

4.4.1 Dudgeon Extension Project North

Two distinct areas of sandy habitat run through the northern area of Dudgeon Extension Project (Figure 24 and Figure 29) and around these sandy areas the seabed is comprised of coarse or mixed sediments with patches of polychaete-rich deep Venus community in offshore mixed sediments.

4.4.2 Dudgeon Extension Project South

The southern area of Dudgeon Extension Project (Figure 25 and Figure 30) has a sand bank feature encroaching into the north-west of the area with small pockets of *Crepidula fornicata* with ascidians and anemones on infralittoral coarse mixed sediment and *Sabellaria spinulosa* on stable circalittoral mixed sediment. This area is not considered to be reef habitat. The remaining seabed in this area is coarse or mixed sediments.

4.4.3 Interarray Corridors

A relatively small, raised sand feature crosses the interarray corridor between the southern area of the Dudgeon Extension Project and Sheringham Extension Project area and another sand habitat feature extends from the northern area of the Dudgeon Extension Project into the interarray corridor between the two areas of the Dudgeon Extension Project (Figure 26 and Figure 31). The interarray corridors are otherwise dominated by coarse or mixed sediments and sample data show confusion between these habitats. Samples of epifaunal habitats from video are attributed as coarse or mixed in nature with infaunal samples from the same station often contradicting this allocation and being an alternate habitat.

4.4.4 Sheringham Extension Project area

The seabed habitats of the Sheringham Extension Project area (Figure 27 and Figure 32) again are dominated by mixed and coarse sediments but in the south eastern sector of the area sandy habitats are more frequent. The project area has numerous samples and areas of *Crepidula fornicata* with ascidians and anemones on infralittoral coarse mixed sediment and *Sabellaria spinulosa* on stable circalittoral mixed sediment and these are found throughout the Sheringham Extension Project area. None of the samples of *Sabellaria spinulosa* on stable circalittoral mixed sediment were classified as biogenic reef and therefore no biogenic reef extents can be mapped. The area around the north eastern edge of the project areas is unsurveyed and therefore the habitats mapped here are purely predicted and based on EUSeaMap EUNIS habitat maps.

4.4.5 Export Cable Corridor

Sheringham Shoal sand bank crosses the export cable corridor approximately 12 km from shore (Figure 28 and Figure 33). Offshore from this feature are mixed and coarse sediments interspersed with areas of *Crepidula fornicata* with ascidians and anemones on infralittoral coarse mixed sediment and *Sabellaria spinulosa* on stable circalittoral mixed sediment, although none of this habitat is considered to be biogenic reef.

Close inshore is an area of subtidal rock which is predicted from a sole sample point and the extent of this habitat is overpredicted and this feature has been mapped separately, see Section 5.2. Between the subtidal rock area and the section of Sheringham Shoal sand bank crossing the corridor, coarse and mixed sediment occur. As in other areas, samples of epifaunal habitats from video are attributed as coarse or mixed in nature with infaunal samples from the same station often contradicting this allocation and being an alternate habitat.

5 Environmentally Significant Habitats

5.1 Sediments

A wide range of subtidal sediments (coarse, mixed and sand) are designated features of Cromer Shoal Chalk Beds MCZ and these are found to occur throughout the export cable corridor (Figure 14). Areas of sand (A5.2 / SS.SSa) within the benthic habitats mapped for the SEP-DEP export cable corridor are found to coincide with area of sand previously mapped within the MCZ, with a belt of sand occurring at the offshore perimeter of the MCZ and inshore there is sand habitat interspersed with coarse sediments (A5.1 / SS.SCS).

Of note, the current mapping shows mixed (A5.4 / SS.SMx) and coarse sediments (A5.1 / SS.SCS) to occur interspersed together throughout the remaining area of the export cable corridor within the Cromer Shoal Chalk Beds MCZ, where previously a belt of mixed sediment was found adjacent to a uniform area of coarse sediment. Sample data supports this variation with grab samples from the area being attributed as coarse sediment and with video samples indicating mixed substate. This indicates the proportion of silt content within the sediment is varied which will affect the habitat class found to occur.

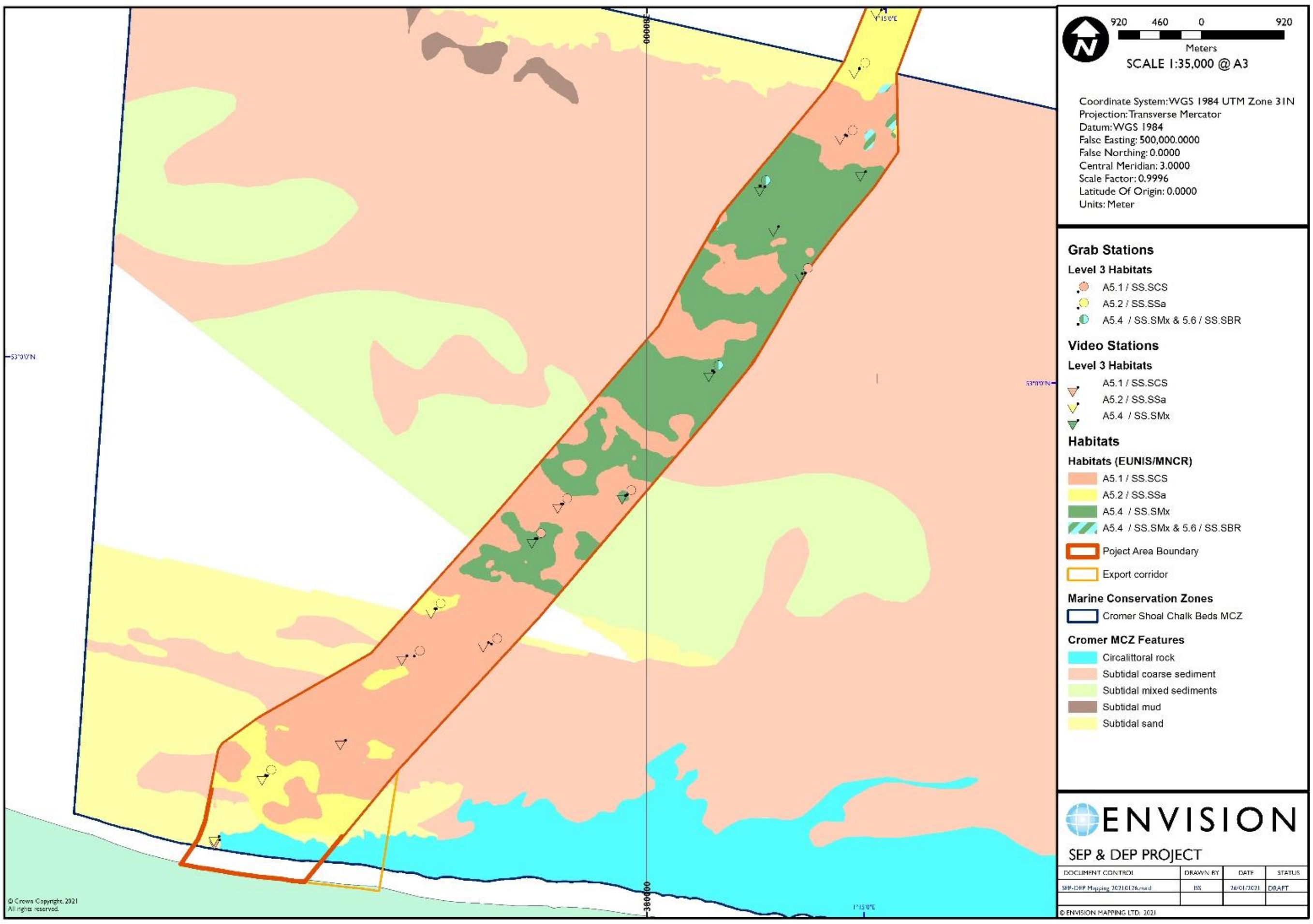

Figure 14.

MNCR benthic sediment habitats within the SEP-DEP export cable corridor with Cromer Shoal Chalk Beds MCZ feature map

5.2 Subtidal chalk and rock

One of the features Cromer Shoal Chalk Beds MCZ is designated for is subtidal chalk, in addition to subtidal rock features. Existing sample records were reviewed (Envision, 2020) which showed rock and chalk features to be present in the inshore area of the export cable corridor. Sampling planning selected stations within suspected areas of chalk/rock areas but only one station was successfully sampled meaning mapping and confidence in the distribution of the habitat "A3 / A4 – Subtidal rock" is relatively low.

As only a single sample was collected which was recorded as (A3 – Infralittoral rock) there is a paucity of 'ground truth' data for this habitat yet existing samples with the area show there to be circalittoral habitats present also. Therefore, it should be noted that the mapped habitat of "A3 / A4 – Subtidal rock" includes both infralittoral (A3 – Infralittoral rock) and circalittoral (A4 – Circalittoral rock) habitat classes.

The predicted extent of A3 / A4 – Subtidal rock extends across the whole cable corridor and review of geophysical data suggested this extent is overpredicted. The use of existing sample data contained in Marine Recorder to assist in the mapping process did not improve the prediction, this is most likely due to the geographic/positional accuracy of the stations. It should be noted the samples were collected between (1987-2018) and the confidence in the geographic position of each sample does not allow for detailed boundaries or refined spatial interpretation to be undertaken.

In order to provide a more confident assessment of the extent of subtidal rock and chalk features, geophysics data were reviewed, and boundaries were manually digitised around areas of high side scan sonar reflectance and where rugosity is increased (Figure 15).

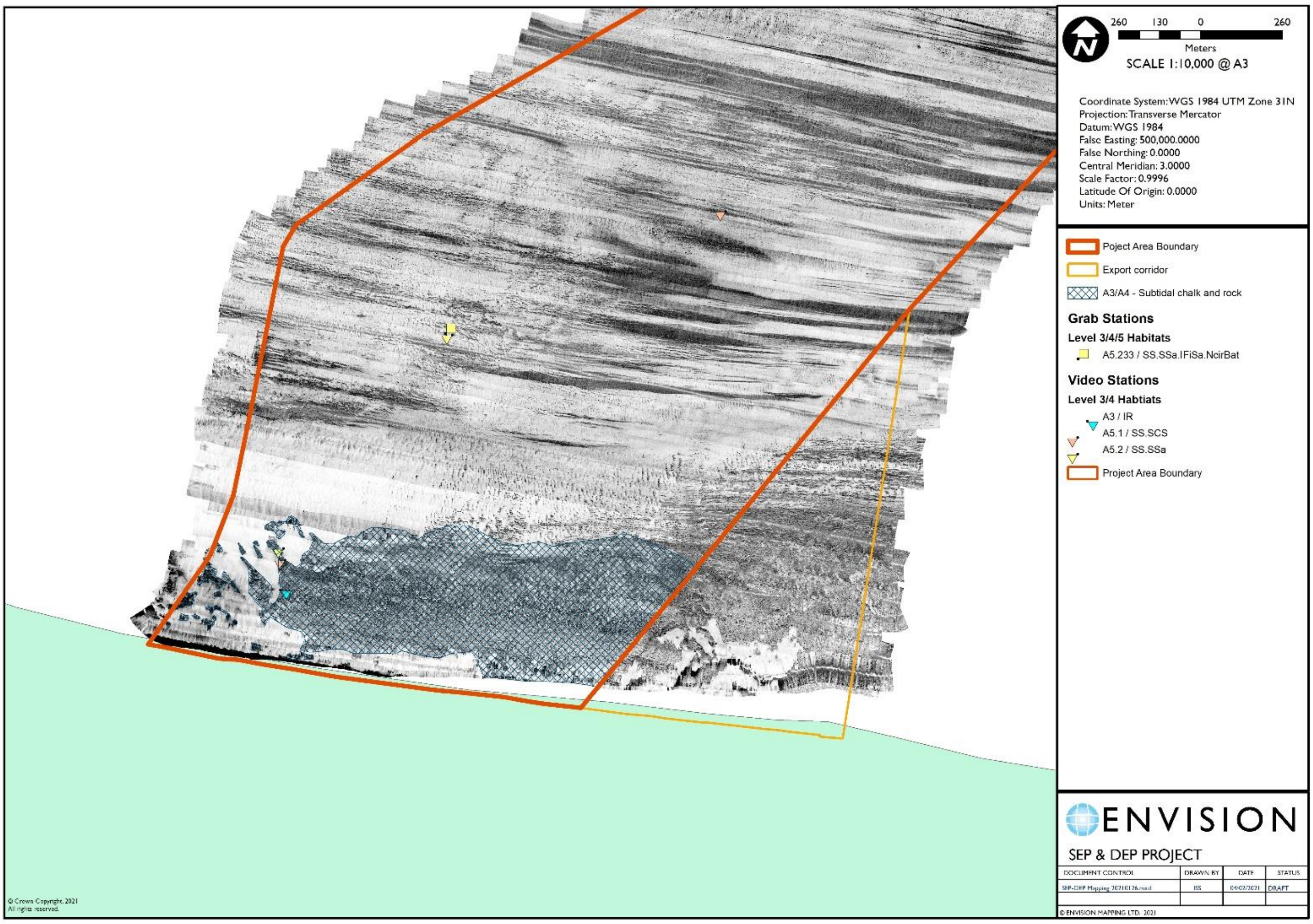

Figure 15.

Extent of subtidal chalk and rock features digitised using sidescan and bathymetric data for the inshore section of the export cable corridor for the SEP-DEP project

The predicted extent of Subtidal rock and chalk have been reviewed in context with existing habitat maps and also the sample data from Marine Recorder (Figure 16). This shows the current extent is well matched to the extent predicted within the MCZ marine habitat maps and supports rocky reef extending from the eastern section of the export cable corridor towards the western edge where rock is replaced with sand and coarse sediment habitats with occasional outcrops of rock or chalk.

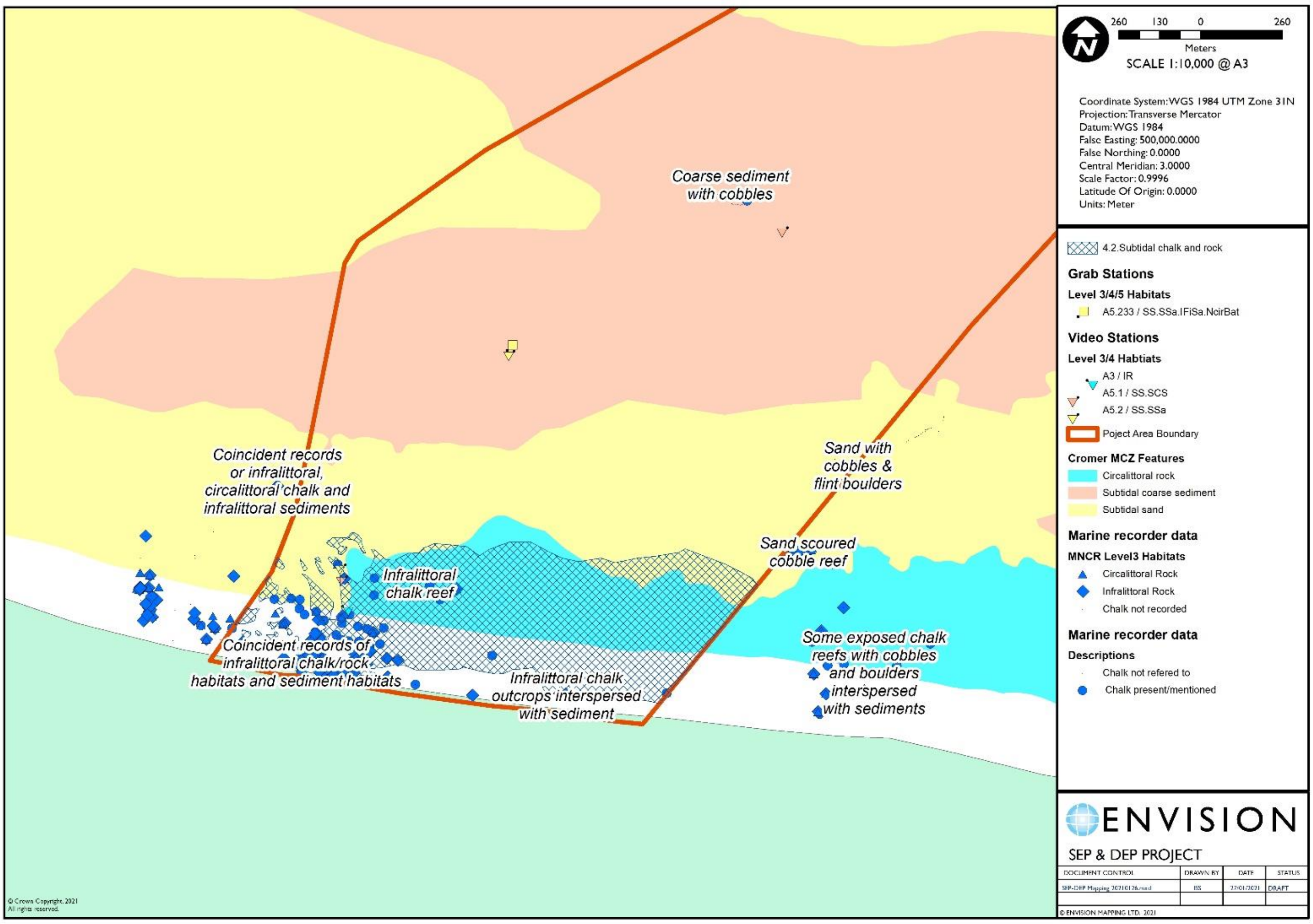

Figure 16.

Extent of subtidal chalk and rock features overlain on Cromer Shoal Chalk Beds MCZ feature map and sample data extracted from Marine Recorder with summary descriptions shown

5.3 Potential Herring Spawning Habitats

Herring spawning grounds can be spatially discrete and found on coarse sand or gravel (and sometimes shell debris, maerl or algae), with a low proportion of fines, as cited in MarineSpace *et al.*, 2013; Reach *et al.*, 2013) and often raised seabed areas are favoured.

The method of assessing potential spawning habitat developed by MarineSpace *et al.* (2013) & Reach *et al.*, (2013) is routinely used to support Environmental Impact Assessments where a marine license is required and is considered an appropriate method by the regulator (the Marine Management Organisation).

5.3.1 Method A – Extent predicted from sediment sample data and mapped from geophysical data

Site specific sediment samples and habitats maps have been classified and related to the Folk sediment classes shown in Figure 17 and habitat classes have been identified as 'preferred potential spawning habitat', 'marginal potential spawning habitat' and 'unsuitable spawning habitat' based upon the proportions of sediments and the Folk sediment categories the habitats relate to. The resulting maps show sediment samples and areas which are potential spawning habitats (Figure 18).

Three categories of habitat preference based on Folk (1954) sediment categories have been used:

- **Preferred** Herring Habitat: Gravel, **S**; Sandy gravel, **sG**;
- **Marginal** Herring Habitat: Gravelly sand, **gS**
- **Unsuitable** Herring Habitat: All other sediment categories

5.3.2 Method B – Extent predicted from existing sediment maps, sample data and spawning areas

As an alternate to site specific data, PSA data from the SEP-DEP project and from CEFAS One Benthic data portal (OneBenthic database, 2020), with British Geological Survey (BGS) Seabed Sediments 250k data, were processed according to the methodologies described in Reach *et al.* (2013).

As with Method A, the same three categories of habitat preference based on Folk (1954) sediment categories have been used:

- **Preferred** Herring Habitat: Gravel, **S**; Sandy gravel, **sG**;
- **Marginal** Herring Habitat: Gravelly sand, **gS**
- **Unsuitable** Herring Habitat: All other sediment categories

The resulting maps show sediment samples and areas which are potential herring spawning habitats (Figure 19).

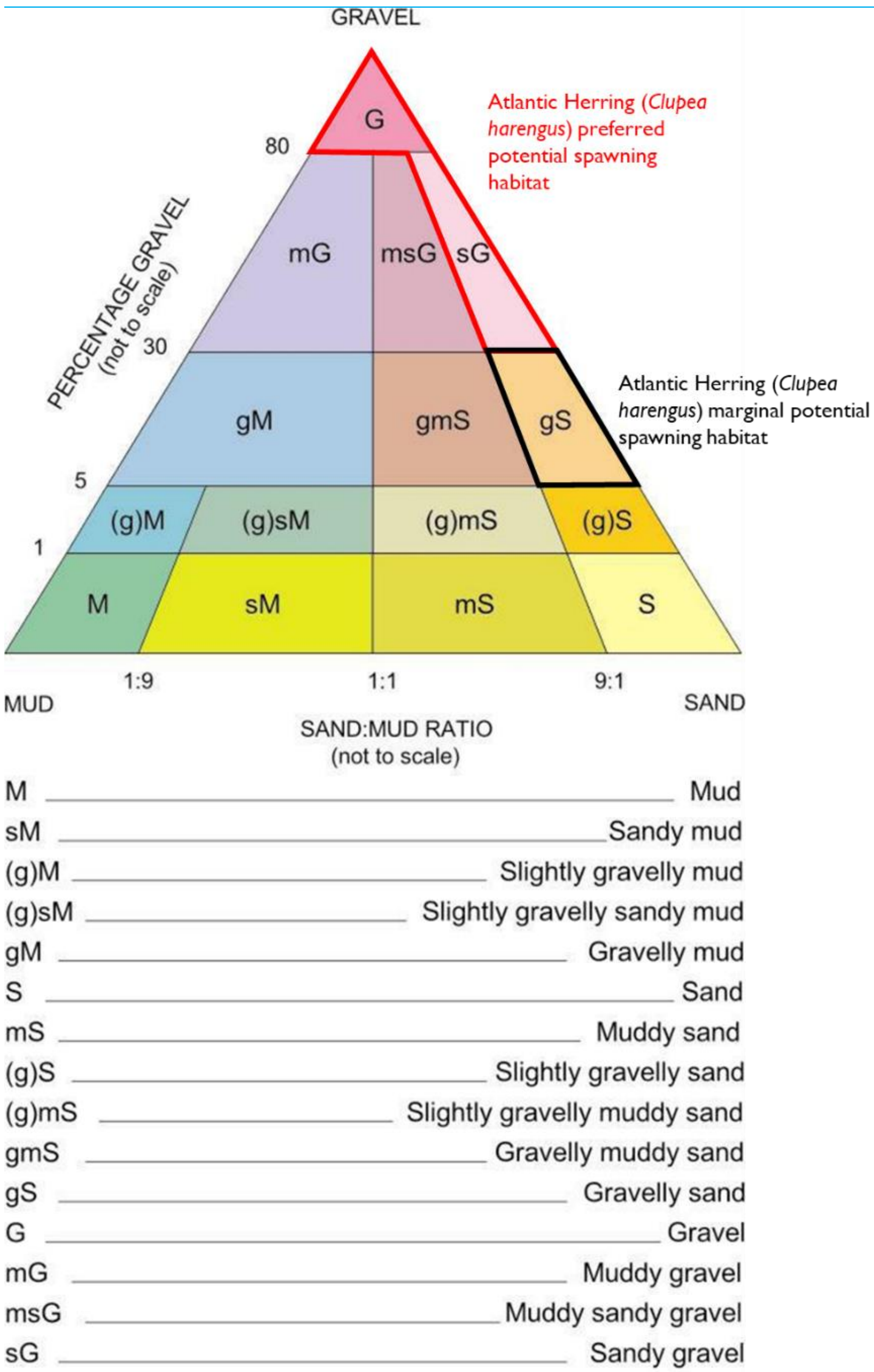

Figure 17.
The Folk sediment triangle with Atlantic Herring preferred and marginal potential spawning habitat.
(Source: Folk, 1954; MarineSpace Ltd et al. 2013)

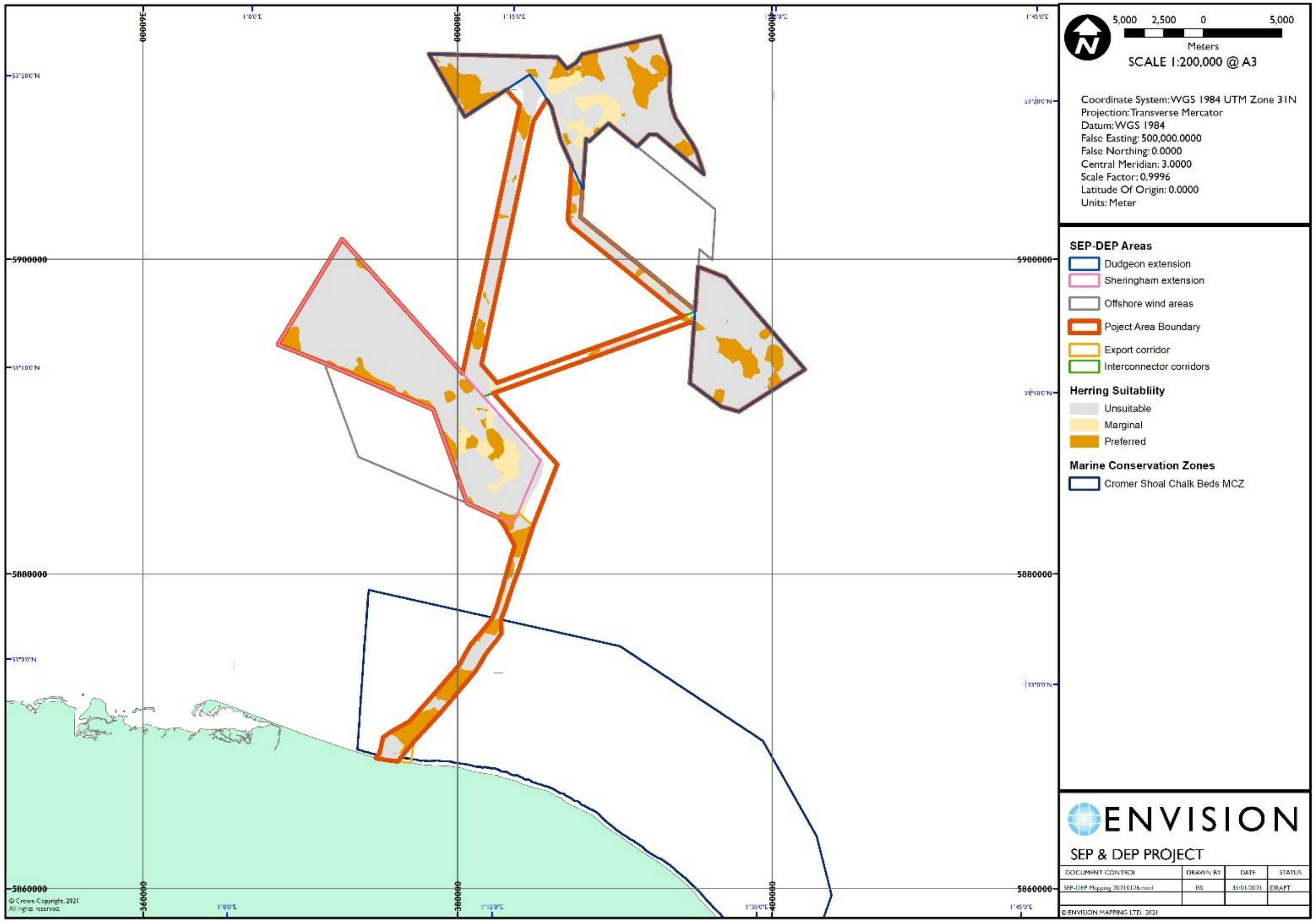

Figure 18.

Method A: Potential spawning habitat areas for the SEP-DEP project area based on project specific habitat maps.

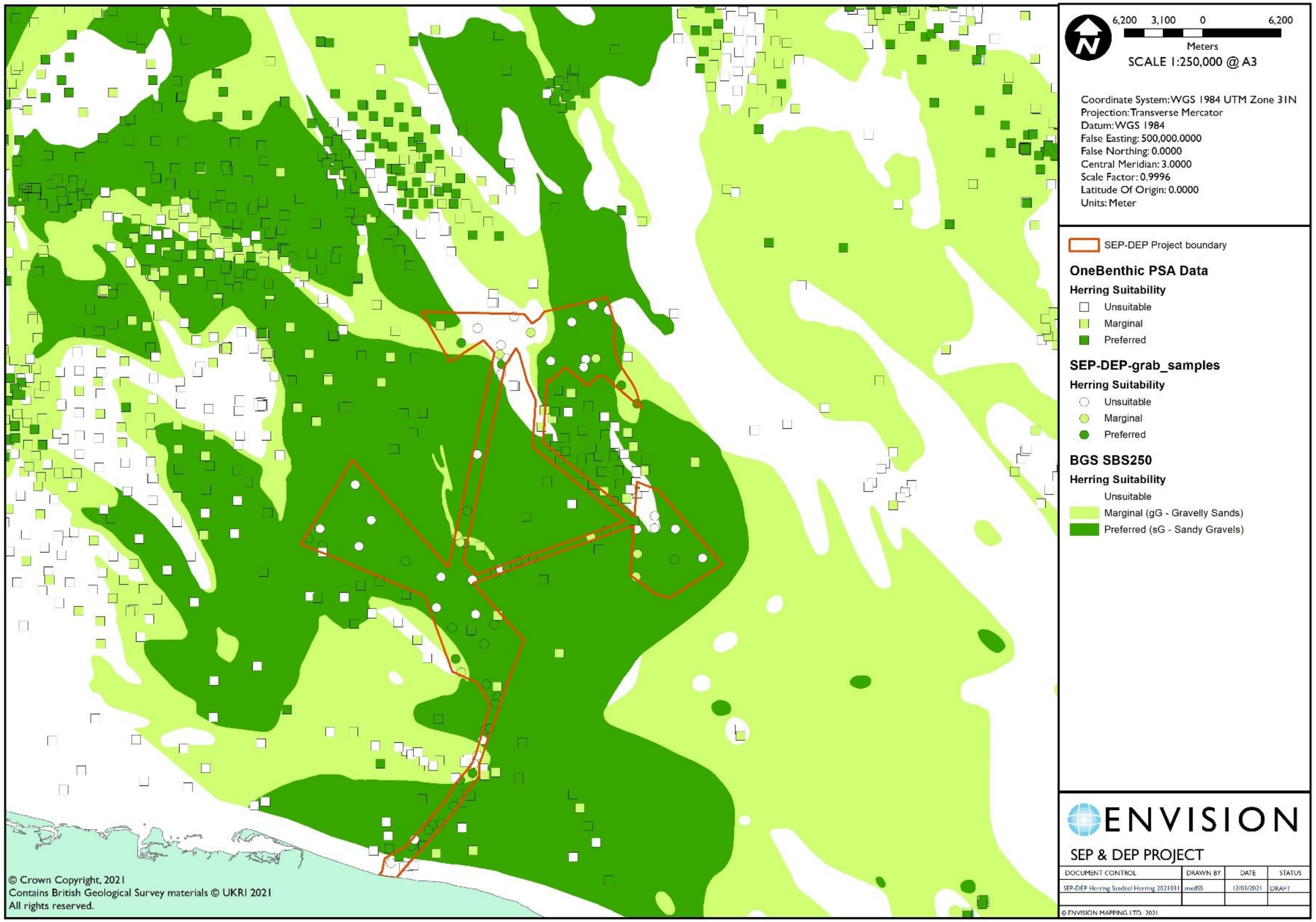

Figure 19.

Method B: Potential spawning habitat areas for the SEP-DEP project area, based on BGS SBS 250k sediment maps, sample data and spawning grounds

5.4 Potential Sandeel Habitats

5.4.1 Method A – Extent predicted from sediment sample data and mapped from geophysical data

Holland *et al.* (2005) used PSA data from 2885 grab samples from an area off the Firths of Forth & Tay to determine sandeel preference for particular sediment types in terms of particle size. Greenstreet *et al.* (2010) then examined the relationship between the ratio of fine sediment and coarse sediments to sandeel presence and defined four sandeel sediment preference categories on the relationship between the percentages of silt and fine sand and of coarse sand in the sediment and the proportion of samples with sandeels recorded present.

Using these defined categories enables grab samples collected for the proposed development to be assigned a sandeel sediment preference and then the geophysical data can be classified using the same categories.

Maps of sandeel sediment preference were produced following analysis of seabed sediment particle size distribution across the SEP-DEP project area. Analysis made use of particle size analysis (PSA) data from 75 grab samples.

5.4.1.1 Classification of individual grab samples sandeel habitat suitability

The PSA data from each grab sample were grouped to identify the percentage content of 'coarse sands' and 'sands and fine sands' as per Greenstreet *et al.* (2010) and Holland *et al.* (2005). For sites which did not have PSA data available, the visually identified sediment fractions from video footage were used. The sand and silt fractions from the PSA data were merged to produce the 'sands and fine sands' category with the two coarser sand fractions combined to produce the 'coarse sands' category. These data were then plotted on an XY axis and overlain onto the four sandeel sediment preference categories presented in Greenstreet *et al.* 2010 (Figure 20).

- Unsuitable
- Suitable
- Sub-Prime
- Prime

These four categories are based on sandeel preferences for sediment particle size (Table 2 of Holland *et al.*, 2005). As the percentage of finer sediments (<0.25mm diameter) increase, sandeels increasingly avoid the habitat whereas, as the percentage of medium and coarser (0.25 to <2.0m diameter) sediments increase, sandeels show an increased preference for the habitat. Figure 20 illustrates the number of sandeels that can typically be found within each category from Greenstreet *el al.*, 2010.

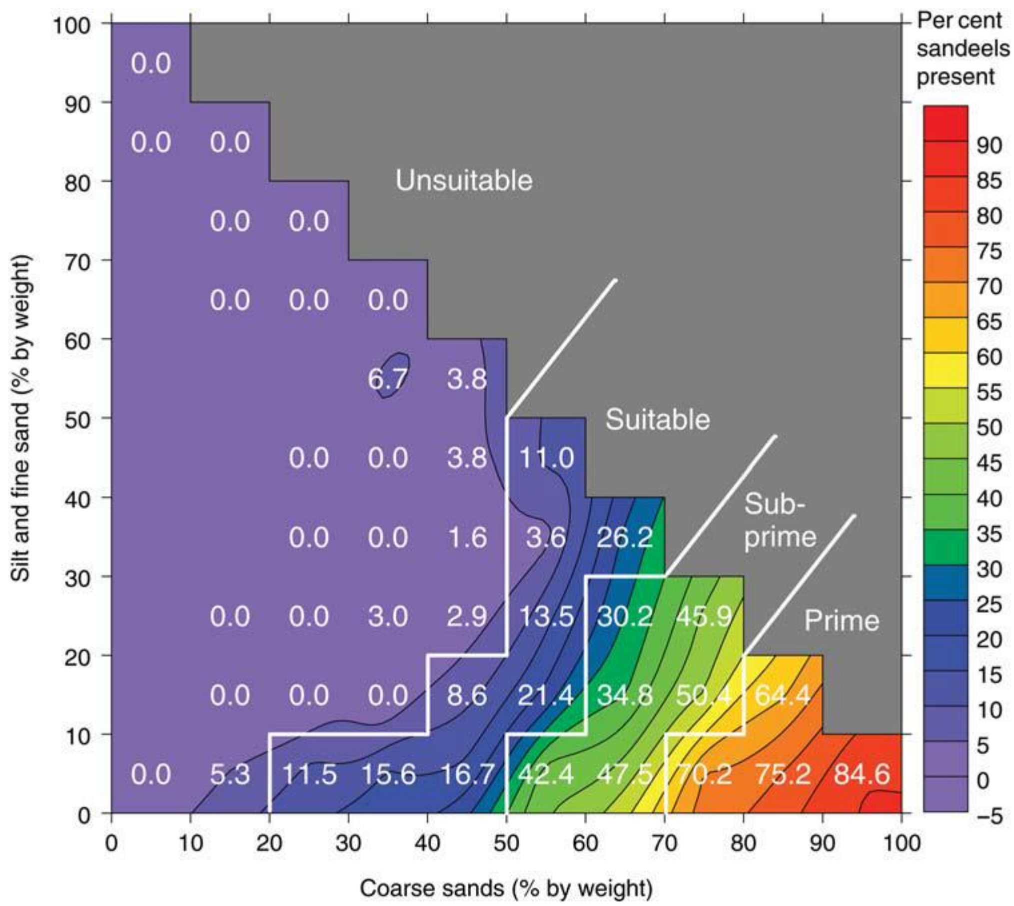

Figure 20.

Categorization of the seabed sediment into four sandeel sediment preference categories, depending on the relationship between the percentages of silt and fine sand and of coarse sand in the sediment and the proportion of samples with sandeels recorded present. (From Greenstreet et al. 2010)

Using the sandeel sediment preference categories defined above and the categorization system shown in Figure 20, the sediment ratios at each of the sample sites were then analysed and assigned to one of these four categories based on the relevant percentage of the two key sediment classes: 'coarse sands' and 'sands and fine sands'.

This resultant plot (Figure 21) shows a point for each sample site within the four sandeel sediment preference categories marked for the possible ratios of fine to coarse sediments. Each point is assigned to the sandeel sediment category into which it falls and allows each sample station to be allocated to one of four habitat suitability categories; Prime, Subprime, Suitable or Unsuitable, depending upon the ratio of silt and fine sand to coarse sand in each sample.

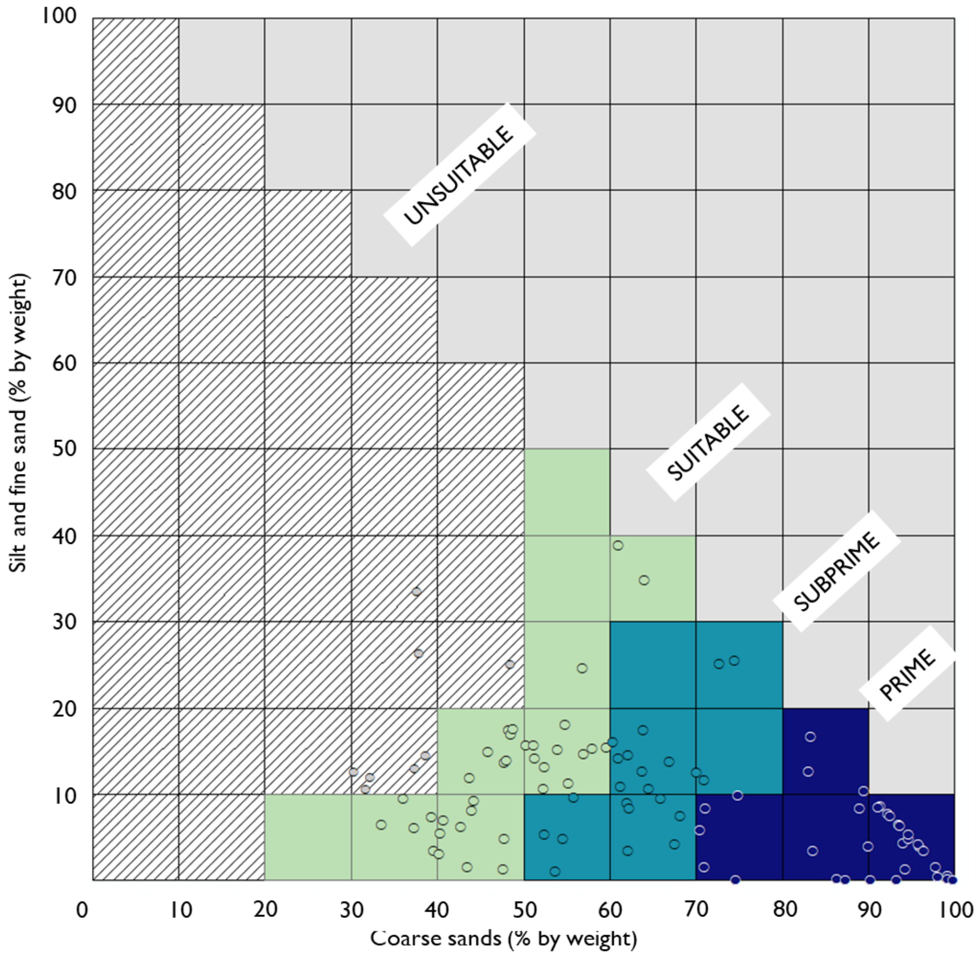

Figure 21.
Plot of sample sites from the SEP-DEP development area plotted over sandeel suitability

Figure 22 below shows the location of each of the sample stations in the proposed SEP-DEP project area and the sandeel habitat suitability at each location.

5.4.1.2 Classification of sandeel habitat suitability across the DEP and SEP wind farm sites and offshore cable corridors

Once the PSA sample points were allocated to a sandeel sediment preference category, the geophysical datasets and the sample points were intersected with each other to determine the geophysical values and parameters associated with each sandeel preference category. This process of signature development produces statistics for each category (mean, variance and covariance) which can then be applied to the whole of the geophysical data using a random forest classification. Random forest classification is an ensemble algorithm, which creates multiple decision trees from a randomly selected subset of the training areas, the outputs from each decision tree are then evaluated to determine the suitability class to be mapped based upon the average value or majority class from all the decision trees generated.

The key output of this process is a full coverage map representing the most likely category of sandeel sediment preference associated with the area (as shown in Figure 22).

5.4.1.3 Sandeel habitat suitability results

Results of mapping (see Figure 22) indicate that the Dudgeon extension project is comprised of sediments with 'suitable' to 'prime' sandeel habitat categories. Sheringham extension project area is comprised of either 'unsuitable' or 'suitable' sandeel habitats with pockets of 'prime' and 'subprime' sandeel habitats.

Inter array corridors have some areas of 'prime' habitat and 'subprime' sandeel habitat with the majority of the seabed being 'suitable' sandeel habitat.

The export cable corridor has some 'prime' habitat in the offshore area with the inshore area being subprime and the central section suitable. Coarse sediments closer to shore are shown to be subprime habitat.

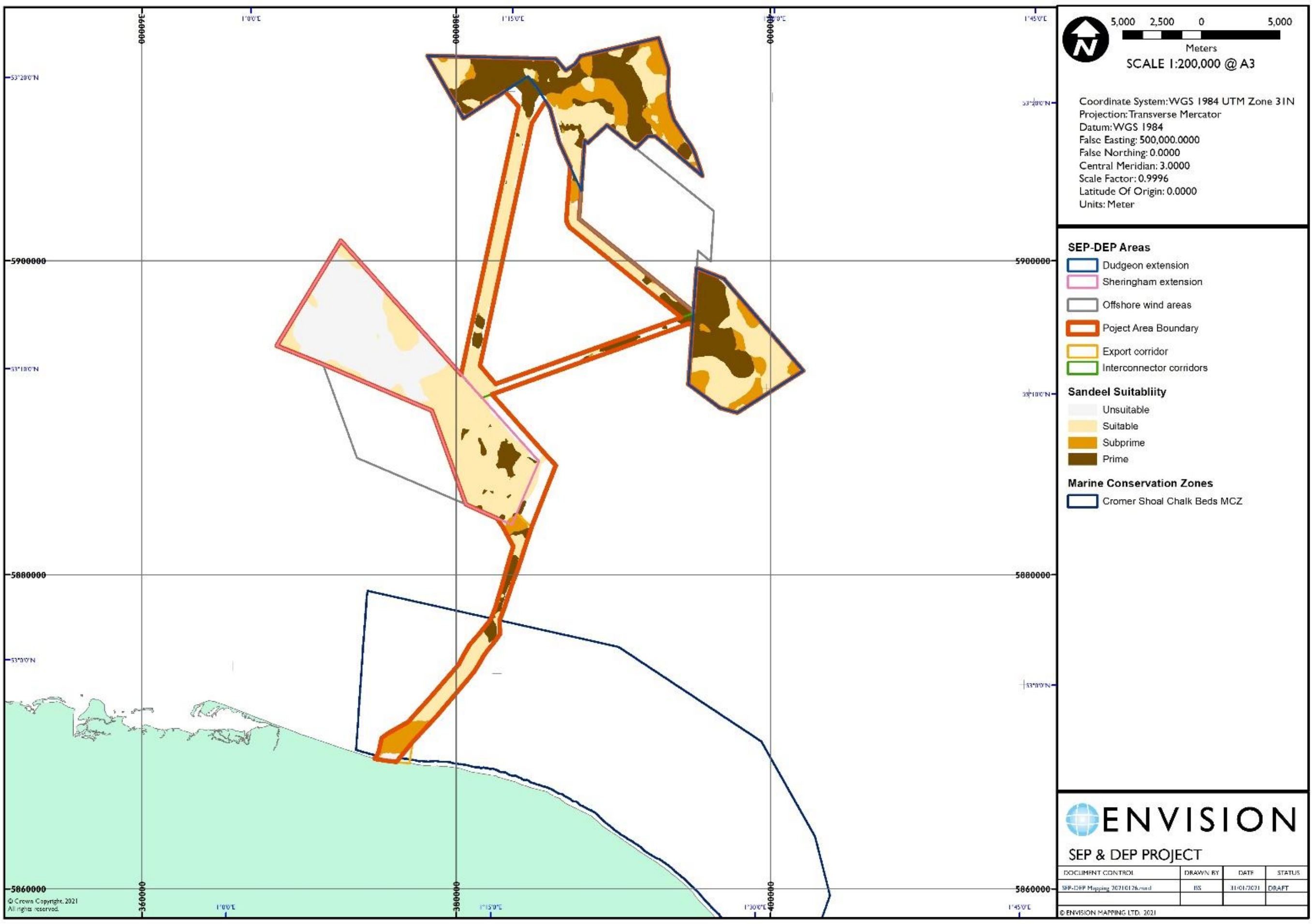

Figure 22.

Method A: Potential sandeel habitat areas for the SEP-DEP project area.

5.4.2 Method B – Extent predicted from existing sediment maps, sample data and spawning areas

PSA data from the SEP-DEP project and from CEFAS One Benthic data portal (OneBenthic database, 2020) and British Geological Survey (BGS) Seabed Sediments

250k data were processed according to the methodologies described in Latto *et al.* (2013).

Three categories of habitat preference based on Folk (1954) sediment categories have been used:

- **Preferred** Sandeel Habitat: Sand, **S**, slightly gravelly sand, **(g)S** and gravelly sand, **gS**;
- **Marginal** Sandeel Habitat: Sandy gravel, **sG**
- **Unsuitable** Sandeel Habitat: All other sediment categories

The resulting maps show sediment samples and areas which are potential sandeel spawning habitats (Figure 23).

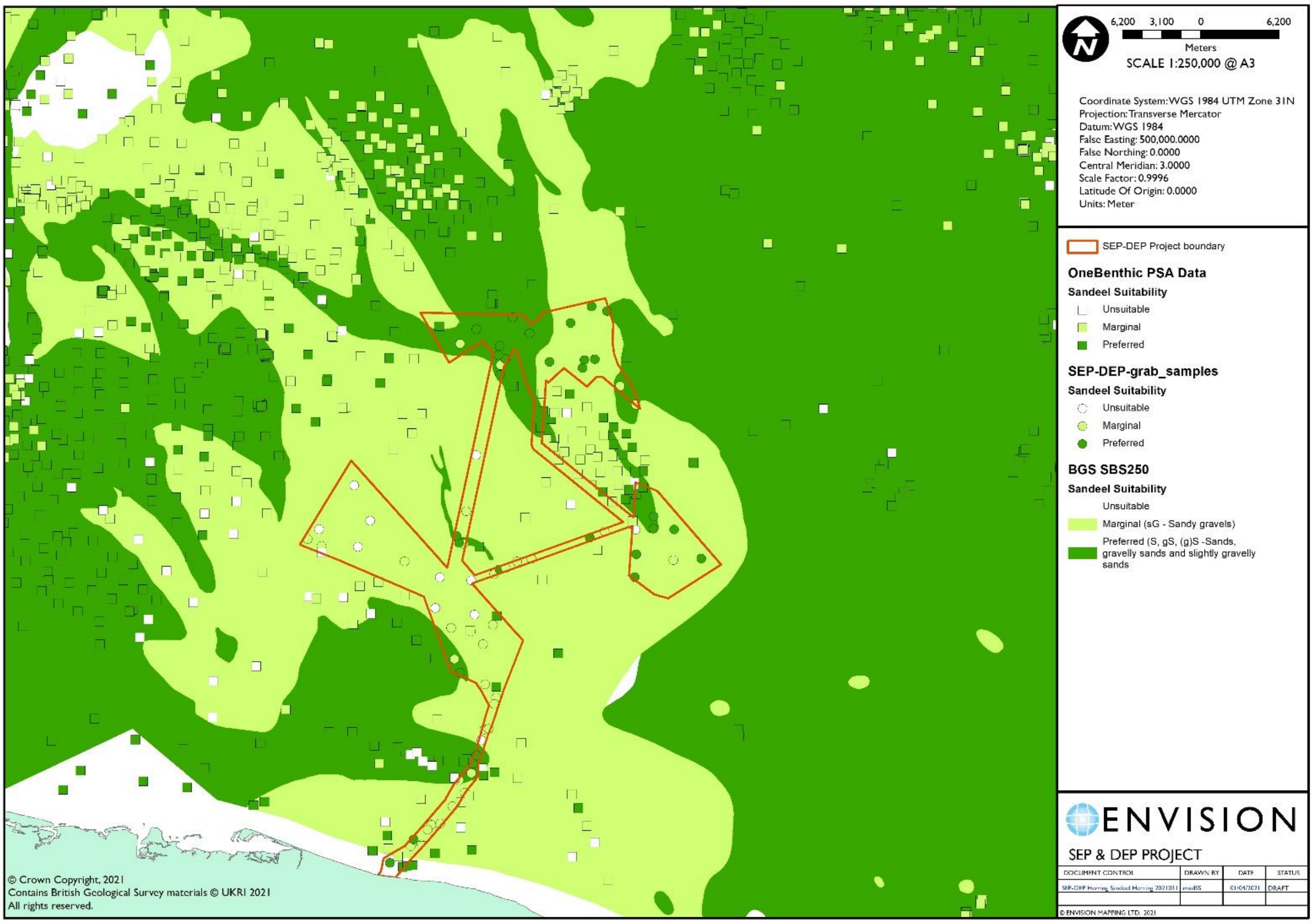

Figure 23.
Method B: Potential sandeel habitat areas for the SEP-DEP project area.

The areas of preferred sandeel habitat (Figure 23) which have associated sample data and are within predicted spawning and fishing areas are found in the Northern area of the Dudgeon extension project with smaller areas found around sand habitats in the Southern area of the Dudgeon extension project and across the export cable corridor where the Sheringham shoal sandbank feature crosses the corridor. The habitat in other areas of the project is found to be marginal for sandeels.

5.5 Biogenic reefs

Sabellaria spinulosa is widely distributed throughout the southern North Sea and can be found as individuals or on occasion as biogenic reefs. *S. spinulosa* is often found within sample records and the presence of the taxa within samples does not indicate the presence of reef but does provide an indication of the species distribution within the proposed development areas.

The sample planning process selected sites where *S. spinulosa* numbers were elevated in historical samples and where the geophysical data suggested variable seabed or indications of potential reef. All sample data results (Fugro 2020a,b) indicated no biogenic reef to be present throughout the SEP-DEP area.

6 Discussion

Benthic habitats maps have been produced with processes and methods which use sample station data and habitats identified at each sample location to determine project area wide habitat distributions based upon geophysical data collected throughout the project area. All extents within the project development area have been attributed with a habitat type where geophysical data exists, and in some areas third party (EUSEAMAP) data have been used to supplement the habitat maps.

The benthic habitats within the Dudgeon and Sheringham Extension Projects are sediment based with mixed and coarse sediments dominating. There are sand banks, namely Sheringham Shoal, and areas of sand which intersect with the project area and cross the export cable corridor. Areas of mixed sediments are found to have biotopes of *Crepidula fornicata* with ascidians and anemones on infralittoral coarse mixed sediment combined with *Sabellaria spinulosa* on stable circalittoral mixed sediment. In other samples the mixed sediment habitats were found to be Polychaete-rich deep *Venus* community in offshore mixed sediments. Coarse sediments have been identified to physical habitats (EUNIS Level 3) only and no biotopes have been identified. Within the sand habitats, the biotope *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand was found infrequently (3 samples from 18 identified as fine sand).

There are some mismatches between biological communities and physical habitats in the benthic sample data on which the habitats maps are based, which should be considered. The biological depth zones each of the biotopes are found in range from infralittoral to offshore and there are mismatches in the depths at which the biotopes occur, with infralittoral biotopes being found in what is likely to be circalittoral habitat and vice versa. Likewise, where mixed or coarse sediments were attributed to the sample data on which the habitat maps are produced from, there are frequent mismatches between the physical habitat (derived from particle size data from grab samples) and the biological habitat attributed to the sample data. i.e. a sample has been attributed as SS.SMx.IMx - Infralittoral mixed sediment, when the particle size data indicates a coarse sediment habitat, SS.SCS.ICS - Infralittoral coarse sediment or SS.SCS.CCS - Circalittoral coarse sediment, is present. This is to be expected as reporting of the analysis of the sample data (Fugro (2020a,b) suggested the biological communities present to be uncertain and appropriate habitat at the next level up has to be assigned to relevant samples (Parry, 2019). These physical mismatches should be considered when reviewing or examining the habitat maps for decision making purposes as it is likely that the physical habitat (based upon particle size data) may be different to the biotopes or habitats which have been mapped. It should also be noted boundaries between mixed and coarse sediments are notoriously difficulty to delineate and small changes in silt content can affect the assigned habitat class therefore the boundaries and areas of mixed and coarse sediments should be considered 'fluid'.

Sample station selection was undertaken to best survey representative locations and seabed types found throughout the project development area (ENVISION, 2020) and sites were targeted on suspected environmentally significant habitats such as chalk reef, suspected areas of increased *Sabellaria spinulosa* densities and in areas of designated conservation features found within the within Cromer Shoal Chalk Beds MCZ. From the sample data and subsequent mapping process, areas of *Sabellaria spinulosa* biotope were found to occur throughout the project development areas. Numerous patches in the Sheringham Extension Project area and in the northern regions of the export cable corridor and several areas central to the southern section of Dudgeon Extension Project were mapped as this biotope. Despite the biotope being present in the project development area, no biogenic reef was recorded within the project development area.

Potential herring and sandeel preferred habitats have been identified to occur within the project development area but it should be noted that these areas are attributed on the basis of physical habitat alone which is one of numerous determining factors for whether sandeels or herring utilise an area of seabed. Data from fisheries studies are also applicable in determining if the habitats identified to occur within the project areas are actually used by herring and sandeel populations.

With regards to the designated features of Cromer Shoal Chalk Beds MCZ, subtidal infralittoral rock was found in the nearshore area of the export cable corridor. The extent of the feature was over predicted within the initial processing and this was due to under representation of the habitat within the sample data, with only a single sample being attributed with this habitat type. The extent of the feature was mapped using digitised boundaries from sidescan and bathymetry data derivatives and this showed the feature to extend from the eastern boundary of the export cable corridor almost to the western boundary, but an area of sediment appears to influence the western periphery. Historic sample data in the area suggest the seabed is influenced by coarse sediments which may be ephemeral and the presence of these is likely to be seasonal and influenced by tidal currents.

The predicted extent of Subtidal rock and chalk have been reviewed in context with existing habitat maps and also the sample data from Marine Recorder (Figure 16). This shows the current extent is well matched to the extent predicted within the MCZ marine habitat maps and supports rocky reef extending from the eastern section of the export cable corridor towards the western edge where rock is replaced with sand and coarse sediment habitats with occasional outcrops of rock or chalk.

The remaining export cable corridor within Cromer Shoal Chalk Beds MCZ has been mapped to show the varying extents of mixed and coarse sediment habitats, and the sand feature of Sheringham Shoal crossing the export cable corridor approximately 12 km from shore. There does appear to have been some shifting of boundaries of mixed and coarse sediments from that indicated within the designated feature map of the MCZ. Boundaries between coarse and mixed sediments are difficult to delineate yet it is noted both features are still found to occur throughout the export cable corridor and are supported by sample data.

At accuracy assessment of the habitat maps ranges from 41% to 93% dependent upon the level of habitat detail mapped. Confusion at the more detailed level of biotopes is often explained by several biotopes occurring within the same higher-level habitat and the higher accuracy of 93% in the EUNIS Level 2-3 habitat maps reflects this. The methods and data employed to produce the maps are considered to impart a high level of confidence in the maps, with relatively high confidence scores reduced only due to multiple samples of some habitats not being collected as a result of on-site condition (A3 – IR, Infralittoral Rock) or relative rarity of the habitat (A4.231-CR.MCR.SfR.Pid).

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8 Appendix1: EUNIS Level 2-3 Map Portfolio

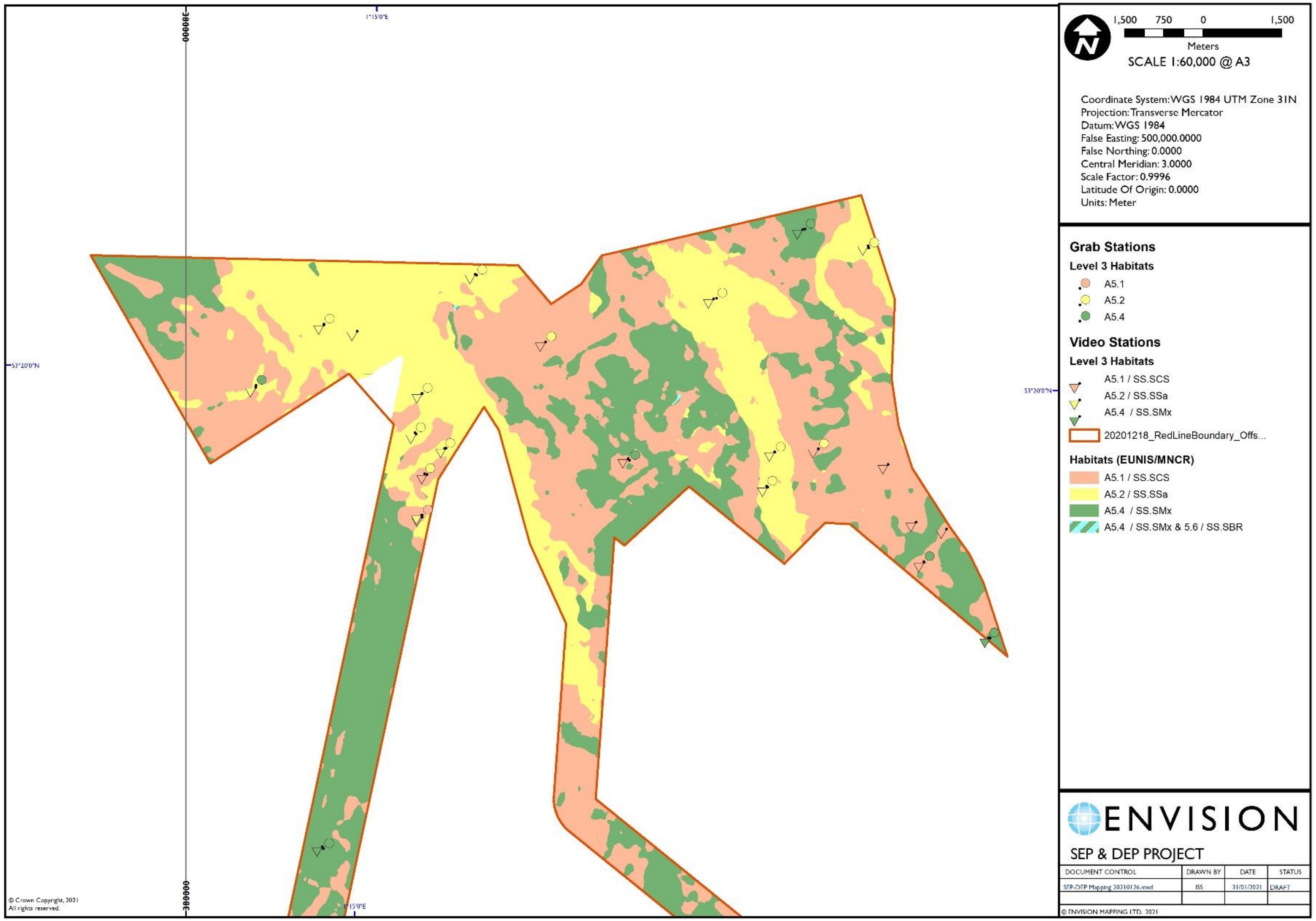

Figure 24. *Dudgeon Extension Project North section of the SEP-DEP Project area showing EUNIS Level 2-3 habitats used for habitat mapping*

Figure 25. *Dudgeon Extension Project South section of the SEP-DEP Project area showing EUNIS Level 2-3 habitats used for habitat mapping*

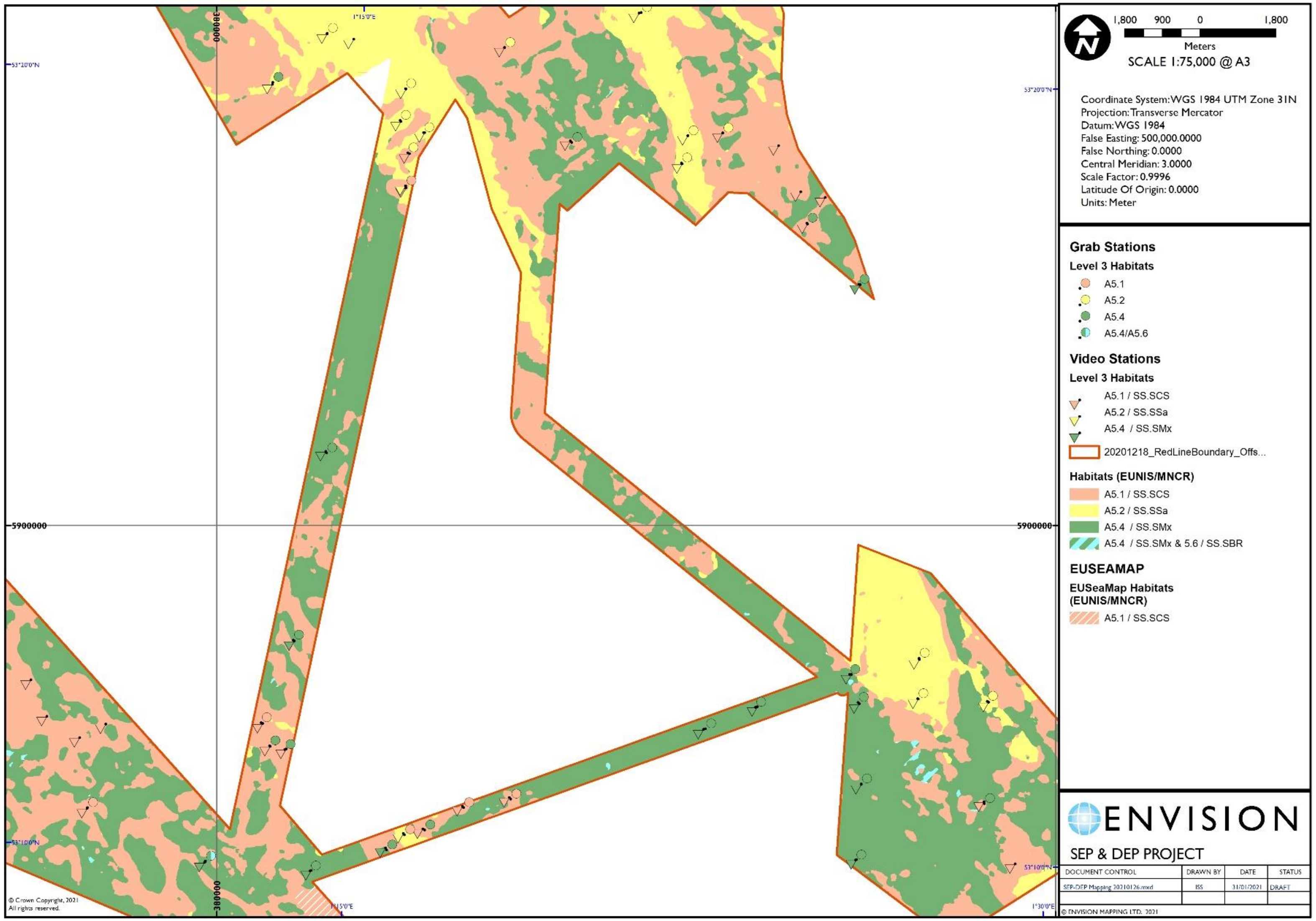

Figure 26. *Interarray Corridors of the SEP-DEP Project area showing EUNIS Level 2-3 habitats used for habitat mapping*

Figure 27. *Sheringham Extension Project area of the SEP-DEP Project area showing EUNIS Level 2-3 habitats used for habitat mapping*

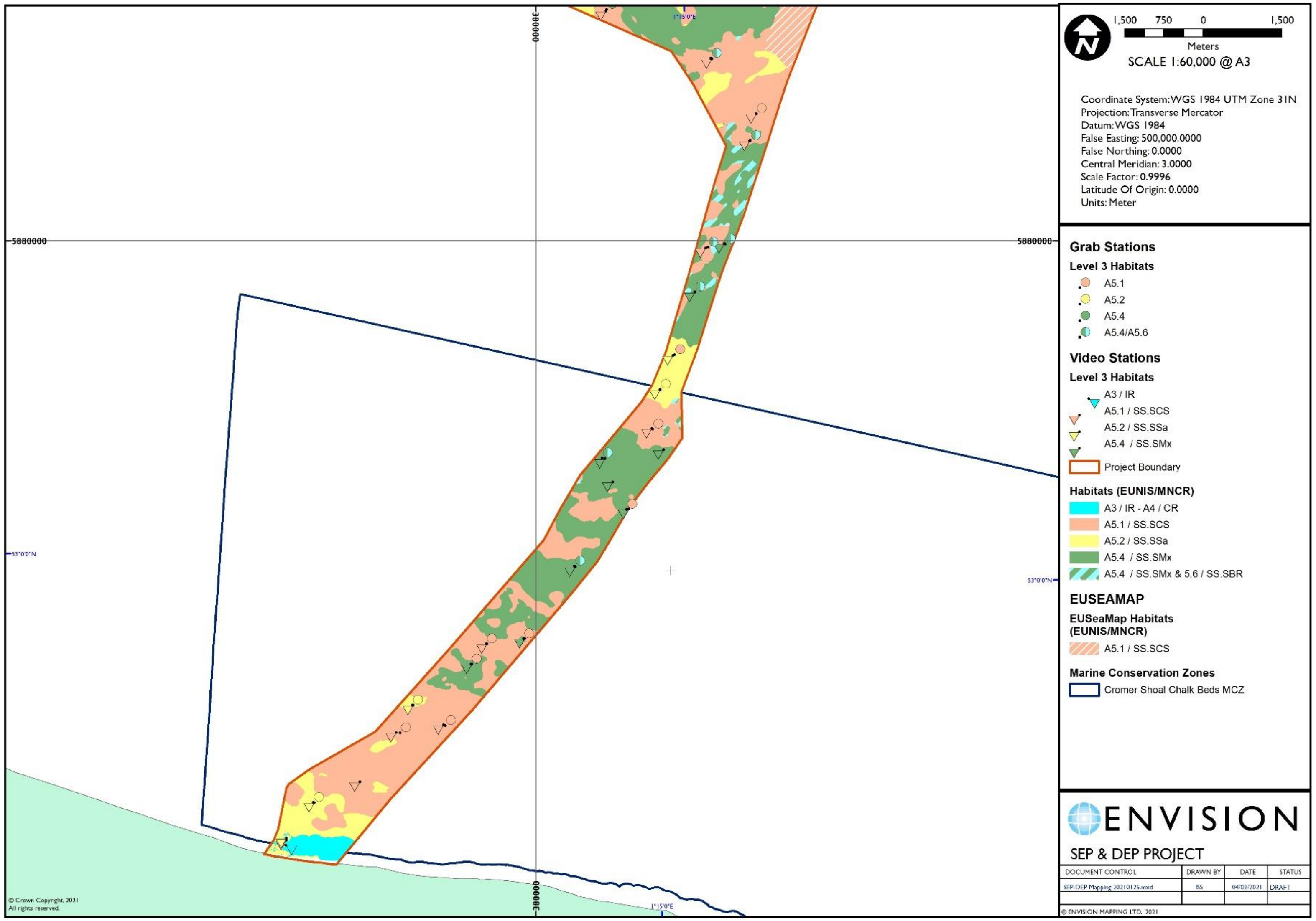

Figure 28. *Distribution of Export Cable Corridor of the SEP-DEP Project area showing EUNIS Level 2-3 habitats used for habitat mapping*

9 Appendix2: EUNIS Level 2-5 Map Portfolio

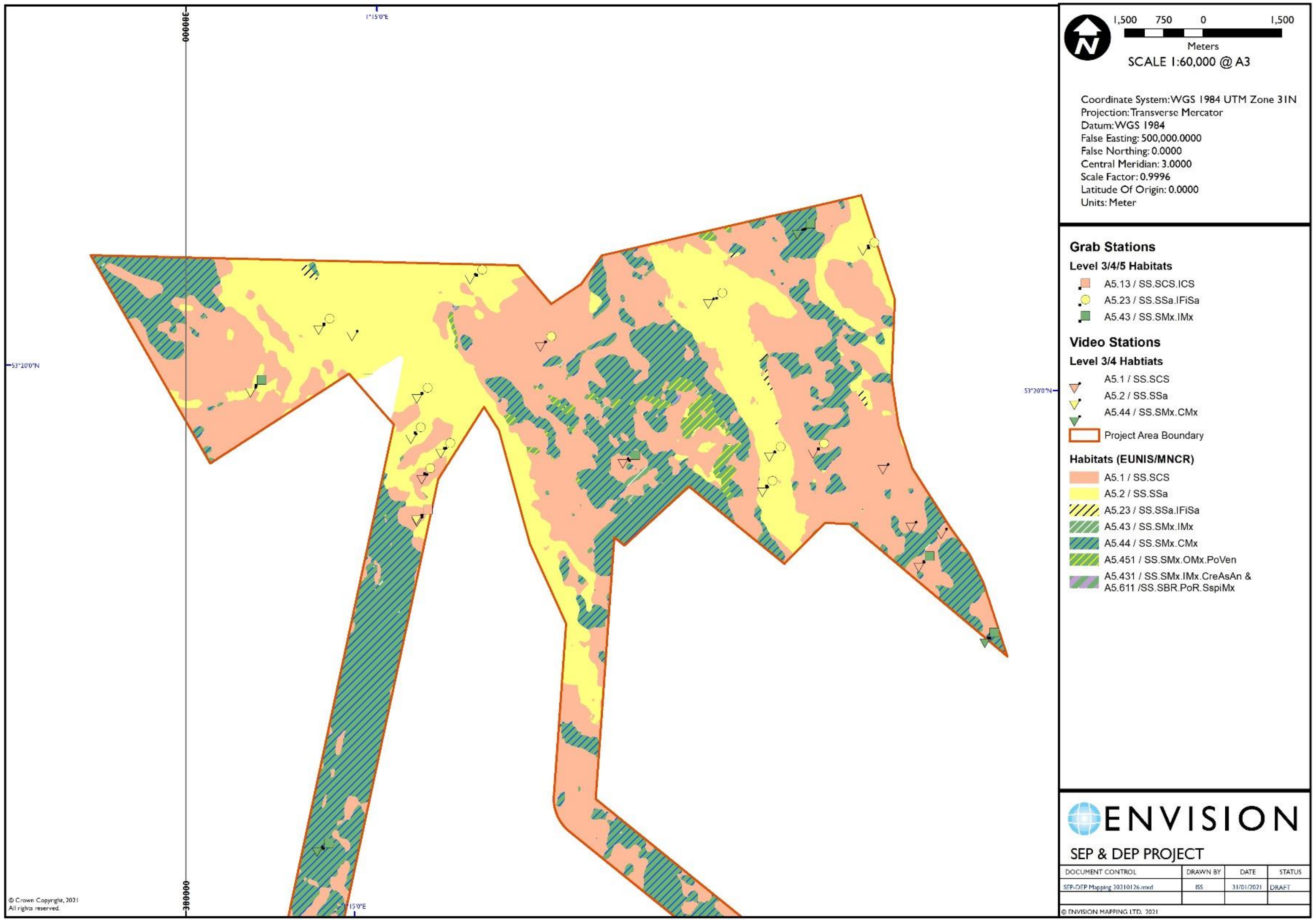

Figure 29. *Dudgeon Extension Project North section of the SEP-DEP Project area showing EUNIS Level 2-5 habitats used for habitat mapping*

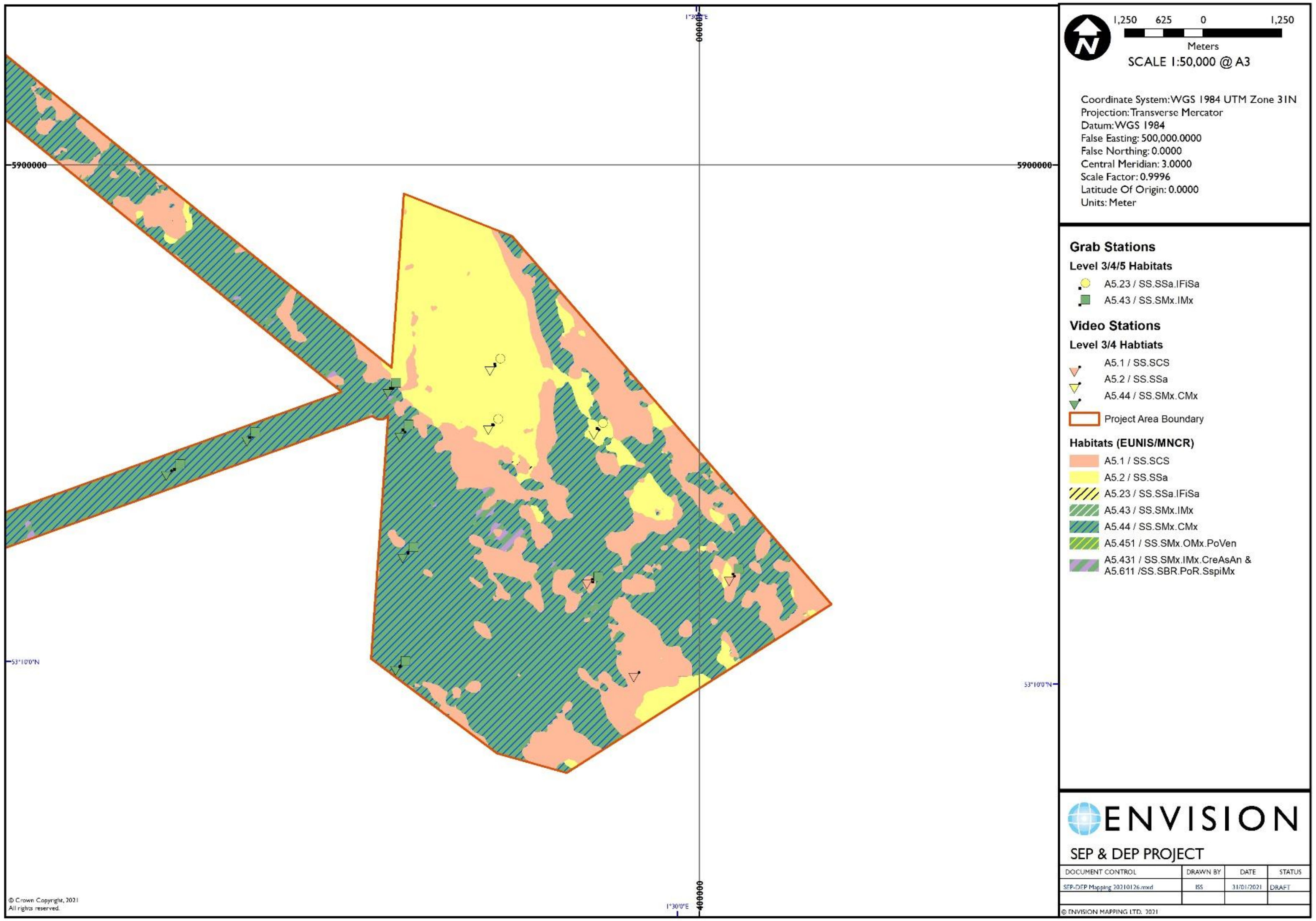

Figure 30. *Dudgeon Extension Project South section of the SEP-DEP Project area showing EUNIS Level 2-5 habitats used for habitat mapping*

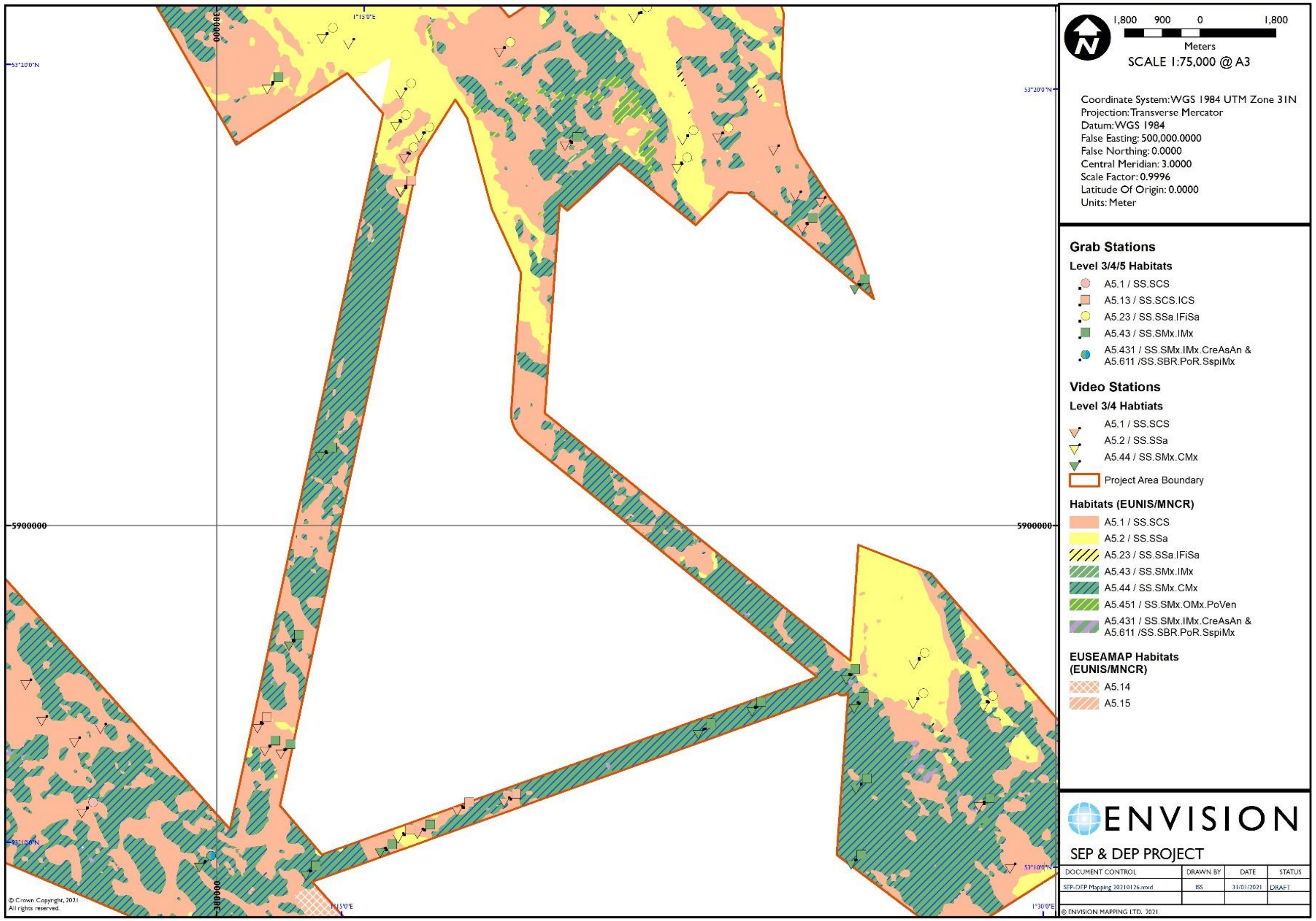

Figure 31. *Interarray Corridors of the SEP-DEP Project area showing EUNIS Level 2-5 habitats used for habitat mapping*

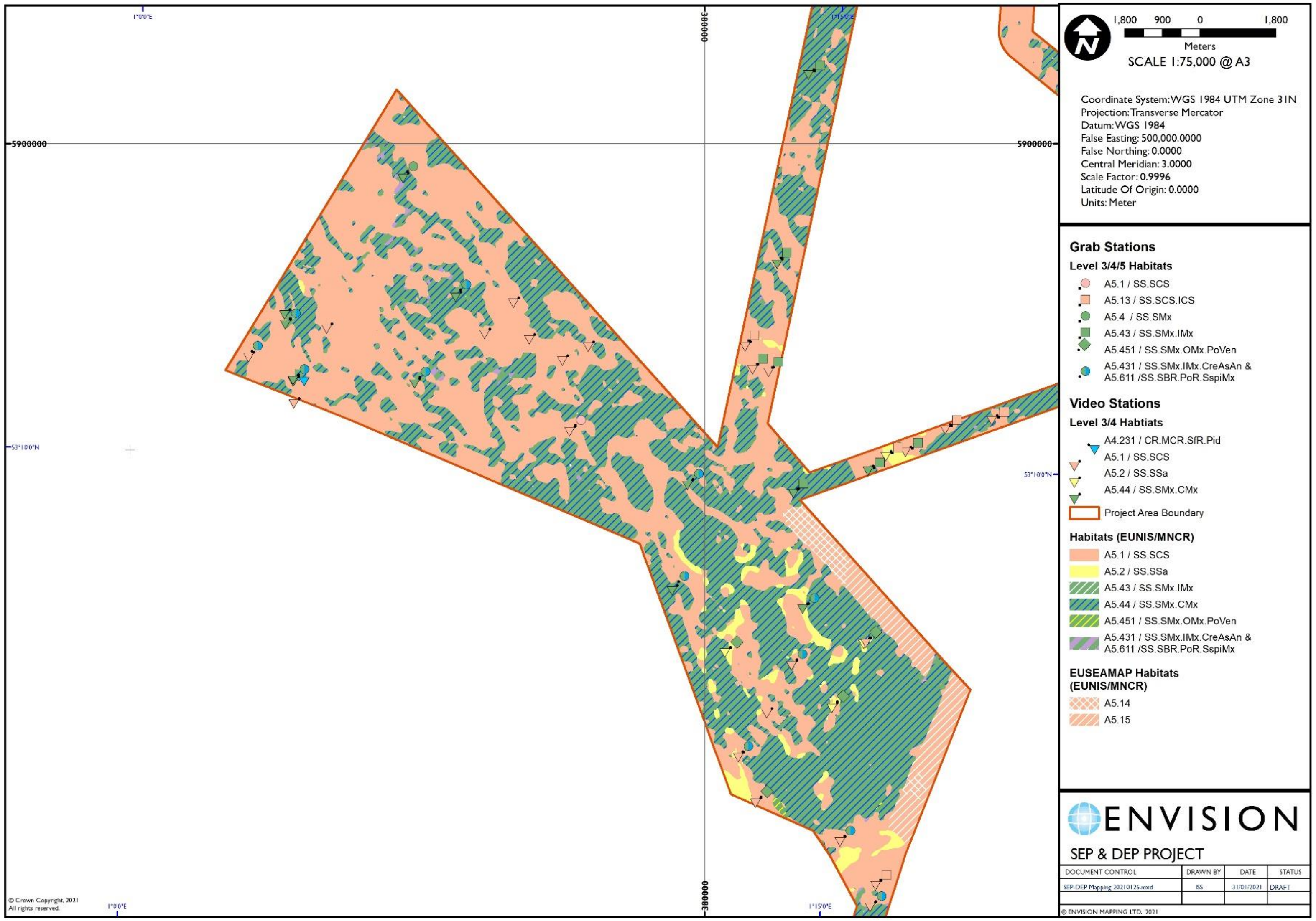

Figure 32. *Sheringham Extension Project area of the SEP-DEP Project area showing EUNIS Level 2-5 habitats used for habitat mapping*

Figure 33. *Distribution of Export Cable Corridor of the SEP-DEP Project area showing EUNIS Level 2-5 habitats used for habitat mapping*