Natural England Research Report NERR065

# Core reef approach to *Sabellaria spinulosa* reef management in The Wash and North Norfolk Coast SAC and The Wash approaches

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# Core reef approach to *Sabellaria spinulosa* reef management in The Wash and North Norfolk Coast SAC and The Wash approaches

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# Executive Summary

*Sabellaria spinulosa* is a tube building, polychaete worm that is found in UK waters (Hayward and Ryland, 1990). It aggregates, creating subtidal biogenic reefs which are protected as Annex I reef under the EU Habitats Directive (EEC, 1992) due to their reported association with high biodiversity (Pearce and others. 2011). *S. spinulosa* reef presence is highly variable in space and time, which poses a challenge when developing advice on management of the feature. A 'reef index' was developed within Natural England by Bussell & Saunders in the '2010 Wash *Sabellaria spinulosa* synthesis' which appraised and synthesised historic data, assessing the techniques used to determine the presence of *S. spinulosa* and crediting each report with a confidence score. Geographic information systems (GIS) were then used to identify areas of consistent reef within The Wash and North Norfolk Coast Special Area of Conservation (SAC).Using this approach, areas which most consistently support reef, evidenced by datasets with the highest confidence, were identified as 'core reef', and this information was used to inform management of damaging and potentially damaging activities. Current management has focussed on these core areas of reef, for example, the closed areas introduced in 2014 by the Eastern Inshore Fisheries and Conservation Authority (EIFCA) to protect reef in The Wash (EIFCA, 2014).

The core reef mapping methodology developed by Bussell & Saunders (2010) in the '2010 Wash *Sabellaria spinulosa* synthesis' has not previously been made publicly available. Since the production of the Bussell & Saunders (2010) synthesis, new evidence has become available. The current report builds on the work of Bussell & Saunders (2010) by further developing the process involved in identifying areas of core reef, and describes in full the robust methodology. New evidence has also been incorporated into the synthesis, updating our understanding of the distribution of core reef.

This updated methodology has been applied to the original data included in the '2010 Wash *Sabellaria spinulosa* synthesis', with the output being referred to as the 2010b synthesis. New datasets were then added to these original data, with the output being referred to as the 2014 synthesis. As the same methodology has been applied to both the 2010b and 2014 syntheses, the outputs can be directly compared, in order to understand how core areas of reef may change over time, and how this affects management of the feature within a European Marine Site (EMS).

The total extent of core reef identified in the 2014 synthesis shows an increase of approximately 50% when compared to the 2010b core reef extent. This change is likely to reflect improvements in our evidence base arising from additional surveys rather than a genuine large increase in extent. The location of core reef varied considerably between the two syntheses, with only approximately a fifth of core reef detected in exactly the same location in both syntheses. Despite the exact locations shifting, areas of core reef were generally in the same vicinity, often being only 0.5 – 1.0 km apart, with some larger areas of reef consistently occurring along a 5 km stretch within the Lynn Knock area. These changes in location are likely to be due to the variable distribution of *S. spinulosa* reef, as well as the limited resolution of some sampling methods. The uncertainty associated with detecting and mapping *S. spinulosa* reef raises questions as to how appropriate it is to target management at specific, small-scale reef areas. It may, therefore, be more appropriate to use reef index outputs to identify wider areas that are suitable (i.e. consistently support reef, and target management at this broader scale.

The core reef approach provides a useful tool for informing management. The utility of this approach lies in its adaptability as syntheses can be carried out on varied datasets. However, it requires a historical dataset of suitable confidence. This currently limits its application in other European Marine Sites (EMS) due to the resources required to develop a sufficient evidence base. The synthesis of The Wash and North Norfolk Coast SAC data provides insight into the variable nature of *S. spinulosa* reef, and offers the potential to use reef index mapping in conjunction with environmental data to inform modelling of areas likely to support reef.

# Contents

# Appendices

# List of tables

# List of figures

# 1 Introduction

1.1 *Sabellaria spinulosa* reef is an ephemeral habitat for which Natural England has a responsibility to designate fixed protected sites. This necessitates a method of identifying areas that consistently contain *S. spinulosa* reef in order to provide protection to those areas in which the reef is most likely to form.

1.2 *S. spinulosa* reefs comprise dense sub-tidal aggregations of the small, tube-building polychaete worm (Figure 1), and are important given the reported abundance of benthic fauna they support (Pearce and others, 2011). These biogenic reefs are included within the definition of the Annex I 1170 *Reef* habitat under the EU Habitats Directive (EEC 1992) and are listed as a priority habitat under the UK Post-2010 Biodiversity Framework (JNCC & Defra, 2012). *S. spinulosa* reef, alongside all other Annex I habitats, is considered to be a habitat particularly in need of conservation at the European level. As such, the Habitats Directive requires all member states to designate Special Areas of Conservation (SACs) to help ensure that the habitat is maintained or restored to *favourable conservation status*[1]. The commercial importance of these reefs is also evident in the aggregations of crustacean and flatfish species such as pink shrimp *(Pandalus montagui)* and Dover sole (*Solea solea)* that are associated with them.

**Figure 1** Underwater images of *S. spinulosa* reef within the Lynn Knock area of Inner Dowsing, Race Bank and North Ridge SCI as surveyed by Curtis and Rance (2014)

1.3 *S. spinulosa* reef is often described as ephemeral, but in truth the use of this term is a conflation of our variable ability to detect it and its actual variability in space and time. *S. spinulosa* reef exhibits highly variable temporal stability, with reef capable of forming, disintegrating and disappearing on an inter-annual basis (Limpenny and others, 2010). The variable nature of *S. spinulosa* reef, combined with the frequent patchiness of its spatial distribution, presents a challenge when developing advice for the management of the feature. This is further exacerbated by the difficulties inherent to delineating *S. spinulosa* reef such as; measuring spatial extent, the variety of reef forms (as discussed in Gubbay, 2007, Table 1) and differentiating acoustic signals between low elevation, patchy reef and the sea floor. Without an accurate understanding of the current distribution of *S. spinulosa* reef within a site, there is a risk that potentially damaging activities may occur in areas of reef to the detriment of its conservation and the sites' conservation objectives.

[1] The concept of favourable conservation status is central to the EC Habitats Directive and is defined within Article 1 of the directive.

1.4 When delineating *S. spinulosa* reef, methods, equipment and resolution can vary between surveys. Initially, when attempting to delineate the area covered by *S. spinulosa* reef, acoustic ground discriminating systems (AGDS) or sidescan sonar (SSS) is used to map the seafloor. The acoustic signals received from SSS are given a ground type classification and this information is then used to predict areas where *S. spinulosa* reef may occur. In such areas, ground truthing is carried out to corroborate the acoustic signature and thus delineate a reef extent based on the verified *S. spinulosa* reef acoustic signatures. AGDS maps the seabed in terms of 'hardness' and 'roughness', providing scans from which software can pick out features, in this case, potential *S. spinulosa* reef locations. These features are then ground truthed and where *S. spinulosa* reef occurs, nearest neighbour modelling is often used to delineate reef area around those points. Ground truthing includes the use of grabs to examine the physical attributes of the sea floor, as well as the use of video and stills from drop down cameras and remotely operated vehicle (ROVs). In addition to the use of different survey methods, survey results can vary with weather conditions; rough weather can make it difficult to obtain accurate acoustic readings of the sea floor and increased turbidity and suspended sediment can reduce the quality of video and stills.

1.5 Surveys targeting *S. spinulosa* reefs at the same geographical locations have found drastically different results over short periods of time, i.e. apparent disappearance or appearance of established reef over a number of months or years. It can be difficult to ascertain whether an area of reef has established or degenerated, or whether a survey did not accurately record reef extent due to the challenges collecting high confidence data for *S. spinulosa* reef. Where there is high confidence in repeated survey data at a location, it can be assumed that the reef extent has changed, as has been recorded at the Saturn Reef in the southern North Sea. In this case, well developed reef was first observed in June 2003, but had all but disappeared by August 2003 (Limpenny and others 2010). However, little is known about the natural or anthropogenic reasons for reef degeneration/regeneration. Possible causes may be natural predation, demersal trawling or undetermined natural conditions (Limpenny and others 2010).

1.6 In response to the management challenges associated with *S. spinulosa* reef, Bussell & Saunders (2010) developed the core reef approach to map the distribution of the reef in the 2010 Wash *Sabellaria spinulosa* synthesis, which is referred to in this report as the 2010a synthesis. The approach sought to appraise and synthesise existing survey information on *S. spinulosa* reef distribution. This enabled the comparison of datasets collected using a wide range of different survey methodologies and with varying confidence levels in order to identify areas where reef is most likely to occur. These areas are termed 'core reef', where conditions are favourable to consistent presence of *S. spinulosa* reef, either continuously or frequently recurring. Critical to the approach was the calculation of a 'reef index' value for surveyed areas within a site. This consisted of the spatial assessment of areas of reef in relation to the survey effort each area received. This approach was piloted within The Wash and its approaches by Bussell & Saunders, where *S. spinulosa* reef is a feature of both The Wash and North Norfolk Coast SAC and Inner Dowsing, Race Bank and North Ridge Site of Community Importance (SCI). The core reef approach is being incorporated into Natural England's programme to assess the condition of reef within these sites. However, core reef areas do not represent the full extent and distribution of reef; therefore non-core reef areas also contribute to the status of the feature.

1.7 This report aims to update the 2010a synthesis on core reef conducted by Bussell & Saunders with new survey datasets collected since 2008 and to subject this core reef mapping methodology to formal quality assurance. In doing so, it is anticipated that as additional data become available the synthesis can be regularly updated and the approach may be replicated in other European Marine Sites (EMS).

1.8 The aims and objectives of this project and a discussion on the ecology and conservation of *S. spinulosa* reef and the core reef approach to *S. spinulosa* management are further elaborated on in Section 1.9 - 1.17).

## *S. spinulosa* reef ecology and conservation

1.9 The ross worm *Sabellaria spinulosa,* Leuckart 1849, is an epibenthic suspension-feeding polychaete worm, capable of building rigid dwelling tubes by binding sediment particles with a mucus cement (Last and others. 2011). While the individual worm is not protected, it is the reef habitat it forms that is of conservation importance.

1.10 Abundant and widespread at low densities in UK waters (Hayward and Ryland 1990) (Figure 2), *S. spinulosa* can form gregarious aggregations under favourable conditions; on coarse sediments with naturally elevated turbidity and suspended sediment loads, leading to the construction of crusts and reefs. In contrast to crust, *S. spinulosa* reef shows significant elevation, whilst crusts do not stand particularly proud of the sea bed (Gubbay 2007).

1.11 *S. spinulosa* worms require suspended sediments to build their tubes. *S. spinulosa* reef is therefore most likely to occur in areas with high turbidity and suspended sediment loads and moderate tidal currents, such as the edges of sand banks and channels (Last and others 2011). *S. spinulosa* worms also require an attachment surface; a firm, stable surface such as bedrock, cobbles or mixed sediment assumed to be preferable. Once a colony has been established then *S. spinulosa* can increase in extent without the need for a firm attachment surface (Last and others 2011). *S. spinulosa* reef is not thought to be sensitive to temperature variations, and is found at a variety of depths from the low intertidal to offshore (Last and others 2011).

1.12 Reported to occur along the majority of the European coastline, in the UK *S. spinulosa* reef aggregations have been recorded in the Bristol Channel, Dorset, the Thames and the Southern North Sea, notably in The Wash (Limpenny and others 2010). The importance of *S. spinulosa* reef in The Wash and North Norfolk Coast SAC is evident in the decision to upgrade its classification from a qualifying feature to a primary feature for classification of the SAC (JNCC 2014).

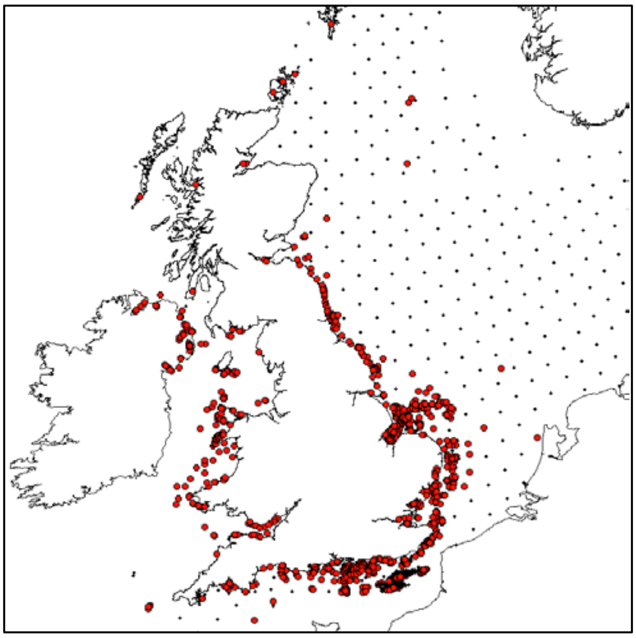


**Figure 2** Distribution of *S. spinulosa* around the UK. Red dots indicate presence of *S spinulosa* individuals; black dots indicate absence of *S. spinulosa* individuals. Data provided from Envision, Cefas and the JNCC Marine Recorder Database, and reported by Limpenny and others (2010).

1.13 The structure and extent of *S. spinulosa* reef is highly variable; where found, reefs can extend over large areas of sea bed, and up to 30cm into the water column (Foster Smith & White 2001). Where they occur, these biogenic reefs act as ecosystem engineers, stabilising sediment and providing additional habitat for colonisation by a rich diversity of associated flora and fauna, notably macrofauna (George & Warwick 1985). In doing so, *S. spinulosa* plays a further role in food web dynamics. For example, in The Wash, *S. spinulosa* sites have been found to be associated with twice the number of species and three times the faunal abundance of sites devoid of reef (Fletcher and others 2012; NRA 1994). In addition, *S. spinulosa* forms a component of the diet of certain flat fish, including Dover sole (*Solea solea)*, dab (*Limanda limanda)* and plaice (*Pleuronectes platessa)* (Pearce and others 2011).

1.14 The ability of *S. spinulosa* to enhance biomass (Pearce and others 2011), combined with its affinity for mixed sediment, means that reefs are often likely to coincide with commercial fishing and aggregate extraction, exposing them to physical damage by anthropogenic activities. Although limited spatially and temporally, the direct impact of aggregate extraction on *S. spinulosa* reef is considered to be locally severe (Holt and others 2007). Conversely, research following aggregate extraction at Hastings Shingle Bank has shown that *S. spinulosa* aggregations can quickly recover from damage or decline. Colonisation and development of a significant *S. spinulosa* aggregation was recorded within 18 months after activity had ceased, and development to a stage equivalent to the oldest aggregations observed in the area was assessed as likely to be complete within three years (Pearce and others 2007). Such studies are useful for researching reef formation and longevity. However, these timelines are dependent on larvae and suitable substrate availability, and it must be considered that *S. spinulosa* reef may exhibit different growth rates under different environmental conditions and in different geographical locations (Pearce and others 2007). Demersal fisheries, in particular pink shrimp trawling, have been associated with the damage and destruction of *S. spinulosa* reefs (Limpenny and others 2010), which is reflected in the rating of ‘high risk’ from mobile demersal gears under Defra’s revised approach to fisheries management (MMO, 2014a).

1.15 The decline in *S. spinulosa* reef across Europe is well documented in areas such as the Wadden Sea and Morecambe Bay, with the latter showing no signs of recovery from anthropogenic disturbance (Holt and others 1997; Reisen & Reise 1982). The importance of *S. spinulosa* reef in underpinning beneficial ecosystem processes, alongside their relative rarity and fragility in light of certain anthropogenic activities, is reflected in their UK and European conservation status.

1.16 The definition of *S. spinulosa* reef has been ambiguous given the spectrum of physical states it presents and the inherent difficulty in providing direct evidence of the ecosystem services associated with *S. spinulosa* reef (Fletcher and others 2012). Driven by its status as an Annex I species of the Habitats Directive, in 2007 the Joint Nature Conservation Commission (JNCC) hosted a workshop on *S. spinulosa* reef (Gubbay 2007). One of the key outputs of the workshop was the establishment of a definition for *S. spinulosa* reef within the context of the Habitats Directive.

1.17 The reef characteristics developed assess the ‘reefiness’ of *S. spinulosa* aggregations at four thresholds (‘not reef’, ‘low’, ‘medium’ and ‘high’) and are commonly referred to as the Gubbay (2007) criteria. Summarised in Table 1, these criteria consider thresholds for elevation, extent and patchiness, providing a working definition of *S. spinulosa* reef. In essence, Gubbay (2007) states that for an *S. spinulosa* aggregation to be considered as reef, it must have an elevation of greater than 2cm and cover an area of at least 25m$^2$ with no less than 10% coverage. In addition, Gubbay (2007) also draws upon criteria outlined in Hendrick & Foster-Smith (2006) noting that reef with a degree of longevity is of higher quality than reef with no evidence of longevity. Gubbay (2007) is now widely considered as the working definition for defining *S. spinulosa* reef in UK waters.

**Table 1** Gubbay (2007) criteria for assessing S. spinulosa 'reefiness'

| Characteristic | Not a reef | 'Reefiness' | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Elevation (cm) average tube height | <2 | 2-5 | 5-10 | >10 |
| Extent ($m^2$) | <25 | 25-10,000 | 10,000-1,000,000 | >1,000,000 |
| Patchiness (% cover) | <10 | 10-20 | 20-30 | >30 |

## The core reef approach to *S. spinulosa* reef management

1.18 In 2009 Natural England hosted a workshop to determine the presence and extent of *S. spinulosa* reef in The Wash (Burton and others 2009). The workshop reviewed existing datasets, held by the then Eastern Sea Fisheries Joint Committee (ESFJC) and Centrica Plc on the distribution of *S. spinulosa* reef, with the aim of informing the management of this feature within The Wash Site of Special Scientific Interest (SSSI) and The Wash and North Norfolk Coast SAC. It was recommended that Natural England conduct a synthesis of all available datasets, assessing their compliance with the Gubbay (2007) criteria and the confidence in the survey techniques employed, to identify core reef areas. The workshop defined core reef areas as those that consistently support *S. spinulosa* reef over a number of years. It was suggested that these core reef areas could then inform exclusion zones from which damaging activities would be excluded.

1.19 In order to identify core reef areas, a preliminary synthesis of the available data was presented by Natural England at a further workshop in 2010, where additional discussions were held to develop the methodology for identifying and defining areas of core reef. The workshop minutes are available as an internal Natural England document (Bentley 2010). This work culminated in a non-published report by Bussell & Saunders (2010), referred to in this report as the 2010a synthesis, where core reef found in Wash and North Norfolk Coast SAC and The Wash approaches was mapped (Figure 3). The report summarised the core reef mapping methodology, appraised and then synthesised the available datasets, to produce maps depicting the reef index calculated for The Wash and North Norfolk Coast SAC and The Wash approaches.

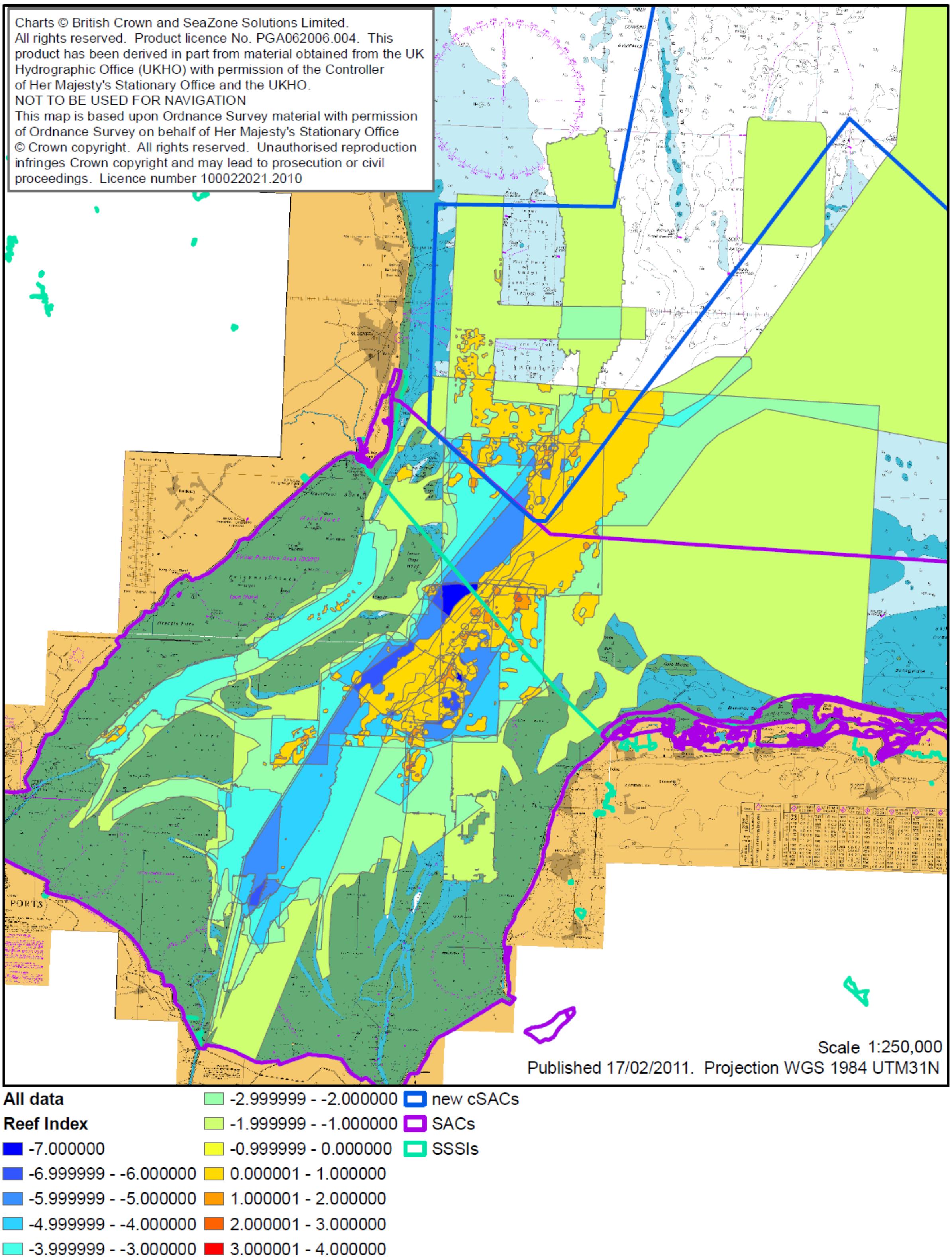



**Figure 3** Reef index for *Sabellaria spinulosa* reef in The Wash using data collected between 1999 and 2009. Higher values of reef index are indicative of the amount of times reef has been described relative to survey effort. Negative reef index indicates reef has never been found. Source: Bussell & Saunders (2010).

1.20 The reef index is based on the ratio of the number of times an area has been surveyed compared to the number of times reef has been found, with areas where reef is consistently found receiving a higher reef index. The equation used to calculate reef index is outlined in Figure 4 alongside a table illustrating possible reef index scores (Table 2). Rather than prescriptively identifying core reef areas, the reef index and confidence maps produced by Bussell & Saunders (2010) were intended to inform discussion between the relevant authorities around which areas may qualify as core reef within The Wash and The Wash approaches.

$$\text{Reef Index} = \frac{\text{Number of times reef found}}{\text{Number of times surveyed}} \times \text{Number of times reef found}$$

*If Number of times reef found = 0 then Reef index = -1 × Number of times surveyed*

**Figure 4** The equation used for calculating the reef index

**Table 2** Possible values of reef index that depend on the number of times an area had been surveyed compared to the number of times reef had been found

| Number of times surveyed | Number of times reef found | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| **0** | - | - | - | - | - | - | - |
| **1** | *-1* | 1.00 | - | - | - | - | - |
| **2** | *-2* | 0.50 | 2.00 | - | - | - | - |
| **3** | *-3* | 0.30 | 1.30 | 3.00 | - | - | - |
| **4** | *-4* | 0.25 | 1.00 | 2.25 | 4.00 | - | - |
| **5** | *-5* | 0.60 | 0.80 | 1.80 | 3.20 | 5.00 | - |
| **6** | *-6* | 0.17 | 0.67 | 1.00 | 2.67 | 4.17 | 6 |

Red cells contain reef index values ≥ 2, the threshold which was used to define core reef within The Wash and North Norfolk Coast SAC. The green cell represents the additional value included where the threshold for core reef is ≥ 1.8, as was the case in Inner Dowsing, Race Bank and North Ridge SCI due to less data being available for this site.

1.21 In 2013, the core reef approach was utilised to inform *S. spinulosa* reef management. The maps produced by Bussell & Saunders (2010) were used by Natural England in their advice to the relevant authorities on the feature's distribution within The Wash and North Norfolk Coast SAC and Inner Dowsing, Race Bank and North Ridge SCI under Defra's revised approach to commercial fisheries management within European Marine Sites (MMO 2014b; EIFCA 2014).

1.22 While developing the core reef approach in 2011, there were discussions regarding what reef index value would represent an appropriate threshold to define core reef. A reef index of 1.8 and 2 were both considered, with ≥ 2 selected when developing management advice for The Wash and North Norfolk Coast SAC. The rationale for selecting ≥2 is not clearly documented, but it was deemed to represent an appropriate level of precaution, given the age and confidence in the data underpinning the reef index scores. For a given area to qualify, reef must therefore have been surveyed for in the area on at least two separate occasions and found on both of those occasions (Table 2).

1.23 In contrast, within Iner Dowsing, Race Bank and North Ridge SCI the decision was made to protect areas of core reef with a reef index value of 1.8 and above. This allowed the inclusion of areas that had been surveyed five times in which reef had been detected three times. This comparatively precautionary approach taken to defining core reef within the Lynn Knock region of Inner Dowsing, Race Bank and North Ridge SCI, utilising a lower reef index value compared to The Wash and North Norfolk Coast SAC, was deemed appropriate because of poor data coverage within the site leading to lower confidence in reef index calculations, and uncertainty around the feature's conservation objective. It was intended that the reef index be reviewed as new evidence becomes available and that a suitable index is selected taking site specific considerations into account (e.g. quantity and quality of evidence). A reef index value of 2 will be considered the default value for defining core reef throughout this report. Where other values, such as 1.8, are considered for defining core reef then this will be stated.

1.24 Following the implementation of Defra's revised approach to fisheries management within The Wash and North Norfolk Coast SAC and Inner Dowsing, Race Bank and North Ridge SCI, it was recognised that the initial 2010a synthesis conducted by Bussell & Saunders required updating with newly available datasets. The integration of new data allows for the assessment of how the distribution of core reef area within The Wash and its approaches changes with the inclusion of new data, which has important implications for advice on the condition and management of features. This new synthesis will be referred in this report as the 2014 synthesis.

## Aims and objectives

1.25 This report aims to update the 2010a synthesis with new survey datasets and to verify and refine the core reef mapping methodology, so that the synthesis may be updated and replicated in other EMS's. Specifically, the project has the following objectives:

1) Describe and elaborate the core reef mapping methodology summarised in the 2010a synthesis (Bussell & Saunders 2010), and subject it to a formal quality assurance process in line with Natural England's quality management standard.
2) Complete two syntheses using the updated, standardised methodology; one of data used in the 2010a synthesis (referred to henceforth as the 2010b synthesis), and one including all data used in the 2010b synthesis plus data which has become newly available since 2009 (to be known as the 2014 synthesis).
3) Draw comparisons between the outputs of the 2010b synthesis and the 2014 synthesis.
4) Assess the appropriateness of this methodology for use in other EMS's.

# 2 Methodology

2.1 This chapter provides an overview of the core reef mapping methodology. This methodology compiled survey data from a variety of sources in ArcGIS, and calculated reef index values for each surveyed area. A MESH confidence score for the data underlying a given area was also produced to measure the confidence in the technique to detect the presence or absence of *S. spinulosa* reef. All mapping was carried out in Arc GIS 9.3.1. The methods can be summarised as follows:

1) Compile data from a variety of sources
2) Assess the confidence in each dataset according to adapted MESH criteria
3) Appraise the data suitability according to pre-defined criteria
4) Extract the data to create a standard format shapefile for each survey
5) Synthesise the shapefiles for each survey to create a composite reef index shapefile
6) Review the outputs of the synthesis
7) Interrogate the outputs of the synthesis
8) Manage the data

2.2 These methods are described in more detail below.

## Compiling the data

2.3 The sixteen datasets included in the 2014 synthesis were obtained from a variety of sources, including Natural England, the Eastern Inshore Fisheries and Conservation Authority (EIFCA) and renewable energy developers. These datasets, collected between 1996 and 2012, were provided in a variety of formats including paper and digital reports, GIS data and photographs. Raw data were rarely available and the majority required some processing. Of the sixteen datasets, eleven had been used in the original 2010a synthesis (Table 3), with five additional datasets used in the 2014 synthesis (Table 4).

**Table 3** Surveys used in both the initial 2010 *S. spinulosa* reef synthesis conducted by Bussell and Saunders and in the updated 2014 synthesis

| Dataset | Year data collected |
|---|---|
| Foster-Smith, R.L. and Sotheran, I. 1999. Broad scale remote survey and mapping of sub-littoral habitats and biota of The Wash and the Lincolnshire and the North Norfolk coasts. English Nature Report 336 | 1996, 1997 and1998 |
| Foster-Smith, R.L. 2000. Establishing a monitoring baseline for The Wash sub-tidal sandbanks | 1999 |
| Foster-Smith, R.L. and White, W.H. 2001. *Sabellaria spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part I, mapping techniques and ecological assessment. ESFJC and English Nature Number 545 | 2000 |
| Jessop, R.W. and Stoutt, J. 2006. Broad scale *Sabellaria spinulosa* distribution in the central Wash as predicted with the AGDS RoxAnn | 2005 |
| Jessop, R.W., Graves, K.M., and Woo, J.R. 2006. Eastern Sea Fisheries Joint Committee 2006 Research Report | 2006 |

Table continued…

| Dataset | Year data collected |
|---|---|
| Woo, J.R. 2008. The ‘reefiness’ of *Sabellaria spinulosa* in The Wash: a report of the 2007 AGDS survey | 2007 |
| Jessop, R.W., Woo, J.R. and Harwood, A.J.P. 2008. Eastern Sea Fisheries Joint Committee Research Report 2008 | 2008 |
| Jessop, R.W., Harwood, A.J.P. and Woo, J.R. 2009. Eastern Sea Fisheries Joint Committee Research Report 2009. | 2009 |
| Osiris Projects and Emu Ltd. 2008. Centrica energy and Amec geophysical investigation at the proposed race bank and docking shoal wind farm sites with associated cable route corridors, Section 4, Greater Wash area cable route survey report. | 2005 and 2006 |
| Emu. 2008. Acoustic surveys for the proposed Lincs wind farm sites. | 2008 |
| Emu. 2009. Docking Shoal and Race Bank Offshore Wind farms. Additional Geophysical Survey Areas in The Wash for Centrica Energy. | 2009 |

**Table 4** Additional surveys used only in the 2014 *S. spinulosa* reef synthesis

| Dataset | Year data collected |
|---|---|
| Foster-Smith, R.L. 2001. *Sabellaria spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part II, fine scale mapping of the spatial and temporal distribution of reefs and the development of techniques for monitoring condition. | 2001 |
| Jessop, R.W., Hinni, S., Skinner, J. and Woo, J.R. 2010. Eastern Sea Fisheries Joint Committee Research Report 2010. | 2010 |
| Jessop, R.W. and Maxwell, E. 2011. Eastern Inshore Fisheries and Conservation Authority Research Report 2011. | 2011 |
| Jessop, R.W., Åkesson, O. and Smith, L.M. Eastern Inshore Fisheries and Conservation Authority Research Report 2012. | 2012 |
| Meadows, B. and Barrio Froján, C. 2012. Baseline Monitoring Survey of Large Shallow Inlet and Bay for The Wash and North Norfolk Coast SAC. Cefas. | 2011 |

## Assessing confidence in the data

2.4 As a result of the varied survey techniques and the long temporal scale over which data were collected in The Wash, the level of detail and the degree of confidence placed in each dataset to accurately map *S. spinulosa* reef varies. Each dataset underwent an appraisal using an adapted MESH Confidence Assessment Tool (Appendix 3) to assess the confidence in each dataset.

2.5 The MESH Confidence Assessment Tool comprises a multi-criteria questionnaire, applying scores based on the appropriateness of the underlying remote sensing and ground truthing methods, and their combined interpretation. As a result, datasets of high confidence obtain higher MESH scores, while surveys with lower confidence data obtain lower scores. The EU-wide scheme was developed to assess marine habitat maps in general, and has been adapted for the purpose of this report to reflect methods appropriate for surveying *S. spinulosa* reef. Refinement of the MESH scoring criteria aimed to decrease the inherent subjectivity associated with ascribing MESH values. Prior to individual survey reviews, each of the survey methods (i.e. SSS, AGDS etc.) was assigned a score based on its expected effectiveness of detecting reef (based upon Limpenny and others, 2010; see Appendix 3).The MESH framework was then systematically applied to each individual survey to ensure its appropriateness for inclusion within the synthesis. Scores apportioned to surveys were cross checked to ensure consistency in the application of scoring criteria by different reviewers.

2.6 The question "How appropriate were the sampling techniques in determining the geophysical nature of the seabed?" was excluded from the current project's confidence assessment. The question "How appropriate were the sampling techniques to determining the biological nature of the seabed?" was believed to be sufficient to capture the information needed for assessing reef and prevented sampling technique from being over-weighted in the MESH scores. The question "What level of information is contained" was adapted to evaluate how many of the Gubbay (2007) criteria for assessing *S. spinulosa* 'reefiness' were considered when interpreting the survey data. The Gubbay (2007) criteria were split into primary and secondary considerations when defining reef (Appendix 4).

2.7 MESH scoring is a qualitative, and therefore subjective approach, and although a standardised approach was applied, it is recommended that the scores given within this report are not directly compared with MESH scores derived from the application of a different set (or weighting) of MESH criteria.

2.8 Table 5 summarises the criteria against which each dataset was assessed, while a full account of each criterion, along with the respective scoring guidelines applied is presented in Appendix 3. The overall confidence score awarded to a dataset was the sum of the scores for each criterion category, which are weighted according to relative importance. Each criterion was scored between 0 and 3 (Appendix 3). A low accuracy survey scoring 1 in each category would result in a weighted MESH score of 33. Although a range of scores could result in a total of 33, this score was selected as a flag, below which careful consideration and clear justification may be required before the survey was included in the synthesis.

**Table 5** The MESH confidence groups and criterion against which each dataset was assessed to determine the confidence score of the technique employed to detect reef

| Confidence group | Confidence criteria |
|---|---|
| **Remote sensing** | Were the techniques used appropriate for the ground type? |
| | Was the ground covered appropriately? |
| | How were the positions determined for the remote data? |
| | Were standards applied to the collection of the remote data? |
| | How recent are the remote sensing data? |
| **Ground truthing** | How appropriate were the sampling techniques to determining the biological nature of the seabed? |
| | How were the positions determined for the ground-truth data? |
| | Was the density of sampling adequate? |
| | Were standards applied to the collection of the ground-truth data? |
| | How recent is the ground-truth data? |
| **Interpretation** | How was the ground-truthing data interpreted? |
| | Were the remote data appropriately interpreted? |
| | What level of information is contained? |
| | How accurate is the map at representing reality? |

2.9 MESH scores for each individual survey and a template with details of the individual component scores are given in Appendix 3, and serves as an audit trail for the confidence assessment process. This template can be used to review the score each survey received, update MESH scores, for example as data vintage changes, and to assess new data which are incorporated into the synthesis with the same adapted criteria.

## MESH confidence scores and reef index values

2.10 The MESH confidence scores provide a metric of confidence in the techniques used to survey *S. spinulosa* reef, while the reef index value provides a metric of the likelihood of *S. spinulosa* reef occurring in a given location. Consideration was given to weighting the reef index values according to the average MESH confidence score underpinning each polygon. However, it was decided that this would not be beneficial to the tool for the following reasons:

1) Despite the scoring process being standardised as far as possible, the MESH Confidence Assessment Tool remains highly subjective. *S. spinulosa* reef is inherently challenging to survey, and best practice is constantly evolving, meaning the confidence associated with a given survey may change. Due to the challenges in accurately surveying *S. spinulosa* reef, it is often difficult to distinguish between methods for which there is high confidence in detecting reef presence compared to those for which there is high confidence in detecting reef absence, which may further confound MESH confidence scores.
2) As there a number of uncertainties which are difficult to tease apart; notably delineating reef with confidence compared to tracking the aggregation and disaggregation of reef, it was decided that by incorporating a qualitative metric into the reef index score there was a risk of confounding patterns in reef index distribution. It is therefore recommended that when making decisions using this tool that the data are fully interrogated, with the reef index score being considered alongside the MESH confidence score of the contributing surveys.

## Formatting the data

### Data projection

2.11 The variation between data sources meant the datasets used several different coordinate systems. GCS_WGS 1984 (D_WGS_1984 Datum) is most commonly used for marine GI analysis and so was used throughout the synthesis. All datasets were transformed into GCS_WGS 1984 using the ‘Project’ tool (Data Management tools) in ArcGIS, before inclusion in the subsequent data processing steps. The most common transformation was from BNG 1936 to WGS 1984, for which the OSGB_1936_To_WGS_1984_Petroleum transformation was used.

### Creating a standardised shapefile

2.12 The fundamental components of the reef index equation (Figure 4) require an understanding of the areas that have been surveyed and where reef has been found. As such, it was necessary to incorporate both the total area that a survey covered and the extent of the reef found within that area of survey for each dataset.

2.13 To achieve this, the first step of geo-processing was to create two shapefiles for each survey; one denoting the area surveyed where reef was not found, and the other covering the area surveyed where reef was found. These two shapefiles were then combined into one consolidated shapefile containing two polygons; the area that was surveyed and where reef was found. This was carried out for all of the surveys included in the synthesis. It was then possible to use the combinations of areas surveyed and areas of reef found to calculate the reef index.

2.14 Where more than one method was used within a survey, then distinct survey regions received different MESH scores based upon the merit of the methodology applied. Individual shapefiles were therefore created for each distinct area of survey method to reflect these different scores. This was the case for Jessop & Stoutt (2006) and for Jessop, Harwood and Woo (2009).

2.15 Each survey was assigned a unique code based on the latter two digits of the year it was produced. Where multiple surveys occurred in one year they were differentiated using a, b, c. For example, Jessop et al. (2012) EIFCA Research Report was assigned 12a whilst Meadows et al. (2012) Baseline monitoring survey of large shallow inlet and bay for The Wash and North Norfolk Coast SAC was assigned 12b. The full list of codes can be found in Table 6. These codes were used to name individual survey shapefiles and in the Survey, Found, and MESH score columns of the attribute table of each shapefile. Shapefile attributes are discussed further in Section 2.18 - 2.20.

**Table 6** Unique codes assigned to surveys

| Survey | Attribute table code |
|---|---|
| Foster-Smith, R.L. and Sotheran, I. (1999) | Survey_99, Found_99 |
| Foster-Smith, R.L. (2000) | Survey_00, Found_00 |
| Foster-Smith, R.L. (2001) | Survey_01a, Found_01a |
| Foster-Smith, R.L. and White, W.H. (2001) | Survey_01b, Found_01b |
| Jessop, R.W. and Stoutt, J. (2006) | Survey_06a and Survey_06b<br>Found_06a and Found_06b |
| Jessop, R.W., Graves, K.M. and Woo, J.R. (2006) | Survey_06c, Found_06c |
| Woo, J.R. 2008 (2007) | Survey_08a, Found_08a |
| Jessop, R.W., Woo, J.R. and Harwood, A.J.P. (2008) | Survey_08b, Found_08b |
| Osiris Projects and Emu Ltd (2008) | Survey_08c, Found_08c |
| Emu (2008) | Survey_08d, Found_08d |
| Jessop, R.W., Harwood, A.J.P. and Woo, J.R. (2009) | Survey_09a and Survey_09b<br>Found_09a and Found_09b |
| Emu. (2009) | Survey_09c* |
| Jessop, R.W., Hinni, S., Skinner, J., Woo, J.R. (2010) | Survey_10, Found_10 |
| Jessop, R.W., Maxwell, E. (2011) | Survey_11, Found_11 |
| Jessop, R.W., Åkesson, O., Smith, L.M. (2012) | Survey_12a, Found_12a |
| Meadows, B., Barrio Froján, C. (2012) | Survey_12b, Found_12b |

*No reef was found in Emu (2008)

2.16 Some of the surveys consisted of separate regions of survey effort, which were provided as individual shapefiles. These were combined using the 'Merge' and then 'Dissolve' tools (Data Management tools) in ArcGIS to produce a single polygon for each survey extent. Where the reef extent data came in separate shapefiles for high, medium and low levels of reefiness, these shapefiles were combined using the Merge and then Dissolve tools to create a single polygon of total reef extent for each survey (Figure 5). This approach differs from that adopted by Bussell and Saunders (2010), who utilised only the medium and high reef shapefiles.

2.17 The decision to include ‘low’ reef as true reef was the result of the following consideration. According to the Gubbay (2007) criteria of ‘reefiness’, low reef qualifies as reef, and is distinct from the dedicated ‘not reef’ category. As reef index scores are based on reef presence or absence, the inclusion of low reef is justified, provided the reefiness assessment was suitably rigorous. To ensure that the Gubbay criteria were adequately applied, the adapted MESH Confidence Assessment Tool included criteria to assess whether suitable parameters were measured to assign reefiness scores (see Section 2.4 - 2.9 and Appendix 3). Surveys that did not demonstrate that the methods could robustly identify reef would therefore be excluded from the synthesis. The incorporation of these criteria into the MESH Confidence Assessment also allowed surveys which were conducted pre-Gubbay to be evaluated. Additionally, only some of the datasets included in the synthesis had data that was split into ‘reefiness’. Therefore to ensure a consistent approach across the datasets, all reef was included.

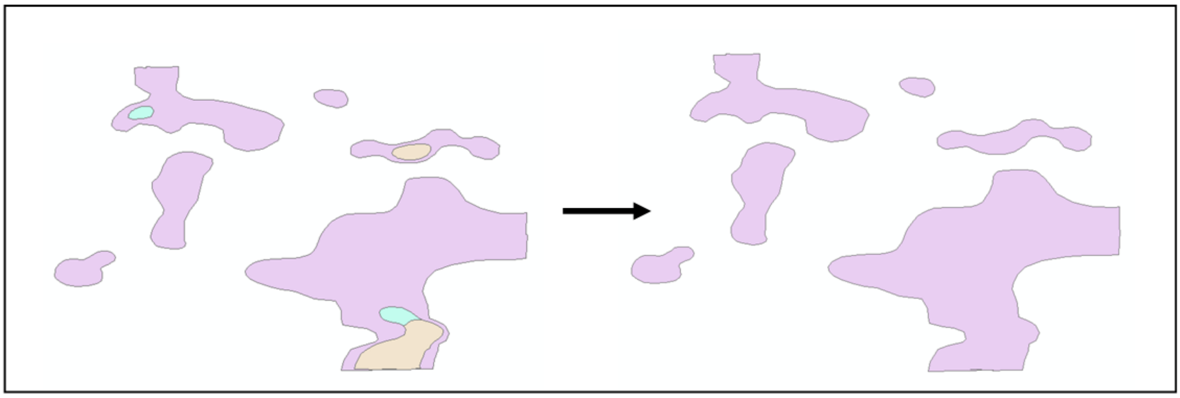


**Figure 5** Production of a single reef extent layer. On the left; individual reef polygons based on ‘reefiness’, on the right; reef polygons combined into one polygon for extent of all reef.

### Attribute table structure and format

2.18 In order to produce a functional attribute table for the final reef index shapefile it was necessary to standardise the attribute table of each component shapefile.

2.19 Previously, the reef index shapefile attribute table produced by Bussell & Saunders (2010a) contained one column listing the years in which a given polygon had been surveyed, and a second column recording each of the years in which reef was found there. As part of the current synthesis, a simple binomial system was devised, whereby each survey was assigned two columns representing the survey extent and the extent of reef found. These columns were populated with a 0 if a survey did not cover a given polygon, while a 1 was used to denote that a given polygon was surveyed (Survey column) or reef found (Found column). Therefore, if reef was found in a survey, then both columns were populated with 1. If reef was not found, then the Survey column was populated with 1 and the Found column with 0. Once these shapefiles were consolidated, this information was used to tally the total number of times a polygon had been surveyed and how many times reef has been found, in order to calculate the reef index. Although this approach resulted in a larger attribute table, it allows for new survey data to be added to the reef index layer with ease and for the reef index to be recalculated with minimal data manipulation using simpler GI tools. Furthermore, this approach allowed for more intuitive and flexible analysis of the final reef index layer, as data from a particular survey could be included or excluded without the need to remove a given survey from the shapefile. For example, the reef index value for a subset of surveys could be calculated in a new column, without needing to re-synthesise the data to exclude the surveys not being used.

2.20 In addition to the Survey_[survey code] and Found_[survey code] columns, the attribute table also contained the following three attributes: FID (a unique identifier for each record within the table), Shape, and MESH_[survey code] (Figure 6). The MESH_[survey code] columns were populated with the MESH confidence assessment score for the corresponding survey.

Attributes of EIFCA_2011

| FID | Shape * | Survey_11 | Found_11 | MESH_11 |
|---|---|---|---|---|
| 0 | Polygon | 1 | 1 | 66 |
| 1 | Polygon | 1 | 0 | 66 |

**Figure 6** Example of attribute table structure and format used for all shape files in current synthesis

### Producing the survey shapefiles

2.21 The survey extent and reef extent shapefiles were combined using the Union tool (Analysis tools) in ArcGIS to produce one shapefile per survey. This shapefile contained two polygons; one for survey areas where reef was found and one for survey areas where reef was not found, denoted as 0 and 1 in the Found_[survey code] column in the attribute table.

2.22 In some cases reef extended outside the acoustic survey effort extent, as a result of GI methods used by the original authors, which relied predominantly on ground truth data to interpolate reef extent (Jessop and others, 2010). Where reef was mapped outside of acoustic survey effort extent, survey extent was delineated to match the extent of reef. This approach differed from that used in the 2010a synthesis. In the 2010a synthesis, where reef extended outside of acoustic survey effort extent, then survey effort was digitised and delineated around all of the grab samples that occurred outside the acoustic survey extent. This resulted in not only the survey extent matching the reef extent but survey extent extending outside of the areas where reef was found. It was decided for this synthesis that survey extent would only be extended to match areas that had been positively identified as reef, and those areas that had been ground truthed only would not be considered as surveyed due to the patchy nature of reef and the risk of missing reef in regions that had not also been acoustically surveyed.

2.23 In instances where reef extended outside the acoustic survey limit then the GI Union tool resulted in three polygons being created when the reef extent and survey area shapefiles were unioned (Figure 7). In order to create a shapefile with just two polygons the reef extent was exported to new shapefiles. The polygon of where reef had not been found was exported to a new shapefile for survey effort so that the reef and survey shapefiles, when re-combined, resulted in a final shapefile containing just two polygons (Figure 7).

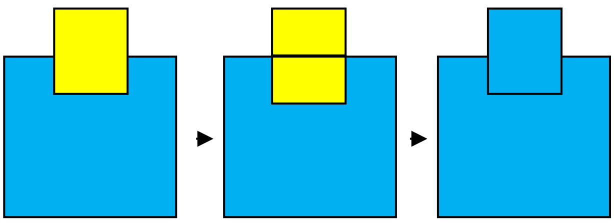


**Figure 7** An illustration of the final survey shapefile with two polygons. On the left the reef extent (yellow) extends outside of the survey area (blue), resulting in three polygons when these were unioned (centre image). The extent where reef was not found was combined with the original reef extent so the final shapefile had two polygons (right image) showing as 2 rows in the attribute table, both with a 1 in the surveyed column.

## Synthesising the data

2.24 The standardised shapefiles for each survey were unioned to produce a master shapefile containing all of the individual polygons representing reef extent and survey effort from each individual survey. This was done in a chronological manner, to ensure that the attribute table reflected the order in which surveys were conducted, from oldest to most recent. This created a shapefile with a polygon for each distinct combination of when an area was surveyed and whether reef was found.

2.25 Five additional fields were added to the attribute table; Tot_MESH, Av_MESH, Tot_Survey, Tot_Found, and Reef_Index. When adding these columns, the field type was set to 'short' with a precision of '5', apart from Reef_Index which was set to a field type of 'float' with a precision of seven '7' and a scale of '4'.

2.26 The five new columns were populated using field calculator with the formulas summarised in Table 7.

**Table 7** Formulas used to populate the attribute table of the reef index shapefile

| Field | Content | Formula |
|---|---|---|
| Tot_MESH | Sum of MESH scores of all surveys undertaken in a polygon | MESH<year> + MESH<year> + MESH<year> etc. |
| Av_MESH | Average MESH score of all surveys undertaken in a polygon | Tot_MESH / Tot_Survey |
| Tot_Survey | Total number of times a polygon was surveyed | Survey<year> + Survey<year> + Survey<year> etc. |
| Tot_Found | Total number of times reef was found in a polygon | Found<year> + Found <year> + Found <year> etc. |
| Reef_Index | Reef Index value | (Tot_Found / Tot_Survey) * Tot_Found<br>If Tot_Found = 0 then Reef_Index = Tot_Survey * -1 |

2.27 The fifth column, Reef_Index, was calculated in two parts. First the formula (Tot_Found / Tot_Survey) * Tot_Found was entered using the field calculator. Polygons where reef had not been found during any survey were populated with a 0 through this equation. In order to ascribe negative reef index values, these polygons were selected (using select by attributes: Tot_Found=0) and then the formula Tot_Survey*-1 entered using the field calculator. This resulted in a negative reef index value proportionate to the number of times a polygon was surveyed.

2.28 A flow chart detailing the process that was used to create standardised survey shapefiles and how to combine them into a synthesised reef index shapefile can be found in Figure 8.

Open a blank map and add all of the shapefiles relating to survey effort and reef extent for the survey you are creating a standardised shapefile for. Ensure that the coordinate systems are the same (WGS_1984). If not then perform the appropriate transformation for example Petroleum. Toolbox>Data Management Tools>Projections and Transformations> Feature>Project.

Using the Merge function combine all of the effort shapefiles so that you are left with one shapefile for survey area. Toolbox>Data Management> General> Merge. Input shapefiles are those you wish to merge (i.e. all survey effort). Output should be specified as where you wish to save the output.> OK. Add this layer to the map.

Was reef found?

Yes

No

As with the survey effort, merge all of the reef extent shapefiles so that you are left with one shapefile for reef found. Add this layer to the map.

Select the survey effort shapefile and open the attribute table. Do you have multiple polygons showing as rows in the attribute table?

Yes

No

Select the Toolbox>Data Management> Generalization> Dissolve. Select the shapefile as the input and specify where you wish to save the output> OK.

Open the attribute table; you should now have one polygon. Repeat this process for the reef extent shapefile (if reef was found).

Open the attribute table of each shapefile, you should now have one polygon in each. Within the attribute table select Options>Add Field.

Add three columns to each attribute table; Survey_[survey code], Found_[survey code] and MESH_[survey code] as shown in the table below. The field type should be short integer, precision 5.

Reef Extent Attribute Table

| ***FID*** | ***Shape*** | ***Survey_99*** | ***Found_99*** | ***MESH_99*** |
|---|---|---|---|---|
| 0 | Polygon | 1 | 1 | e.g. 52 |

Survey Effort Attribute Table

| **FID** | **Shape** | **Survey_99** | **Found_99** | ***MESH_99*** |
|---|---|---|---|---|
| 0 | Polygon | 1 | 0 | e.g. 52 |

Reopen the attribute tables and use the field calculator to populate the fields as above.

↓

Next, join the two shapefiles to produce one shapefile with an attribute table with two rows; a polygon for Reef Extent and a polygon for Survey Effort. Toolbox> Analysis Tool>Overlay> Union. Input the shapefiles for reef and effort, identify the location where you wish to save the output .OK, Add to map.

↓

Open the attribute table of the new shapefile. If it contains two rows as per the diagram at the end of these instructions you can save this shapefile and **finish here**.

If however you have more than two polygons follow the additional steps below.

↓

In the attribute table, highlight the row that corresponds to survey effort (not found). Close the attribute table, right click on the layer shapefile in the Table of Contents >Data> Export Data.

Ensure that Export: selected features is highlighted, output enter the location where you wish the output to be saved> OK.

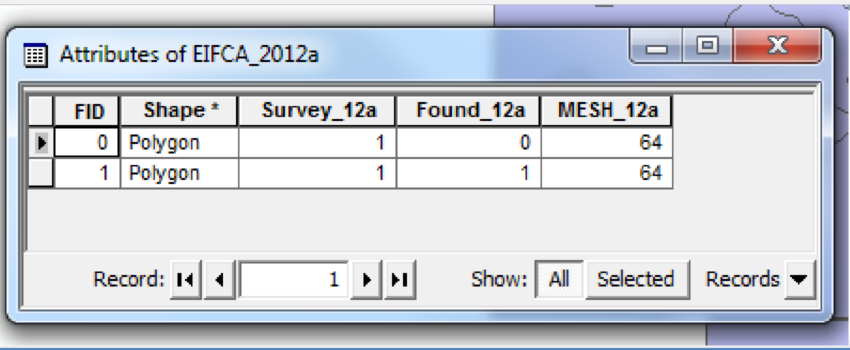
Add the new effort shapefile to the map.

The final stage is to Union the new effort shapefile to the formatted reef extent shapefile that was used in the previous union. Toolbox>Analysis Tools>Overlay>Union.

Input the shapefiles> type in the filename you wish to call the shapefile> OK.

The shapefile is now complete. Some housekeeping may be required to remove extra fields(columns) from the attribute table which are created during geoprocessing. Refer to the image below and delete any additional fields from the table.

Repeat the above stages for each survey.




| FID | Shape * | Survey_12a | Found_12a | MESH_12a |
|---|---|---|---|---|
| 0 | Polygon | 1 | 0 | 64 |
| 1 | Polygon | 1 | 1 | 64 |

Once all of the shapefiles for each survey have been formatted then they must be synthesised. Union all shapes together in chronological order. Unfortunately this process can only be done one shapefile at a time. If you are adding shapefiles to an existing synthesis then union the new survey shapefiles to the existing synthesis shapefile.

As before perform housekeeping on attribute tables to remove any unnecessary fields (columns).

Add five new fields with the following specification:
Tot-MESH -short integer, precision 5
Tot_Survey -short integer, precision 5
Tot_Found-short integer, precision 5
Av_MESH -short integer, precision 5
Reef_Index -float, precision 7, scale 4

Populate the new fields using the field calculator. For example if the survey was carried out in 1999, 2001 and 2002 the fields would be populated as below:

Tot MESH= MESH99+ MESH01+MESH02 etc.
Tot Survey= Survey99 + Survey01 + Survey02 etc.
Tot_Found= Found99 + Found01 + Found02
Av_MESH= Total MESH/ Tot Survey
Reef_Index= (Tot_Found/ Tot_Survey)*Tot_Found

↓

When reef has not been found, calculate negative reef index; select by attribute:
Tot_Found=0

Field Calculator on selected attributes:
Tot_Survey * -1

↓

When adding new surveys into the existing synthesis then these fields will need to be re-calculated to incorporate the new information.

↓

Import the symbology from previous Reef Index layer based on Reef_Index field. To do this add the layer file for this synthesis to the same MXD document as the new shapefile. Enter properties of the shapefile, symbology tab. Click ‘import’ and select the layer file as the target.

**Figure 8** Flow chart detailing the methods used to create the reef synthesis from original survey shapefiles

## Reviewing the outputs

2.30 The synthesis conducted by Bussell & Saunders 2010a differed from the 2014 synthesis in four key aspects;

1) The 2014 synthesis contained data from more surveys;
2) Due to the adaptation of the MESH confidence tool the MESH scores assigned to the surveys differed between the two syntheses;
3) The attribute table was structured differently, and;
4) In some cases the extent of survey effort and reef found in a specific survey differed between the two syntheses (Section 2.11 - 2.23).

2.31 A key aim of this work was to compare the core reef extent between the previous 2010a synthesis and the 2014 synthesis. Comparing these two syntheses would assist in forming an understanding of how accurately this approach can highlight areas supporting consistent reef. The impact of the inclusion of additional data was the factor deemed most important to evaluate. In order to analyse the effect of the addition of new data, it was necessary to standardise the interpretation of reefiness, standardise MESH scores and standardise the delineation of survey effort (Section 2.4 - 2.28). It was therefore decided to recreate the 2010a synthesis with the shapefiles and MESH scores used in the updated synthesis. This alternative synthesis of the 2010 data is referred to as the 2010b synthesis. This ensured that the reef extents and the associated confidence assessments were directly comparable, and not confounded by differences in methodology. There was a considerable difference in core reef distribution between the 2010a and 2010b syntheses (Figure 9), emphasising the importance of utilising a standard methodology.

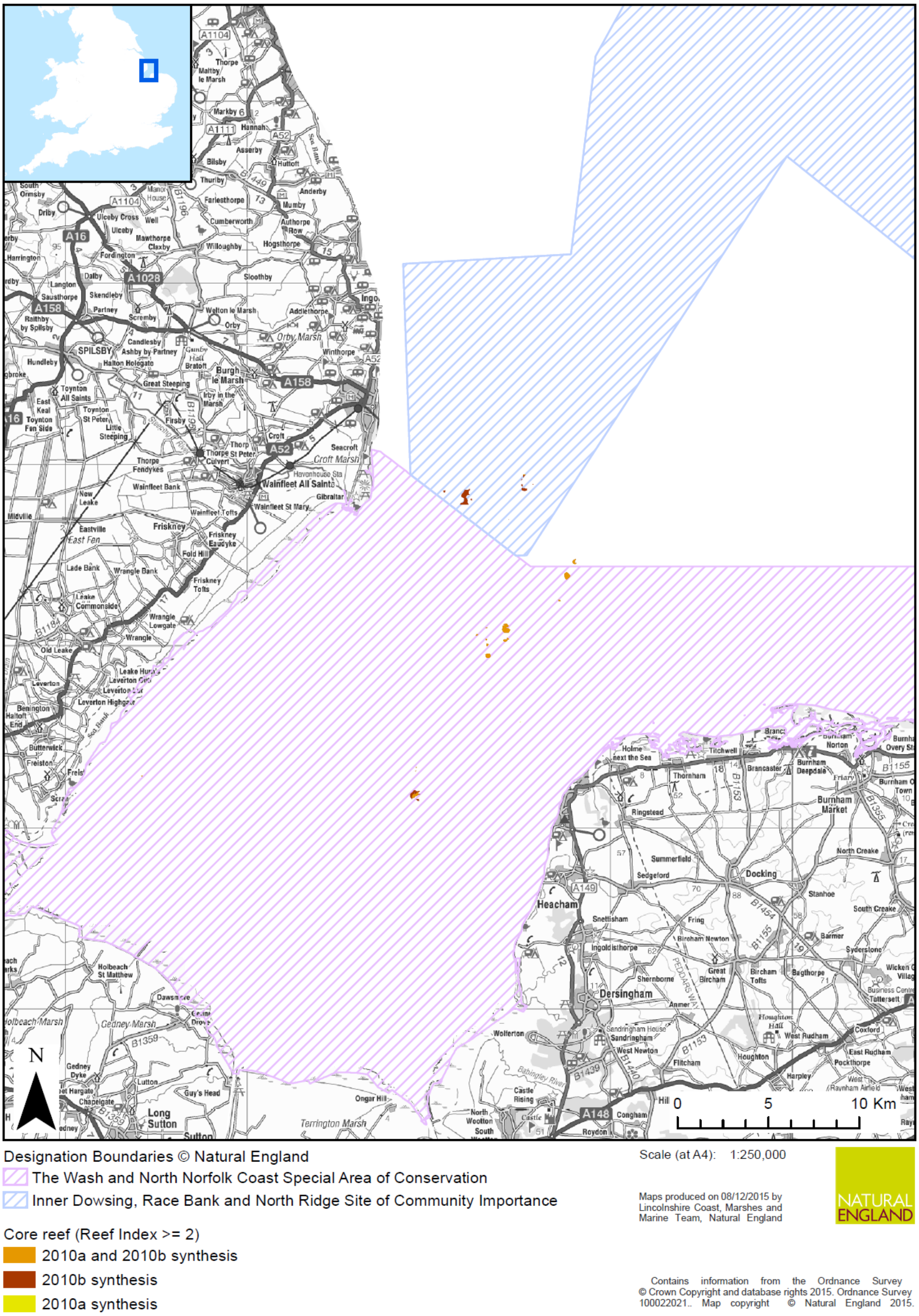



**Figure 8** The distribution of core reef (reef index ≥2) from the 2010a and 2010b synthesis. Note the larger extent for the 2010b synthesis.

## Interrogating the outputs

2.32 Final synthesised reef index shapefiles for both the 2010b and 2014 synthesis with appropriate metadata were created for this report. These shapefiles can be added to maps to allow spatial comparisons with other datasets or interrogated in order to further investigate the data that fed into the reef index calculation. They can also be updated as new data becomes available.

2.33 In this report the maps created from the 2010b and 2014 synthesis were used to directly compare the two datasets. The datasets were also interrogated in order to further investigate the core reef extent. 'Select by attribute' was used to produce shapefiles of all areas with a positive reef index, areas with a reef index ≥ 2 and areas with a reef index ≥1.8. A shapefile of the overlap between the core reef extent in 2010b and 2014 was produced using the 'Intersect' tool (Analysis tools). The area of shapefiles was calculated by dissolving the shapefiles, transforming them to British National Grid projection using the 'Project' tool and the 'Petroleum' transformation, and then using the 'calculate geometry' tool within the attribute table. The attributes of shapefiles were exported to spreadsheets for evaluation.

## Spatial correlation testing of the reef index

2.34 Once the synthesis was complete it was important to statistically test whether the spatial distribution of reef index values, and hence core reef areas, were not an artefact of sampling and confirm that these showed a significantly different distribution from random.

### Centroids

2.35 Firstly, the centroid of each of the polygons (Figure 10) was calculated in ArcGIS by creating two additional fields in the attribute table for longitude and latitude, and using the Calculate Geometry tool to calculate the X and Y Coordinate of Centroids. The full methodology, including how to export these in a table is detailed in Appendix 5.

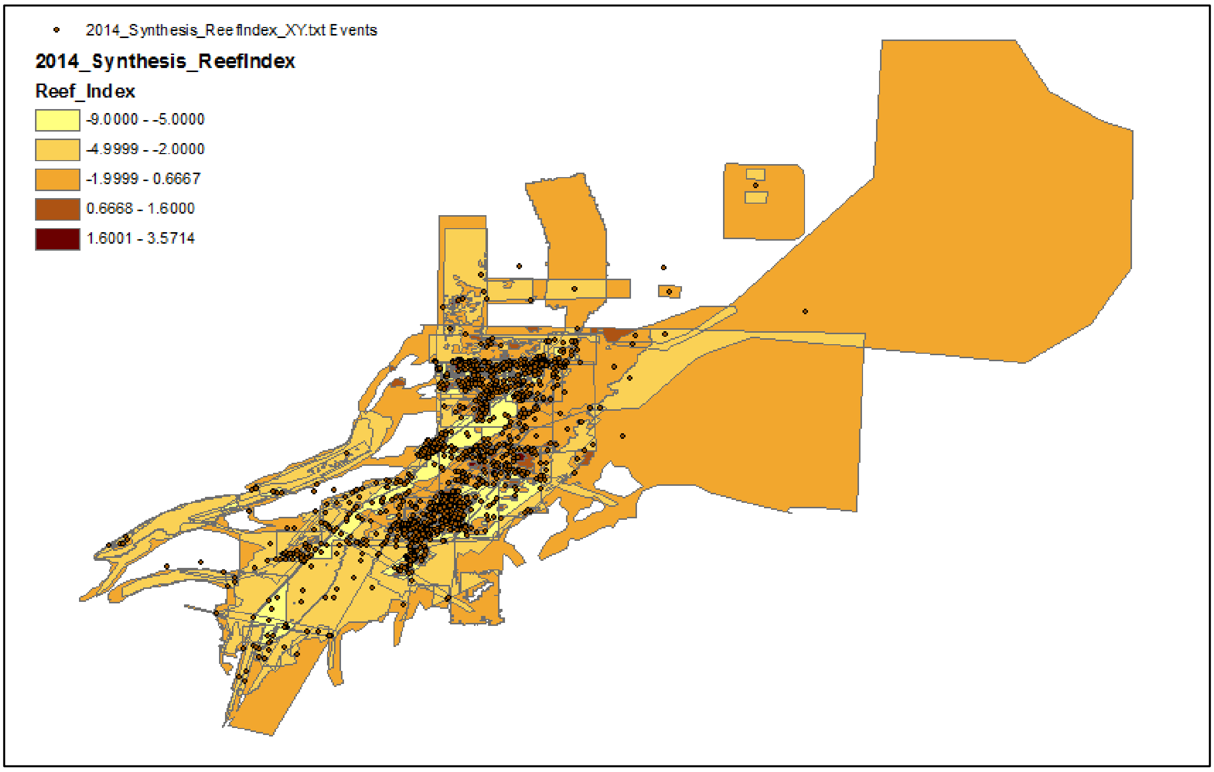



**Figure 9** 2014 synthesis dataset with polygons shaded according to reef index values. Centroids used for calculating Euclidean distances are shown.

## Moran's *I*

2.36 The centroids of each polygon and their associated reef index values were exported to a table. Using the exported table, Moran's *I* autocorrelation coefficient was then calculated in R between polygons' reef index value and the inverse distance between polygons (based on the Euclidean distance of centroids calculated from WGS84 latitude/longitude).

2.37 Moran's *I* was also calculated to test the spatial correlation between areas of core reef using both core reef values of >1 and >2.

## Validating the use of centroids

2.38 The analysis used the centroids of the 2014 reef index synthesis polygons. Because the larger polygons in this dataset tended to have negative reef indices, their centroids tended to be further away than the smaller polygons, which were clustered together. This had the potential to bias the results of the Moran's *I* spatial testing (although the number of large polygons was relatively few).

2.39 To ensure the use of centroids was not biasing the results of the Moran *I* test, two further tests were undertaken.

2.40 Firstly, 1,000 un-stratified random points were created (Figure 11) across the 2014 reef index synthesis extent (which consists of 1226 polygons). The reef index values corresponding to these random points were extracted, and the Moran's *I* test was repeated using these points.

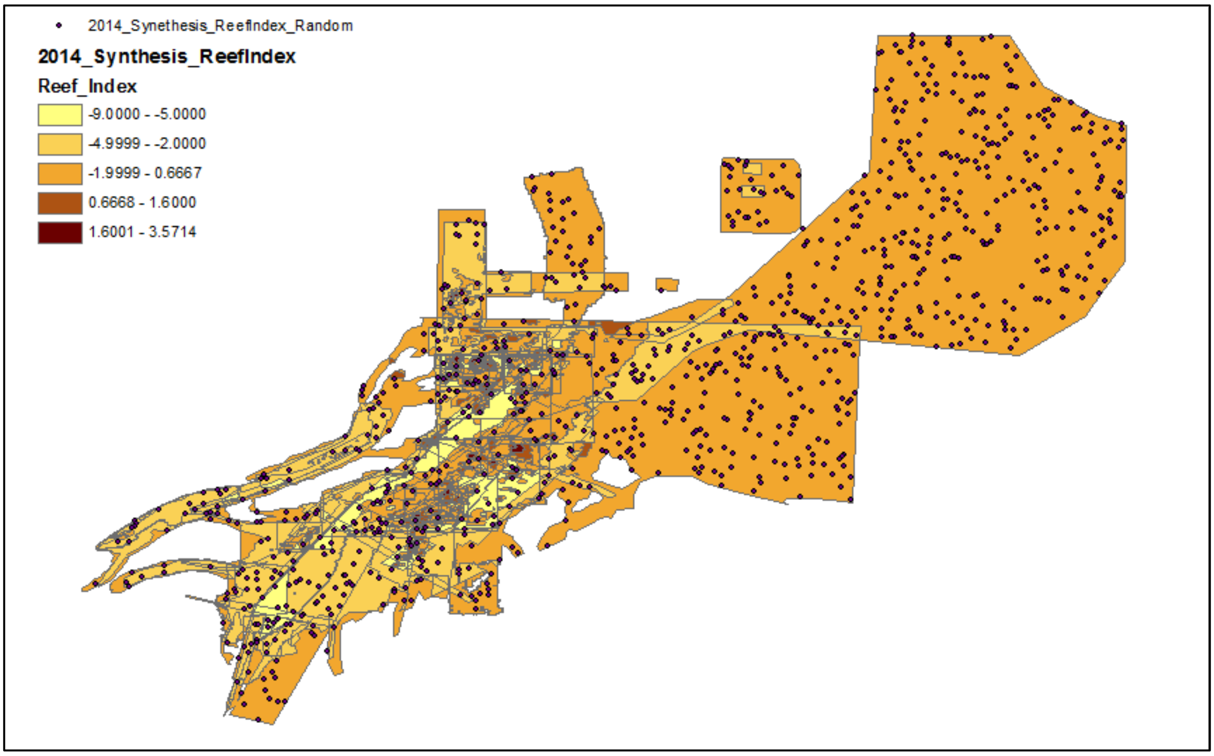



**Figure 10** 2014 synthesis dataset with polygons shaded according to reef index values. Random points used for calculating Euclidean distances are shown.

2.41 Secondly, random values were attributed to each the centroids extracted from the 2014 reef index synthesis polygons, and the 1,000 un-stratified random points. The Morans' *I* autocorrelation coefficient was calculated for these values.

# 3 Results

## Reef index - 2014 synthesis

3.1 The 2014 synthesis covered a total area of 1,098.81 km$^2$, and identified 117.58 km$^2$ of *S. spinulosa* reef, of which 1.22 km$^2$ was identified as core reef (reef index ≥2) (Figure 12).

3.2 Confidence in the data included in the synthesis varied, with MESH confidence scores assigned to surveys ranging from 36 to 90. All datasets were included in the synthesis, as they were all deemed to have used appropriate survey techniques.

3.3 Areas where reef was identified received positive reef index values, reflecting the ratio of the number of times the area has been surveyed in relation to the number of times which reef has been found (Figure 4). Areas which have been surveyed, but where reef was not identified, received negative reef index values. Areas that had been surveyed multiple times but where reef had not been found received increasingly negative reef index scores.

3.4 Within The Wash, positive reef indices (>0) were most consistently found within the easterly extent of Lynn Deeps, around the Well and to the northeast, encompassing Lynn Knock and the surrounding area. Within this positive extent, smaller areas of relatively high reef index (≥2) were recorded, with an extent of 0.85 km$^2$ (Figure 13 and Figure 14).

3.5 In comparison the westerly extent of The Wash presented far more negative reef index values, notably around the Roaring Middle. Boston Deep presented overall similar negativity, however, a scattering of positive reef index was recorded to the far east and west of Boston Deep and additionally around the Trap. The most negative reef indices presented in the Well itself and Wisbech channel. Offshore from the North Norfolk coast and in the area north of Lynn Knock a large area represented a reef index of -1 (Figure 13 and Figure 14).

3.6 The reef index score is heavily influenced by the number of surveys conducted, making survey coverage an important consideration when interpreting the reef index distribution. Crucially, an area needs a minimum to of two surveys to be considered as core reef (Table 2). However, the majority of areas which have only been surveyed once have not found reef (716.35km$^2$ out of 719.34km$^2$), making the areas where reef has been found but it has not received enough survey coverage to be core reef relatively small (2.99km$^2$) (Figure 15).

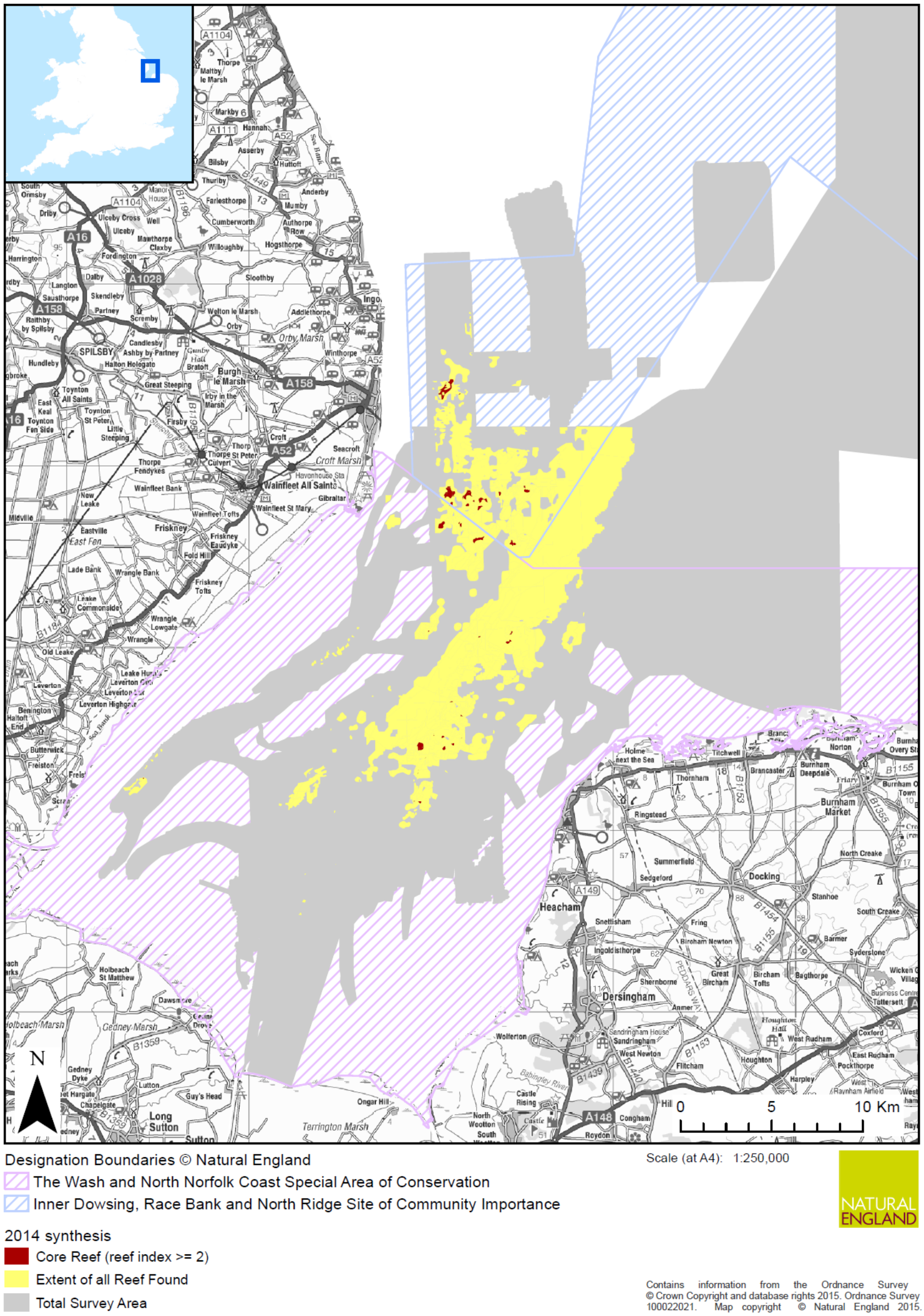



**Figure 11** The total extent covered by the surveys included in the 2014 synthesis, the extent of all reef found, and core reef (reef index ≥ 2)

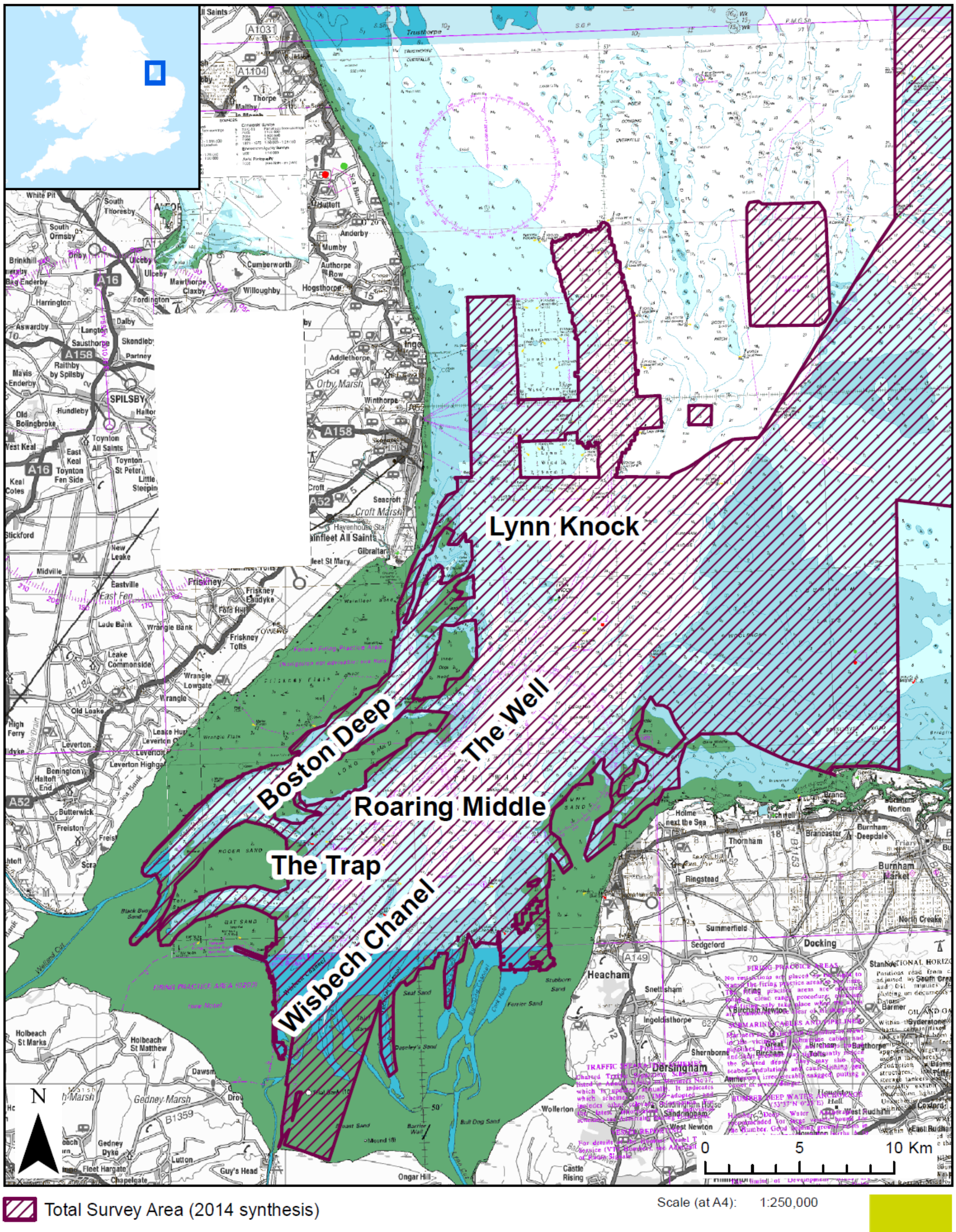





**Figure 12** The total extent covered by the 2014 synthesis overlaid onto an Admiralty Chart. Locations of interest in the synthesis have been labelled.

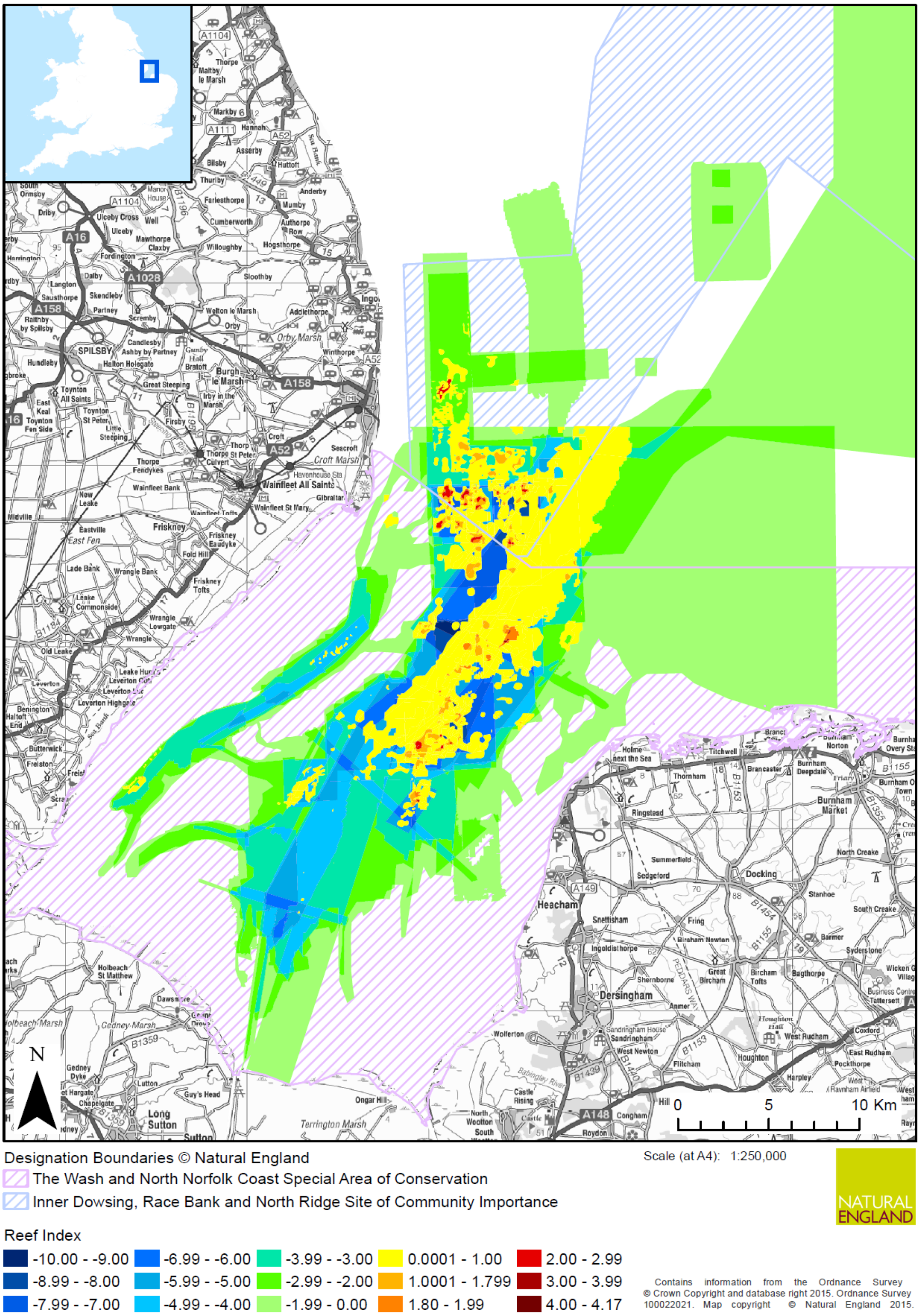



**Figure 13** Reef index values from the 2014 synthesis. Green and blue areas represent a negative reef index, while yellow represents a positive reef index and red indicates core reef (reef index ≥ 2).

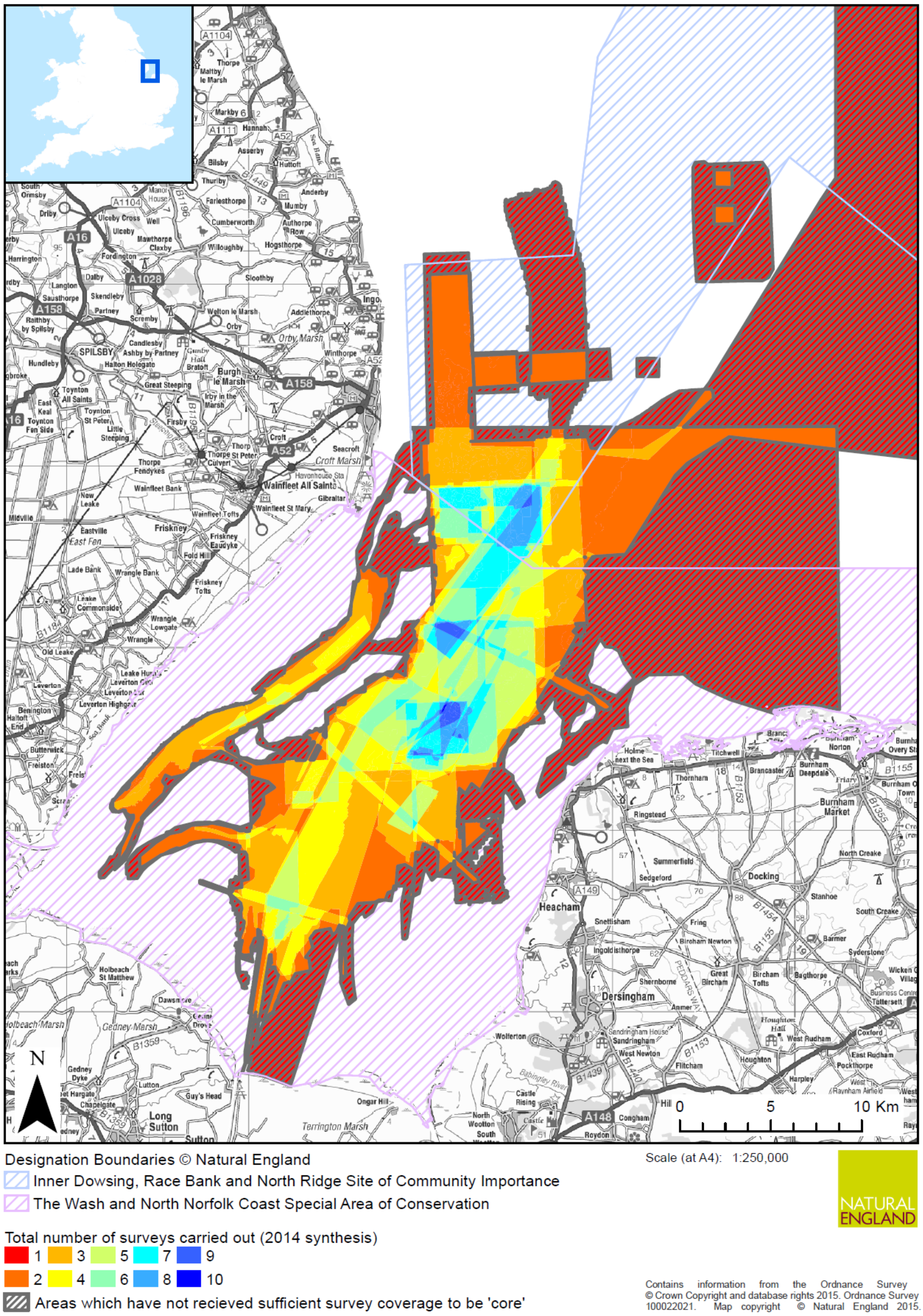



**Figure 14** Extent of the 2014 synthesis mapped according to the number of surveys carried out in a given area. Grey hatching covers areas which have only been surveyed once and so cannot be considered core reef.

## MESH confidence scores - 2014 synthesis

3.7 Average MESH confidence scores were calculated for each polygon based on the MESH scores of the surveys contributing to that polygon. The average MESH confidence scores assigned to polygons included in the 2014 synthesis ranged from 53 to 72. The highest average MESH scores were found in the Well, Boston Deep and the Trap (Figure 21).

## Spatial correlation

### Validation of the use of centroids

3.8 When random values were attributed to the centroids of the polygons then a p value of 0.03 was obtained. This would indicate that we can reject the null hypothesis of no spatial correlation, which is clearly untrue given that the values were random. This indicates that the distribution of the polygons may be biasing the statistical test and that using the centroids is therefore not valid when testing for spatial correlation.

3.9 When random values were attributed to the 1,000 un-stratified points then a p value of 0.302 was obtained. This non-significant value suggests that there is no spatial correlation, which is what would be expected.

3.10 The un-stratified random points are therefore considered to be a valid approach to testing spatial correlation. The results of the spatial correlation test will therefore be reported for the test conducted using the random un-stratified points.

### Statistical results

3.11 The statistical analysis outlined in Section 2.34 - 2.41 tested the following null hypotheses:

1) That there was no spatial correlation in the location of reef index values within The Wash and their distribution did not differ from a random distribution.

3.12 The observed value (the computed Moran's *I)* was 0.181 whereas the expected value of *I* was –0.001. When interpreting Moran's *I*, if the observed value is significantly greater than the expected value, then the values are positively auto-correlated (in this case with inverse distance). The p value is <0 .01 meaning that we can reject the null hypothesis that there is no spatial correlation in the location of reef index values within the Wash. Therefore the distribution of reef index values within The Wash is statistically different from a random distribution.

3.13 Further visible correlation can be seen in the variogram (Appendix 5).

## Reef index - Comparison of 2014 and 2010b synthesis

3.14 Of the 14 core reef polygons in the 2010b synthesis, 13 have been resurveyed at least once by the new surveys added to the 2014 synthesis. This means that the reef index value for all but one of the 2010b core reef polygons will have been liable to change in the 2014 synthesis as the 'times surveyed' will have increased and the 'time found' may have increased.±

3.15 The 1.22 $km^2$ of core reef (reef index ≥ 2) identified in the 2014 synthesis represented an increase of over 50% from the 0.8 $km^2$ of core reef (≥2) identified in the 2010b synthesis. The percentage increase in core reef between 2010b and 2014 is lower (32%) when a reef index value of ≥ 1.8 is used to identify core reef. However, using 1.8 as a threshold doubled the overall area identified as core reef in the 2010b synthesis compared to a threshold of 2.

3.16 There has been a negligible change in the total area surveyed (3.75$km^2$) between the 2010b and 2014 syntheses. The total extent of *S. spinulosa* reef identified was 13.32$km^2$ greater in the 2014 synthesis than that identified in the 2010b synthesis (Table 8). This represented an almost 13% increase in total reef extent despite a negligible increase in survey extent.

**Table 8** Area (km2) of core reef from reef index ≥ 1.8 and ≥ 2, total reef found and total areas surveyed using different reef index values in the 2010b and 2014 synthesis

| Extent | 2010b | 2014 | % Change |
| --- | --- | --- | --- |
| **Reef Index ≥1.8** | 1.66 | 2.19 | 31.9 |
| **Reef Index ≥2** | 0.80 | 1.22 | 52.5 |
| **Areas Surveyed Once With Reef Found Once** | 6.21 | 2.99 | -51.9 |
| **Total Reef Found** | 104.26 | 117.58 | 12.8 |
| **Total area surveyed** | 1,095.06 | 1,098.81 | 0.3 |

3.17 Only 0.23km2 of core reef was attributed to the same location in the 2010b and 2014 synthesis, representing approximately a fifth of core reef (Figure 16). In some cases, the exact location of core reef has altered but remained within a localised area, for example in Lynn Knock. In other cases the reef index of the entire region has fallen below the threshold (≥2) of what was considered to be core (such as in the North Well) or appeared in an area which did not previously support any core reef (such as Roaring Middle and Skegness Middle) (Figure 16).

3.18 In terms of reef that was above the core threshold in 2014, but had not been in 2010, the reef index of these polygons in 2010 varied considerably. Many of these had a low reef index (such as 0.29 or 0.3), whilst some had a higher reef index, verging on the threshold for core reef (for example 1.8 and 1.5). With regard to reef that was core in the 2010b synthesis, but was no longer above the core threshold in 2014, then the reef index of these polygons in 2014 was slightly less varied. There were a number of polygons which had a relatively low reef index (such as 1), but the majority remained near the threshold for core reef (for example 1.8, 1.5).

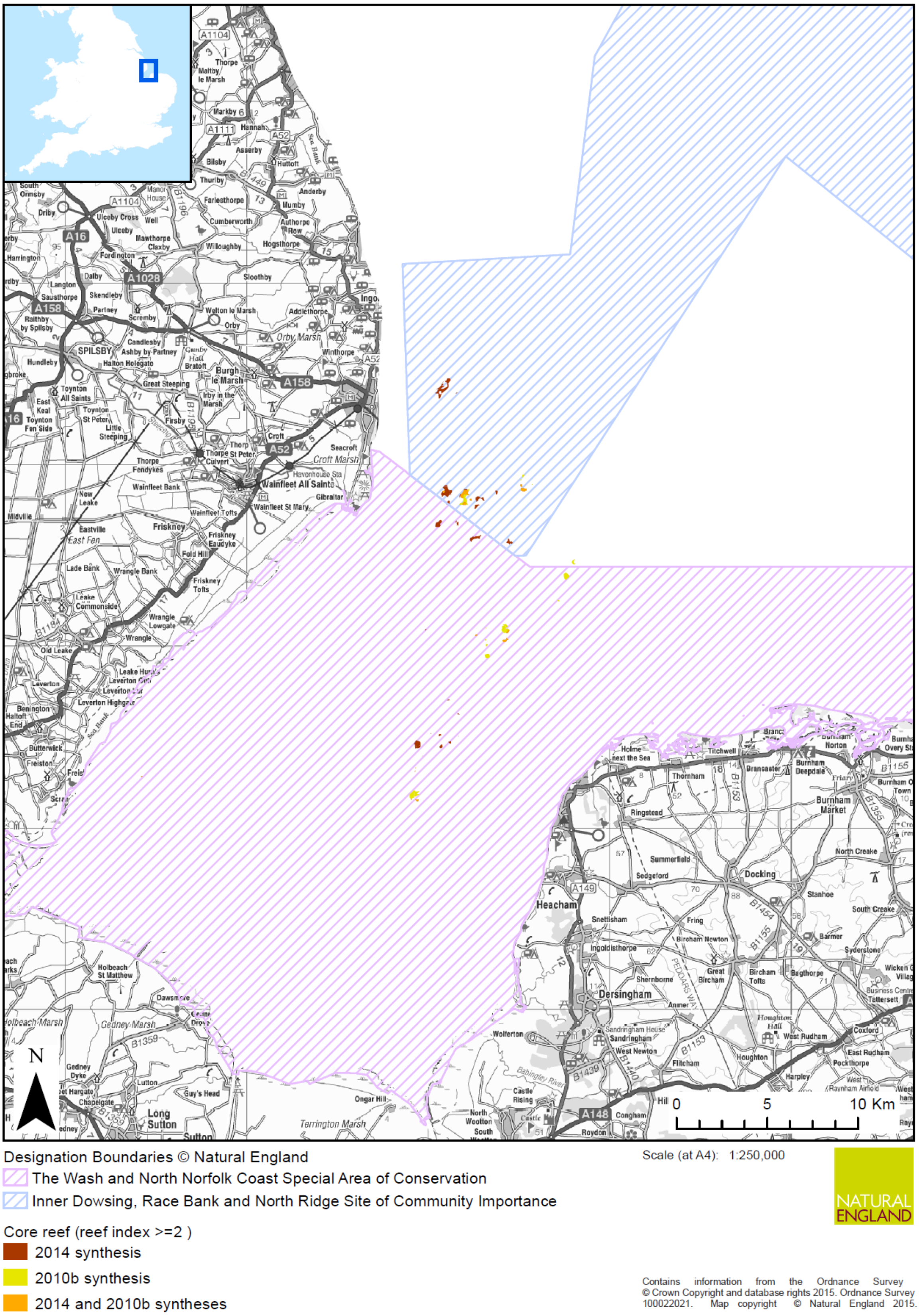


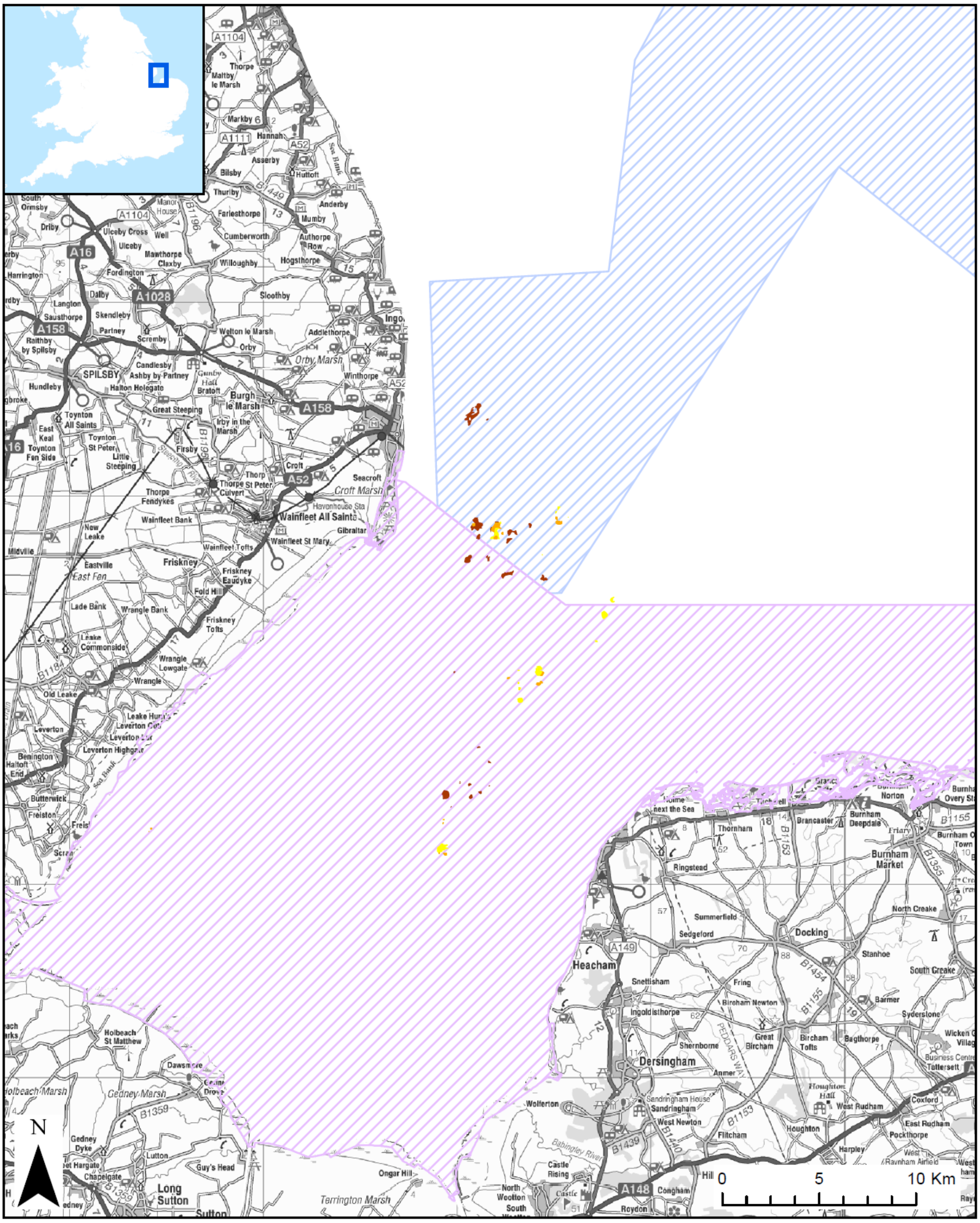

**Figure 15** A comparison of the distribution of core reef (reef index ≥2) in the 2014 synthesis and the 2010b synthesis

## Reef index thresholds

3.19 Current management advice in The Wash and North Norfolk Coast SAC uses a reef index value of ≥ 2 to identify areas of core reef, while a value of ≥1.8 has been used in the Lynn Knock region of Inner Dowsing Race Bank and North Ridge SCI due to less evidence being available. When the distribution of core reef (≥2) between the 2014 and 2010b syntheses were compared, it was found that only approximately a fifth of the extent overlapped. However, the core reef areas did remain within the same general vicinity. This raised the question of whether a lower reef index value would show further consistency in the distribution of core reef in The Wash and North Norfolk Coast and The Wash approaches. This was investigated systematically by incrementally decreasing the reef index values from 2 to 0.6. Figures 17 through 20 illustrate the distribution of core reef found at these incremental reef index values and Table 9 includes the areas of core reef present at those values.

3.20 The distribution of core reef remained primarily around Lynn Knock and The Well at all the reef index thresholds that were mapped (Figures 17 through 20). As the reef index value used to determine core reef decreased, the proportion of core reef area that overlapped between the 2010b and 2014 syntheses increased. In order to measure this increase, areas of core reef which overlapped between 2010b and 2014 were calculated as a proportion of total core reef for each synthesis, rather than using just the extent of overlap. An increase in the proportion of core reef overlap is indicative of an increase in the consistency of core reef distribution (i.e. that areas of core reef are becoming increasingly similar), rather than purely an artefact of the increase in core reef extent.

3.21 Reef index ≥ 1 is the highest reef index value observed where the amount of overlapping core reef was over half of the total area of core reef found for both syntheses. However, between reef index values of 1.4 and 1 a large increase in the area of core reef occurs in the 2014 synthesis (Table 9).



Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Candidate Special Area of Conservation

Core Reef (reef index >=1.8)

2014 synthesis

2010b synthesis

2014 and 2010b syntheses

Scale (at A4): 1:250,000

Maps produced on 04/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

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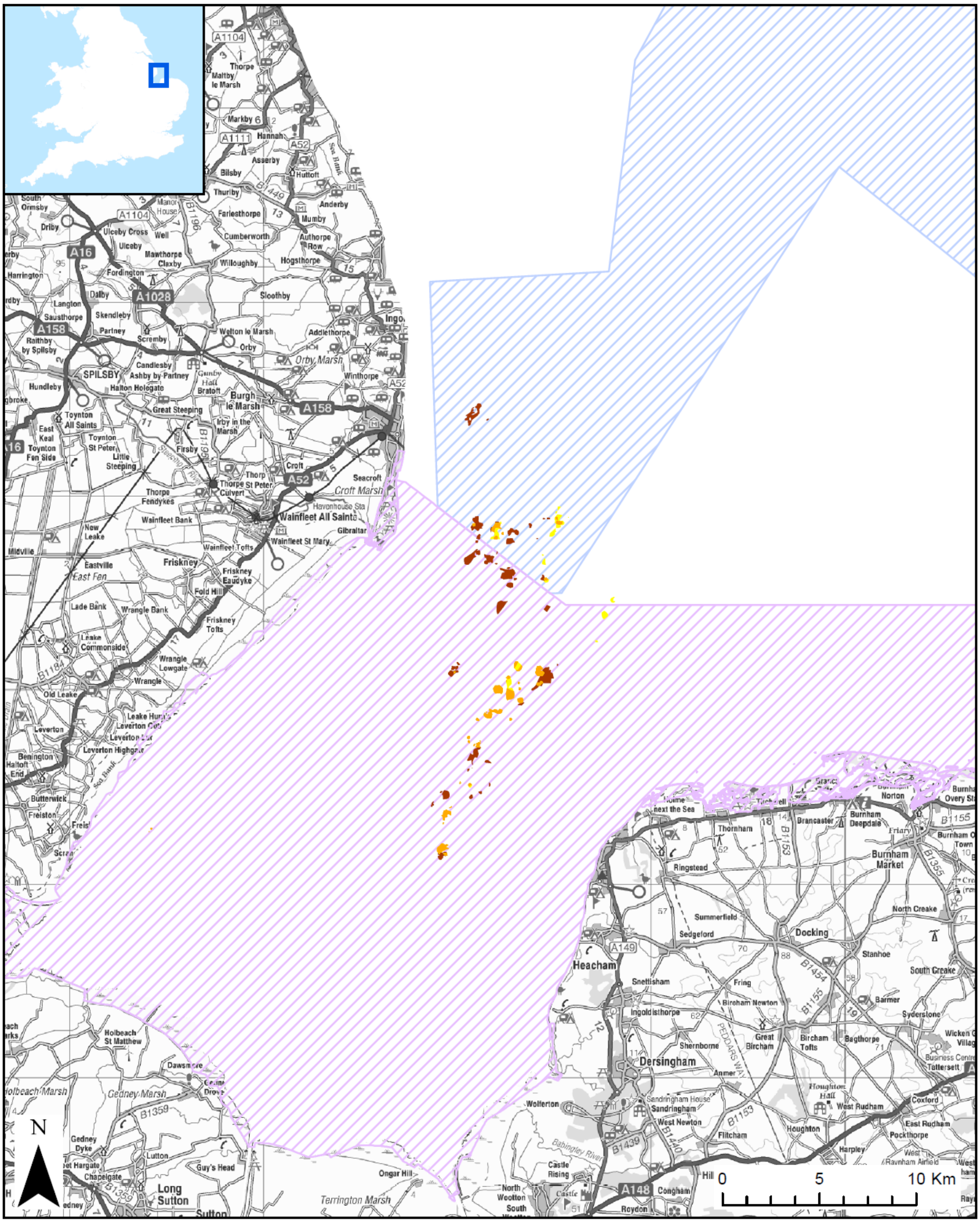
**Figure 16** The distribution of reef with a reef index ≥ 1.8 in the 2014 and 2010b syntheses




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Candidate Special Area of Conservation

Core Reef (reef index >=1.4)

2014 synthesis

2010b synthesis

2014 and 2010b syntheses

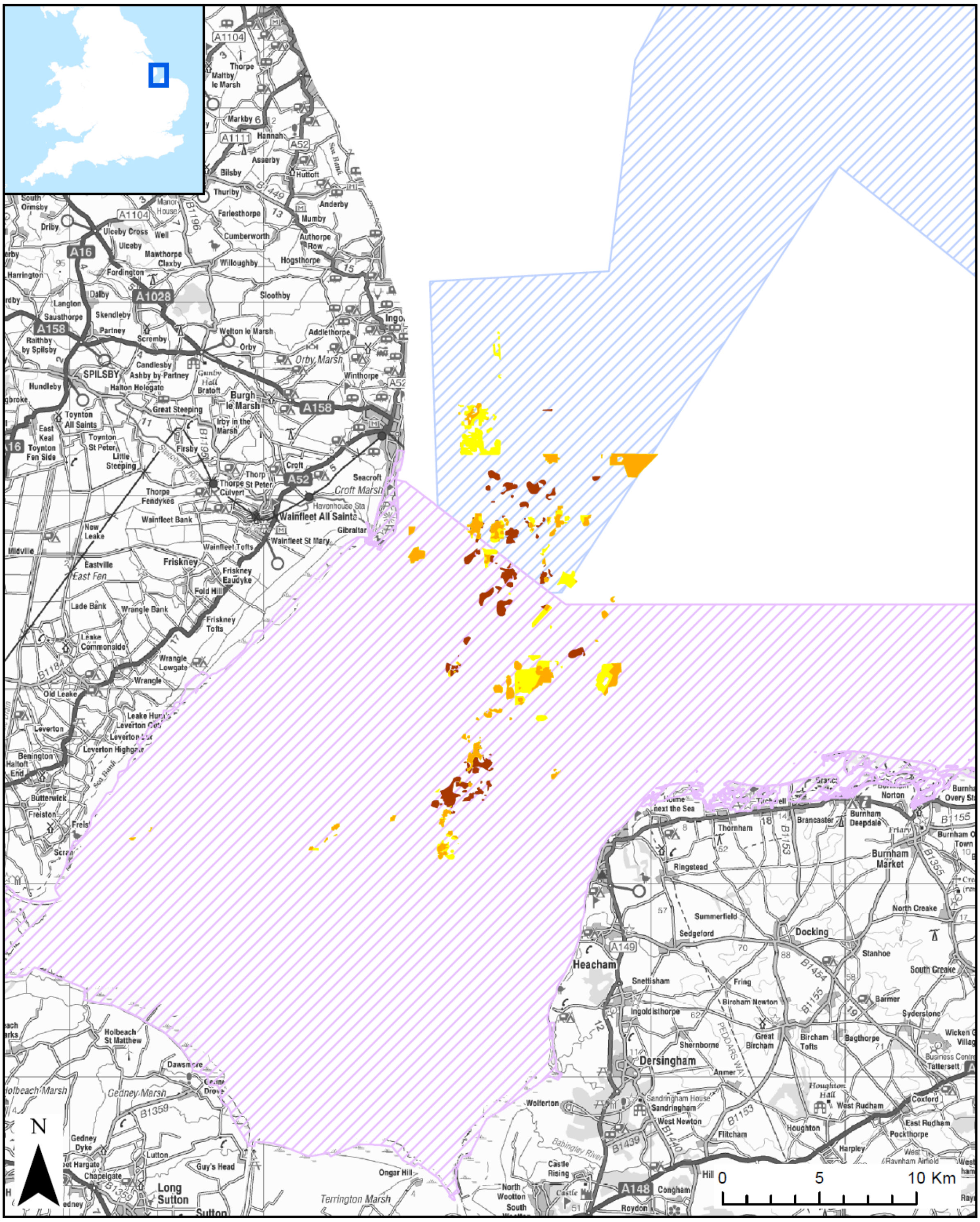
Scale (at A4): 1:250,000

Maps produced on 04/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure 17** The distribution of reef with a reef index ≥ 1.4 in the 2014 and 2010b syntheses




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Candidate Special Area of Conservation

Core Reef (reef index >=1.0)

2014 synthesis

2010b synthesis

2014 and 2010b synthesis

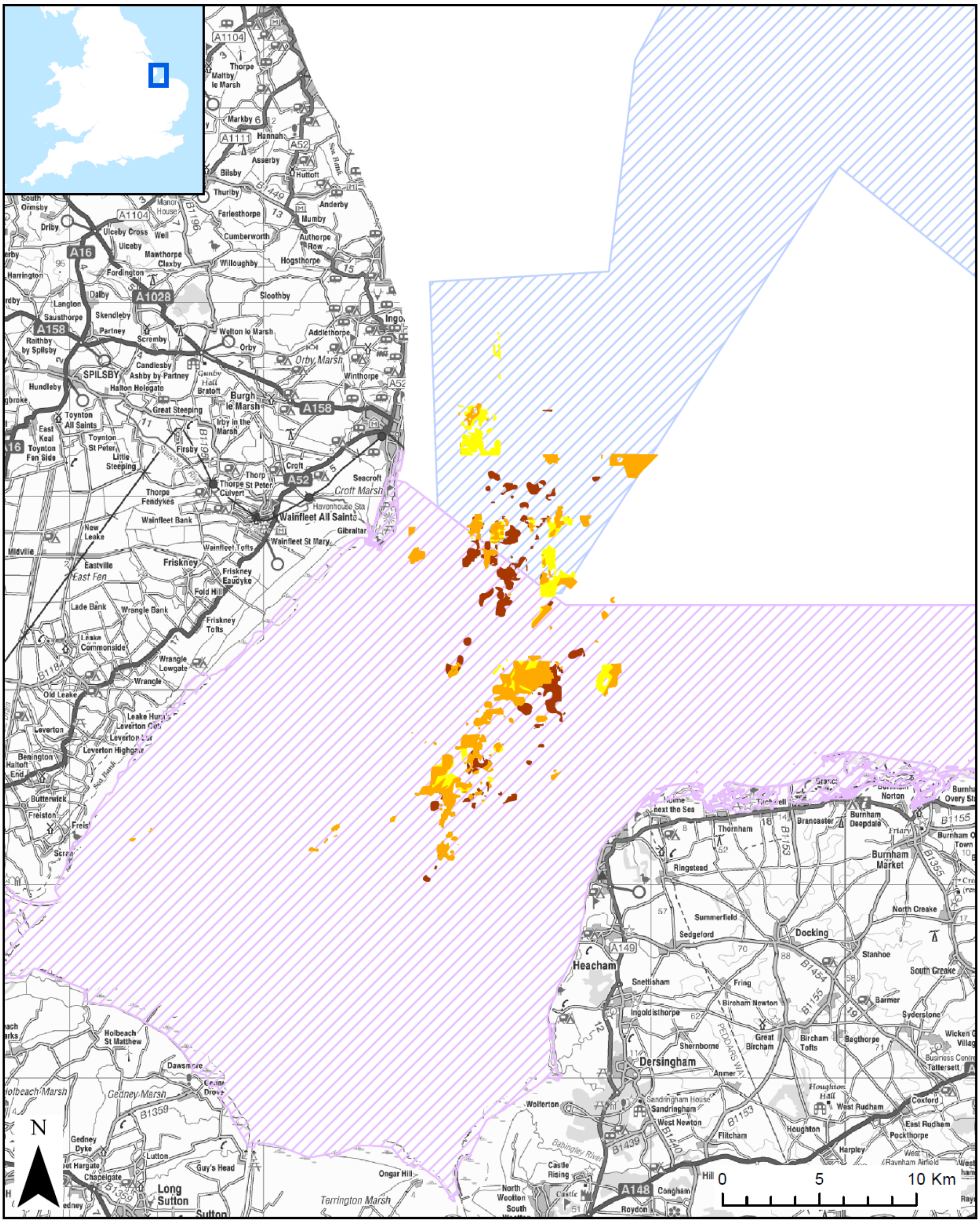
Scale (at A4): 1:250,000

Map produced on 04/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure 18** The distribution of reef with a reef index ≥ 1 in the 2014 and 2010b syntheses



Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Candidate Special Area of Conservation

Core Reef (reef index >=0.6)

2014 synthesis

2010b synthesis

2014 and 2010b syntheses

Scale (at A4): 1:250,000

Maps produced on 04/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

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**Figure 19** The distribution of reef with a reef index ≥ 0.6 in the 2014 and 2010b syntheses

**Table 9** Total area of core reef at a range of reef index values for each the 2010b and 2014 syntheses. Area of overlapping core reef between the two syntheses at different reef index values is given as well as the area of overlap as a percentage of the total core reef area in each syntheses.

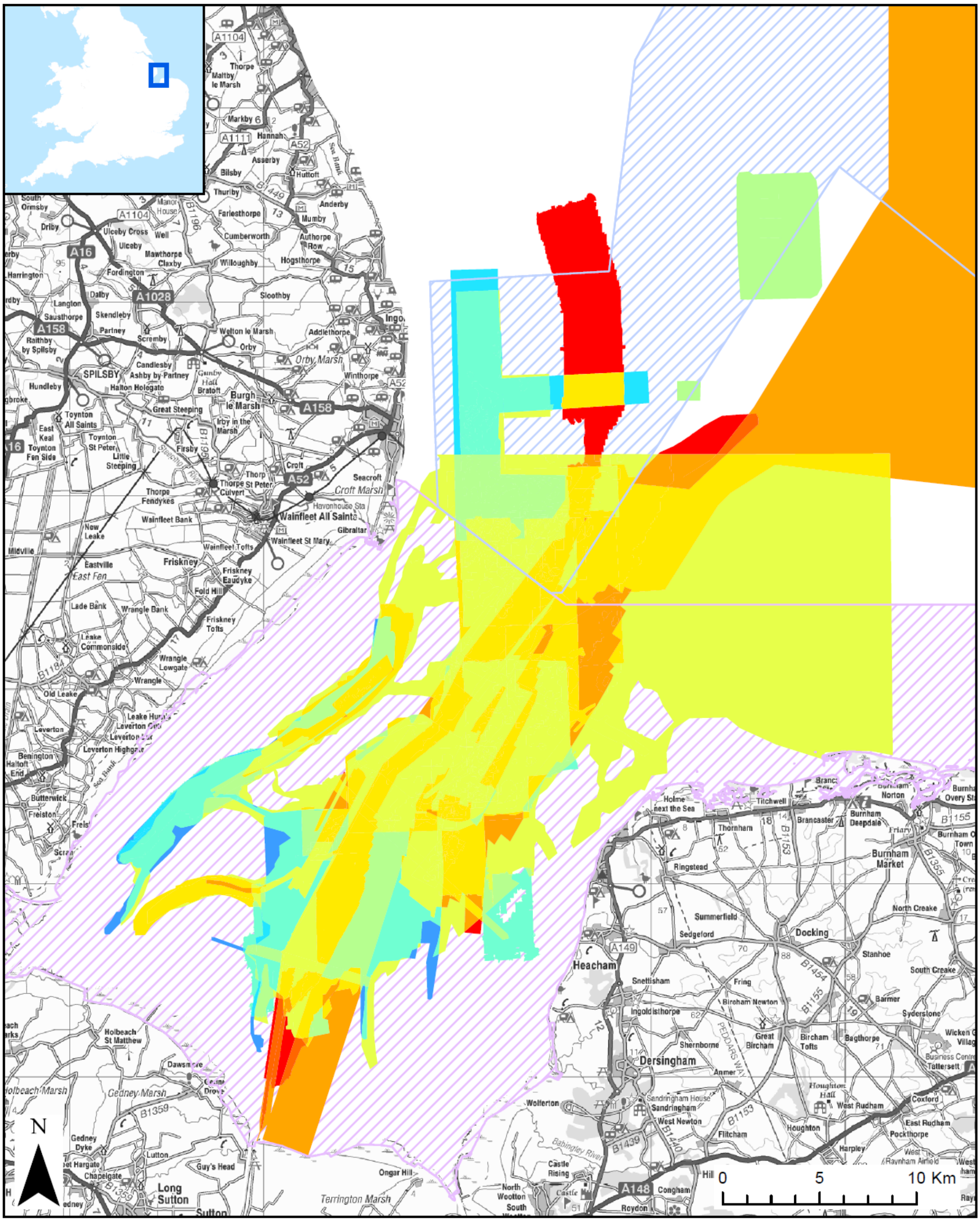
| Reef Index | Area core reef ($km^2$) (2010 synthesis) | Area of overlap as a % of core reef area of 2010 synthesis | Area core reef ($km^2$) (2014 synthesis) | Area of overlap as a % of core reef area of 2014 synthesis | Area ($km^2$) of core reef that overlaps between the two syntheses |
|---|---|---|---|---|---|
| **≥ 2** | 0.80 | 28.75 | 1.22 | 18.85 | 0.23 |
| **≥ 1.8** | 1.66 | 37 | 2.19 | 28 | 0.62 |
| **≥1.6** | 1.66 | 37 | 2.39 | 26 | 0.62 |
| **≥1.4** | 1.97 | 64 | 3.99 | 32 | 1.27 |
| **≥1.2** | 4.01 | 63 | 7.20 | 35 | 2.54 |
| **≥1** | 14.20 | 52 | 12.79 | 58 | 7.39 |
| **≥0.8** | 20.26 | 52 | 16.59 | 63 | 10.51 |

## MESH confidence - Comparison of 2014 and 2010b synthesis

3.22 The average MESH confidence score of all of the surveys used in the 2010b synthesis was 66.91, compared to 67.61 for all the surveys used in the 20114 synthesis, therefore demonstrating a very slight increase in average confidence.

3.23 The average MESH confidence scores varied between core reef (reef index ≥2) polygons and between the 2014 synthesis and the 2010b synthesis (Figure 18). Average MESH confidence scores for core reef polygons between the two syntheses shared a range of 53 to 72.

3.24 Average MESH confidence score for the surveys contributing to core reef (reef index ≥2) polygons identified in the 2010b synthesis was 61.25, compared to 62.27 for the surveys contributing to the 2014 core reef polygons, again demonstrating a very slight increase in average confidence.




Designation Boundaries © Natural England

The Wash and North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Scale (at A4): 1:250,000

Average MESH confidence score (2014 synthesis)

| | | | |
|---|---|---|---|
| 36.0 - 39.9 | 50.0 - 54.9 | 65.0 - 69.9 | 80.0 - 84.9 |
| 40.0 - 44.9 | 55.0 - 59.9 | 70.0 - 74.9 | 85.0 - 90.0 |
| 45.0 - 49.9 | 60.0 - 64.9 | 75.0 - 79.9 | |



**Figure 20** Average MESH confidence score associated with reef index polygons (2014 synthesis)

# 4 Discussion

## Formalising the GI methodology

4.1 The synthesis accomplished its first objective; successfully developing and formalising the core reef mapping methodology summarised in the 2010a synthesis by Bussell & Saunders. The methodology flowcharts produced (Figure 8) provide information that may be of use in future core reef mapping exercises, and if followed they would enable new data to be integrated with previous data collected analysed.

4.2 Within this methodology, the re-structuring of the attribute table has increased the ease with which the synthesis may be updated and makes data interrogation intuitive, notably allowing for the use of the ‘select by attribute tool’ to identify the influence of surveys on a given polygon. Furthermore, representing each survey with three distinct columns within the attribute table reduces the need for retrospective editing, allowing instead for a new survey to be standardised and then unioned as an addition to the master shapefile. The reef index can then be re-calculated without the need for any further manipulation of the attribute table, therefore simplifying the method and reducing the opportunity for errors to occur. Re-structuring the attribute table also allows the effect of a given survey to be swiftly elucidated by selecting to include or exclude it from the reef index calculation without having to remove it from the shapefile.

4.3 The designation of unique codes to each survey further simplifies the interrogation process providing a simple means of gaining full survey references from the information in each polygon. This reference guide can be expanded as new data become available.

4.4 The creation of a set of supporting documents serves as a working audit trail for the methodology. The inclusion of all necessary information regarding a given survey in a standard survey template provides a thorough reference document to maximise the flow of information and future proof the methodology against resource loss (see Appendix 1). Furthermore, the provision of the GI data files and a spreadsheet containing the scores received for each element of the MESH confidence assessment tool ensures that the methodology is both transparent and repeatable.

4.5 The aim is that the audit trail provided will maximise the utility of this approach, allowing it to be critiqued by users and adapted to future data and developments in scientific consensus.

## Updating the synthesis

4.6 The second objective of updating the core reef synthesis was achieved, as five new relatively high confidence datasets were incorporated into the synthesis using the newly formalised methodology.

4.7 The development of standards for the application of the methodology allows for the inclusion of future data, as they become available. Provided these standards are followed, future syntheses will be directly comparable with the current and other future syntheses. The need for a standardised methodology is highlighted in the difference observed between the 2010a and 2010b synthesis (Figure 9). Consistency in the assessment of surveys was maintained by the use of Gubbay (2007) criteria and MESH confidence assessments.

## Statistical analysis of reef spatial distribution

4.8 The results show that there is a strong spatial correlation between reef index and distance. This therefore suggests that the approach to calculating reef index results in outputs that are statistically significantly different to a random distribution, and as such it is an appropriate method for identifying areas which are important for *S. spinulosa* reef contributing to the status of *Sabellaria spinulosa* reef.

## Comparison of reef index distribution between 2010 and 2014 syntheses

### Reef extent

4.9 When comparing the presence and distribution of reef areas between the 2010b and 2014 syntheses, the total area of positive reef index (that is, areas within which reef has been identified) was found to have increased with the addition of new surveys demonstrating that despite a long term dataset there may be new areas suitable for supporting reef that are still to be identified (see Section 3.14 - 3.18).

4.10 The synthesis highlighted the need for caution when interpreting areas with a negative reef index (that is, those which were surveyed, but in which reef was not detected). Areas with increasingly negative reef index scores (for example -7) are intuitively less likely to be found to support reef in the future. However, it may be that environmental and or anthropogenic pressures which restrict reef formation occur in these areas. If so, and these pressures are altered, it may affect the ability of such areas to support reef. Widespread shrimping for brown shrimp, and to a much lesser extent for pink shrimp, occurs in these areas. The impact of shrimping on the formation of *S. spinulosa* reef is currently uncertain, but it may well confound the identification of areas which naturally are not suitable to support reef. EIFCA byelaw fisheries closures will be invaluable for gaining further understanding of the potential influence of anthropogenic activities on the distribution of reef. The 2014 synthesis highlighted areas of very low negative reef index within close proximity of those with high positive reef index. Caution must be applied in these bordering areas and also in the large areas of slightly negative reef index (for example 716km$^2$ with a reef index of -1). Although no reef has been found in these areas, they have only been surveyed once and therefore, it is quite likely that reef may be found there in the future (Figure 14).

### Core reef extent

4.11 Core reef extent (reef index ≥ 2) increased more than 50% between the 2010b syntheses and the 2014 synthesis. However, despite local differences in where core reef occurs, the areas identified as core in 2014 are primarily within the general area core reef has previously been identified in (i.e. as identified in the 2010a and b syntheses), giving weight to the core reef approach. For example, areas such as The Well and Lynn Knock remain important.

4.12 The core reef approach was developed due to the variable nature of *S. spinulosa* reef in order identify areas which consistently support reef and which would be appropriate for management to protect the feature. Approximately a fifth of the core reef (reef index ≥ 2) in the 2014 synthesis was in precisely the same location as core reef identified in 2010b (0.23 km$^2$). This is despite all but one of the 2010b core reef polygons having been surveyed again since, and so having a new reef index value. With the inclusion of the five new surveys then the distribution of approximately 4/5 of core reef was different (Table 8; Figure 16). This relatively large difference in the distribution of core reef occurrences may raise questions as to the appropriate scale of management in order to account for the variability in *S. spinulosa* reef distribution.

4.13 Possible causes of the change in core reef distribution are anthropogenic impacts, artefacts of the mapping methodology, limitations in the resolution of survey techniques, and the associated variable nature of *S. spinulosa* reef. Identifying causal relationships between *S. spinulosa* reef presence and anthropogenic pressures will assist in the evaluation of the core reef approach and determining its viability as a tool for identifying important areas of reef for management. These four potential causes are considered below:

1) Anthropogenic impacts:

*S. spinulosa* reef is associated with higher biomass of commercially important species (George & Warwick 1985; Fletcher and others 2012), increasing the likelihood that areas that support reef are used as fishing grounds. The fragile reef structures are vulnerable to trawling, which can damage and destroy reef (Limpenny and others 2010). A byelaw is currently in place to protect core areas of *S. spinulosa* reef within The Wash and North Norfolk Coast SAC, as identified by Bussell & Saunders (2010), from bottom towed gear. This byelaw closes fisheries activity using bottom towed gear in core reef areas and was established via stakeholder dialogue using the 2010a synthesis (EIFCA 2014). However, this did not come into effect until May 2014, meaning that core reef in both the 2010b and 2014 synthesis could have been impacted by anthropogenic fishing activities, as all of the data used pre-date the management byelaw. Without evidence, either in the form of appropriate fishing activity data or better still, experimental work to specifically assess the impact of trawling on reef, then the potential impact of fishing is difficult to evaluate conclusively. It has proved challenging to undertake experimental work due to the protected status of the reef and difficulty in finding suitable experimental habitat (for example Last and others 2012). However, monitoring of areas closed through the recent byelaws may provide insight into impacts.

2) Artefacts of the mapping methodology:

The comparison between the original 2010a and the 2010b syntheses shapefiles demonstrates that the GI methodology has the potential to bias outputs (Figure 9). However, this was carefully controlled for in the 2014 synthesis by resynthesizing the 2010a output (to create 2010b) with the updated shapefiles and MESH confidence scores. The 2010b and 2014 syntheses are therefore directly comparable and the GI methodology is deemed unlikely to have caused the differences in core reef occurrences.

3) Limitations of survey techniques:

Limitations in the resolution of survey techniques may influence the distribution of reef observed in each survey, and therefore confound the core reef distribution. *S. spinulosa* reef does not always give a clearly discernible acoustic signal. Ground truthing can prove equally challenging due to the sometimes patchy distribution of the reef meaning grab sampling risks not detecting reef in potentially suitable areas. Furthermore, in areas with low visibility, such as The Wash, drop down video may not give clear results. These issues restrict the ability to delineate reef with high confidence, which should be considered when interpreting the data. For each survey, factors such as density of ground truthing and method of delineating may be used to infer whether a survey is likely to over or underestimate *S. spinulosa* reef, as there is not a clear trend towards surveys all overestimating or all underestimating reef. In the case of the core reef synthesis, the areas which are identified as not being reef are as important to the final reef index value as areas which are positively identified as reef, meaning that confidence in identifying areas which are not reef should be as high as confidence in identifying areas which are reef. The majority of surveys are not designed with this in mind, and so this may confound results.

4) Variable nature of *S. spinulosa* reef:

Where the location of core reef occurrences are similar but not identical between 2010b and 2014 syntheses, this suggests that, despite slight differences, the areas in question are important, with the appropriate environmental conditions to support consistent reef presence. This is consistent with ‘pulses’ of reef appearing and disappearing over a number of years within close proximity of each other, which are reported in the minutes of a workshop held to discuss *S. spinulosa* management (Burton and others 2010). It is also consistent with current understanding of the variable nature of *S. spinulosa* reef.

4.14 It therefore seems likely that the small scale differences in the distribution of core reef are due to a combination of the limitations in survey resolution and the widely documented variable nature of *S. spinulosa* reef. Suitable environmental characteristics; naturally elevated turbidity and suspended sediment loads likely explain why core reef remains within the same vicinity but recurs in slightly different locations within that area. The surveys upon which the syntheses are based are snapshots in time of a dynamic marine system and as such, there will be inevitable change in reef distribution in line with shifts in sediment loading and turbidity (Last and others 2011). A key driving force behind developing the reef index was a need to understand some of this variability. That there is still variation in the location of core reef suggests that lower reef index values could be considered when defining core reef, and management considered on a larger scale in order to capture some of this variability and reduce the impact of the addition of new surveys. Such variation should be expected in the location and extent of core reef areas in future syntheses. The inclusion of future survey data will likely highlight new areas of core reef in the vicinity of current core reef or detect it in areas which have as yet not received sufficient survey effort to rule out their suitability for supporting reef.

4.15 With regard to the polygons where the reef index has moved above or below the threshold of core reef (reef index ≥ 2) between the 2010b and 2014 synthesis (see Section 3.8 - 3.10), the magnitude by which the reef index of these polygons has moved from the threshold is different for those which were core in 2010b to those which were core in 2014. Reef that was core in the 2010b synthesis but was not identified as core in the 2014 synthesis generally still had a reef index near the original threshold for core reef (for example 1.5, 1.8). Some of these polygons had been surveyed as many as three more times since the 2010b synthesis, meaning that if reef had not continued to be found there that the reef index value could have dropped by over half (see table 2). This suggests that the majority of these polygons still represent areas where reef regularly occurs, and are arguably important for reef. Conversely, for many polygons identified as core in the 2014 synthesis but was not in the 2010b synthesis, the reef index had increased from relatively low positive values in 2010 (for example 0.29, 0.3). This demonstrates that the addition of high quality data to the 2014 synthesis has highlighted areas of consistent *S. spinulosa* reef which had not previously been identified as being so in 2010a. The weighting of the reef index to account for survey effort ensures that these additional areas are not an artefact of probability but due to the inclusion of high quality data. Therefore, despite a ten year dataset being used in the 2010b synthesis, there remained unidentified areas within the existing area surveyed which are potentially important for consistent reef.

4.16 These findings suggest that the precise location of core reef within these supporting areas may be liable to change with the addition of further new datasets, although primarily remaining within the vicinity. Furthermore, the fact that some areas which previously had relatively low reef index scores are now above the core threshold, highlights the possibility that new important areas could still come to light with the inclusion of additional data. The slight increase in average confidence score associated with the core reef polygons (based on the MESH confidence score of each individual survey contributing to a polygon) suggests that as more datasets are added confidence increases and changes in distribution of core reef may decrease, reflecting the data in which confidence is highest. Although the increase in average MESH confidence score of the core reef polygons is very small (1.02) and caution should be taken before drawing conclusions from this, an increase in confidence is inevitable if high confidence datasets are continually added.

## Core reef thresholds

4.17 Changes in the patterns of core reef distribution between the 2010b and 2014 syntheses (as described in Section 4.11 - 4.16 above) raises the question of what reef index value should be used as a threshold for the identification of important areas. This should be discussed when reviewing current management measures, or developing future management.

4.18 Furthermore many of the core reef polygons are relatively small (width in the order of 100s of metres). This highlights that any uncertainty in the extent of reef delineated, due to the potential for reef to be over or underestimated, may influence the areas which are identified as core reef and further supports the notion that the core reef approach may be best used at broader spatial scale to account for any limitations in survey resolution.

4.19 Under present management conditions, reef index ≥ 2 is used to denote core reef in The Wash and North Norfolk Coast SAC, while a reef index ≥ 1.8 is used to denote core reef in Inner Dowsing, Race Bank and North Ridge SCI due to the limited data available. When a reef index value ≥ 2 was used, approximately 20% of the core reef was identified in the exact same location in both the 2010 and 2014 syntheses. Using a reef index ≥ 1.8, approximately 30% of core reef was identified in the exact same location in both the 2010b and 2014 synthesis. The increase in the area of reef identified as core in both syntheses continues to increase as the reef index threshold used decreases; however, the vicinities within which core reef occurs remains the same, reinforcing the idea of broader areas which are key to supporting reef (see Section 3.14 - 3.18).

4.20 As reef index values are lowered, then the extent of core reef increases but the distribution remains within the same broad regions and the proportion of core reef that overlaps between the 2010b and 2014 syntheses increases (Figs 14-17). This suggests that the use of a lower reef index may be an appropriate means of identifying broader areas which would result in more consistent core reef distribution. However, a reef index value of 0.6 only requires that reef has been found once after 5 surveys, yet when this is used as a threshold approximately a third of the core reef between the 2010b and 2014 synthesis does not overlap (Table 9). Therefore, complete consistency in which areas are identified as core reef is unlikely to occur due to the variable nature of *S. spinulosa* reef, and because the addition of new data will inevitably lead to changes in the areas identified as core reef.

## Wider implications and the application of the core reef methodology

### The core reef approach as a management tool in the Wash

4.21 Through the formalisation of the core reef mapping methodology, and the resulting mapped distribution of reef extent and core reef areas expected to support consistently occurring reef, the concept of using the reef index approach to inform management is supported. When faced with a habitat such as *S. spinulosa* reef, that is both variable and vulnerable, this tool is potentially invaluable. The synthesis has elucidated consistent regions (for example Lynn Knock and the Well (Figure 13 and Figure 14) that are important for *S. spinulosa* reef in The Wash. These core areas can be used to provide an evidence base for facilitating discussions about site management.

4.22 The outputs of the core reef synthesis are not prescriptive in what management would be appropriate, and should be interpreted in the context of the site and data they relate to. Where there are fewer datasets, then the core reef principles can be tailored to the data available before being applied, as was the case in Inner Dowsing, Race Bank and North Ridge SCI. In this example, limited data meant that areas which have been surveyed once and in which reef had been found once were included in management recommendations as these areas did not have enough survey coverage to be considered core reef.

4.23 However, movement of the distribution of core reef even within The Wash and North Norfolk Coast SAC suggests that closures which are delineated very tightly around areas of core reef may not always be appropriate, due to the variable nature of the reef and associated uncertainty in its location. It may be more appropriate to employ an approach whereby the core reef approach presented here could be used to identify wider areas, potentially using lower reef index thresholds, that are consistently important for supporting reef and apply adaptive management measures. The recurrence of reef within these vicinities would guard against unwarranted closures, whilst the larger area being protected would ensure the regions highlighted as important remain a suitable and realistic size for reef that is of ecological and conservation importance to develop. This would allow for natural variation in distribution and reduce conflict between the reef and anthropogenic activities, and would simultaneously facilitate research into the impacts of excluding anthropogenic activities from *S. spinulosa* reef.

## The core reef approach in other EMS's

4.24 The final aim of this report was to assess the appropriateness of this methodology for use in other EMS's. While the core reef approach has the potential to be of high value for application in other EMS's which support *S. spinulosa* reef*,* it is a challenging approach to apply in practice. A historic set of data with several high confidence surveys is fundamental to this approach. However, given the technical challenges of acquiring high confidence datasets, the associated costs (fiscal and temporal) and the competitive nature of research proposals, it may not always be feasible to build as large an evidence base as exists for The Wash. Data availability in The Wash is strong due to collaboration and data sharing with industry. Whilst other EMS's are in the process of adding to their evidence base, The Wash and North Norfolk Coast SAC data could provide lessons learnt around the type of datasets most useful when applying the core reef approach methodology. For example, broad scale surveys provide a solid starting point from which to identify areas which are more likely to support *S. spinulosa* reef. These can then be targeted with more intensive surveys in order to achieve higher confidence delineation of *S. spinulosa* reef. Despite this, challenges inherent to delineating *S. spinulosa* reef remain.

## The use of the core reef approach to develop models to predict reef habitat

4.25 The occurrence of new core reef in the vicinity of previous areas of core reef, but not overlapping, may be due to environmental conditions in the area being particularly suitable for the development of *S. spinulosa* reef. Many of the areas where reefs were found exhibit similar environmental characteristics; namely sandy and gravelly sediments providing a stable attachment surface, naturally elevated turbidity and suspended sediment loads (McIlwaine and others 2014; Ke and others 1996). This is consistent with where reef would be expected to occur based on its ecology (Last and others 2011) as these currents may provide the suspended sediments that the *S. spinulosa* worms need to build their tubes. However, this pattern of 'shifting' areas of core reef may also be due differences in sampling resolution or changes in human activities impacting the feature, and further investigation would be required.

4.26 This provides potential for core reef outputs to be compared with relevant environmental parameters, in order to form the basis for modelling the likely occurrence of *S. spinulosa* reef. There is some data available on such parameters. For example, the Humber Regional Environmental Characterisation has compiled and reviewed evidence on hydrography and sediment dynamics (Tappin and others 2011) that may be suitable. These types of data have previously been effectively used with ecological surveys to develop benthic habitat models (Limpenny and others 2011).

4.27 If a robust model was developed, this could prove to be a valuable aid in areas where a paucity of data makes the application of the core reef approach unfeasible. It would also provide a less resource-intensive platform to apply the core reef findings to other EMS's for reef management.

4.28 When developing a model, potential sources of bias from anthropogenic impacts would need to be considered. If more was learnt about the impact of fisheries on *S. spinulosa* reef distribution from closed areas then this could be invaluable for reducing this bias.

## Limitations and uncertainty in the outputs

### Confidence in evidence

4.29 Despite the robustness of the core reef approach, outputs will only ever have the associated confidence of the data that is input. These data are rarely in raw form, and therefore, there are limitations on its interrogation. All of the surveys incorporated in the syntheses were subject to MESH confidence assessments and so were deemed to be of an appropriate standard. However, there are distinct challenges associated with surveying *S. spinulosa* reef (Chapter 1), such as difficulties differentiating the acoustic signal of low elevation, patchy reef from that of the surrounding seabed. Where reef is patchy, then ground truthing alone can confirm the presence of reef, but cannot confidently confirm an absence of reef, due to the possibility of such targeted sampling missing patches of reef. Furthermore, data collection is extremely resource intensive. These factors therefore limit the evidence available.

4.30 Surveys are often designed to map areas where a habitat is based on the evidence of its presence. The core reef approach is relatively unusual in that areas where the habitat have not been found have as much of an influence on the final output as the areas where it has been positively identified. It therefore needs to be considered when reviewing data whether the confidence in the absence of reef is as great as the confidence in its presence.

4.31 There remains a certain level of subjectivity to the MESH scoring methodology. The adaptation of the scoring criteria to apply specifically to *S. spinulosa* reef has minimised subjectivity. However, the scores used in the synthesis have only been standardised within the context of this project, and therefore cannot be compared to confidence assessments attributed to surveys through other projects. This limits the ability to draw wider conclusions about data confidence.

4.32 *S. spinulosa* reef is naturally variable, may be influenced by anthropogenic activities, and is challenging to delineate with confidence leading to potential over and under estimation of reef extent. However, we have a poor understanding of how these factors affect the distribution of *S. spinulosa* reef we observe. This makes it challenging to tease apart the influence of these different factors, meaning inherent uncertainty in our understanding of *S. spinulosa* reef remains. In some cases, such as two high confidence surveys in quick succession in an area with limited anthropogenic activity, then it can be assumed that survey confidence and anthropogenic impacts have been controlled for as far as possible and so any changes observed are likely to be natural variation. However these factors should be considered carefully when drawing conclusions.

### Uncertainty in the core reef approach

4.33 The variable nature of *S. spinulosa* reef means that a high reef index indicates that an area is *likely* to support reef, but does not indicate that it will definitively support reef at a given moment in time. Several areas with high reef index values have been surveyed on some occasions and found not to support reef. For example, 11 out of the 42 core reef polygons from the 2014 synthesis have been surveyed eight times but reef was only identified on four of these occasions, leading to a reef index value of two. This means that caution must be used when drawing conclusions about where reef does not occur; a slightly negative reef index does not mean reef will not be identified on future surveys. Due to surveys targeting areas where reef is known to occur, there are large areas with a slightly negative reef index which might be suitable for supporting reef but have not been adequately surveyed. The identification of areas which are not likely to support reef may be further confounded by anthropogenic impacts causing areas which are theoretically suitable for reef development to not currently support reef. Equally, if a future survey covers an area of core reef and does not find reef, this does not mean that the area was incorrectly identified as core, as there may still be a high probability of reef occurring there in the future.

## Implications for the use of the core reef approach

4.34 There is clearly a degree of uncertainty that is inherent to *S. spinulosa* reef mapping. However, uncertainty stemming from the challenges associated with mapping *S. spinulosa* reef, the variable nature of the reef, and from limitations in our understanding of influence of anthropogenic activities would apply to other approaches to map *S. spinulosa* reef. Although any of these factors may influence how much confidence we can have in the identification of reef in a given area from a given survey, the fact remains that if several surveys have identified reef in the same location that our confidence that reef occurs in that area is increased. While these causes of uncertainty should be considered when drawing conclusions from the synthesis, the core reef approach still represents a significant advantage in limiting the impact of these uncertainties through identifying areas where reef has most consistently been found and so controlling for uncertainty as far as is possible.

4.35 To limit the influence of these causes of uncertainty in any decisions made, it is crucial that the outputs of the reef index synthesis are fully interrogated during any decision making process. For any polygon, the Identify tool can be used to discern the exact reef index value of the polygon, the surveys which contributed to the reef index value, and the MESH confidence score of those surveys. The higher the reef index value of a polygon, the more confidence we can have that the location is likely to support reef, while the MESH confidence scores of surveys gives an indication of relative confidence in the survey techniques. Furthermore, the unique survey codes can be used to identify the relevant survey summary in Appendix 1, which provides a description of the survey techniques used, thus further informing interpretation.

4.36 The use of the core reef approach, which to date is based upon data of variable quality, is not a substitute for the collection of higher quality data and, despite being a useful approach it is not the only method upon which decisions on *S. spinulosa* reef distribution should be based and may not always be the most appropriate. The core reef approach is a tool, within a suite, which has proven effective and adaptable in the mapping of *S. spinulosa* reef given the current availability of data.

# 5 Future work

5.1 Consider adaptive management of *S. spinulosa* reef at broader spatial scales in order to encompass the difference in distribution of core areas observed between the 2010b and 2014 syntheses. This requires the applied reef index threshold to be lowered, resulting in a higher percentage of the reef extents to overlap between the datasets (as detailed in Section 3.14 - 3.18). This larger area therefore better accounts for the variable nature of *S. spinulosa* reef and allows development of reef in areas that contain suitable habitat conditions and have persistently supported reef.

5.2 The core reef approach can be used as a tool under an adaptive management approach. This is a precautionary but proportionate approach which acknowledges uncertainty in feature extent and sensitivity through providing sufficient protection to ensure site integrity is maintained without disproportionately restricting the fishery. Closed areas are then monitored to better understand how the feature responds in the absence of fishing pressure, and the management measures can be reviewed and adapted as appropriate based on the monitoring outcomes. Starting a management cycle with a lower reef threshold would also be conducive to obtaining a better understanding of natural movement of reef and its maximum potential extent. This is due to a lower likelihood of reef being impacted and restricted in its potential to vary and expand at its periphery

5.3 As part of an adaptive approach, data from monitoring of EIFCA byelaws should be incorporated into the interpretation of reef distribution data. Incorporating data from areas that are excluded from human interference, will aid in understanding the level to which human activities are causing observed changes in reef distribution. Starting a management and monitoring cycle with lower reef thresholds (and therefore larger closed areas), should also help to achieve this aim and provide greater certainty on the level of anthropogenic impacts to natural development of reef.

5.4 Develop a robust model of the likely occurrence of *S.spinulosa* reef by using relevant environmental parameters that have been shown to influence the formation of *S.spinulosa*. Such a model could provide a less resource intensive platform to apply the core reef findings to other EMS’s for reef management, and to focus initial surveys.

# 6 Conclusions

6.1 This synthesis successfully standardised and built upon the core reef mapping methodology developed by Bussell & Saunders in the 2010 Wash *Sabellaria spinulosa* synthesis. The methodology allows for new data to be incorporated into the results with ease, and by re-formatting the data used in the 2010 Wash *Sabellaria spinulosa* synthesis, this report updated The Wash core reef synthesis so that comparisons could be drawn.

6.2 The overall extent of core reef (reef index ≥2) between the two syntheses is comparable, with only an additional 0.42km$^2$ of core reef found in the 2014 synthesis. However, it also shows that the distribution of core reef was different between the two syntheses. This has important implications for management, as despite scoring high reef index values, these core areas are still subject to the variable nature of *S. spinulosa* reef. However, despite the differences in occurrences of core reef, it generally remained within the same vicinity suggesting wider areas which are particularly suitable for supporting reef. This has important implications for discussions about site management, as management could be targeted at this broader scale, rather than tightly aligned around core reef outputs.

6.3 When considering the use of the core reef mapping methodology in other EMS's it is important to consider the availability of data in that area. The area covered by this synthesis benefits from a historical dataset covering sixteen years, yet even so, variability was found in the extent and distribution of reef. The methodology is not prescriptive and can be used flexibly to accommodate the data available. However, the feasibility of developing a sufficient evidence base should be considered when assessing the appropriateness for application in other EMS's.

6.4 The outputs of this synthesis may also be useful when used in conjunction with environmental data and hydrodynamic models to develop predictive models of areas which are favourable for the formation of *S. spinulosa* reef. These models could provide valuable insight into the likely presence of *S. spinulosa* reef and be used to inform management where there is less survey data available.

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# Appendix 1 Survey Templates used in the Synthesis

## Appendix 1.1 FOSTER-SMITH, R.L. and SOTHERAN, I. 1999

### Data source (report title):

FOSTER-SMITH, R.L. and SOTHERAN, I. 1999. Broad scale remote survey and mapping of sub-littoral habitats and biota of the Wash and the Lincolnshire and North Norfolk Coasts. SeaMap, Newcastle University.

### Year data collected:

- 1996 - The Wash
- 1997 - The Wash, North Norfolk and the Lincolnshire coast
- 1998 - North Lincolnshire coast.

### Data summary:

The Broad Scale Mapping Project (BMP) was designed to test a methodology for surveying and mapping distribution of habitats and biota of large areas of sea floor. Finding *S. spinulosa* reef was also a specific output. The project created maps by assigning maximum likelihood to AGDS and ground truth data allowing confidence to be estimated. The survey was completed over 1996, 1997 and 1998. Many biotopes could only be described from the analysis of animals and sediments collected using Day Grabs. Biotopes with an epifaunal component due to presence of rock or *S. Spinulosa* were more effectively sampled using remote video.

Evidence for the Wash was mapped with a fair degree of confidence, while north Lincolnshire was mapped with much less confidence due to wide track spacing and the limited number of ground truth samples. The AGDS data in the form of point data were logged together with time and position as the vessel tracked over the survey area. Point data were used to create continuous digital images. 1998 data, including widely spaced gridded values were combined with the 1996 and 1997 data. A second interpolation of this dataset was carried out using the smaller grid spacing of 100m and smaller search radius of 1.5km.

**1996 -** The Wash area was surveyed in detail using RoxAnn™.

**1997 -** The Wash, North Norfolk and the Lincolnshire Coast, The Wash was again partially re-surveyed but the emphasis was on the areas off the south Lincolnshire and north Norfolk coasts.

**1998 -** North Lincolnshire coast, surveyed by RoxAnn™ unit which worked reliably but was limited to operating in waters shallower than 30m, therefore with respect to deep Silver Pit area off the Lincolnshire coast this survey used the SeaMap unit on a Newcastle University vessel. Results from both the SeaMap and ESFJC RoxAnn™ systems were comparable after standardisation and thus allowed an amalgamation of the data.

The *S. Spinulosa* found was associated with diverse communities even if in low abundance with highest species diversity of samples found associated with *S. spinulosa* reefs. The *S. spinulosa* biotope was subdivided into more detailed biotopes suitable for the local dataset. *S. spinulosa* only positively identified in substantial reefs close to area 107, probably only because reefs can only be positively identified from video and visibility was too poor for deployment of video in much of The Wash.

## MESH Confidence Assessment:

### Remote sensing:

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: AGDS Track spacing was greater than 100m and surveyed an area of moderate heterogeneity (entire area of the Wash and Lynn Knock). **MESH-1**
- Positioning: Used differential global positioning system (DGPS). Due to poor public service DGPS coverage of the UK, differential capability wasn't always available. Positional accuracy varied from 15-50m. **MESH-3**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 1996, 1997 and 1998 therefore over 12 yrs old. **MESH- 1**

### Ground truthing:

- Technique: Ground truthing consisted of day grabs, trawls, dredges and video. *S. Spinulosa* extent and populations density assessed and used to identify *S. Spinulosa* biotopes. **MESH-1**
- Positioning: dGPS used. **MESH-3**
- Density: Every habitat class in the habitat maps was ground truthed at least 3 times. **MESH-3**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 1996, 1997 and 1998 therefore over 12 yrs old. **MESH-1**

### Data interpretation:

- Ground truthing interpretation: Expert interpretation and we have the data that was used to inform their reef assessment. **MESH-3**
- Remote sensing interpretation: Ground Truthing used to inform maximum likelihood analysis. Supervised classification of images derived from interpolation of AGDS track data. **MESH-3**
- Detail: Reef assessment relied up on the assessing reef extent only. **MESH-1**
- Map Accuracy: Report received external QA. **MESH-3**

## MESH Confidence Score: 67

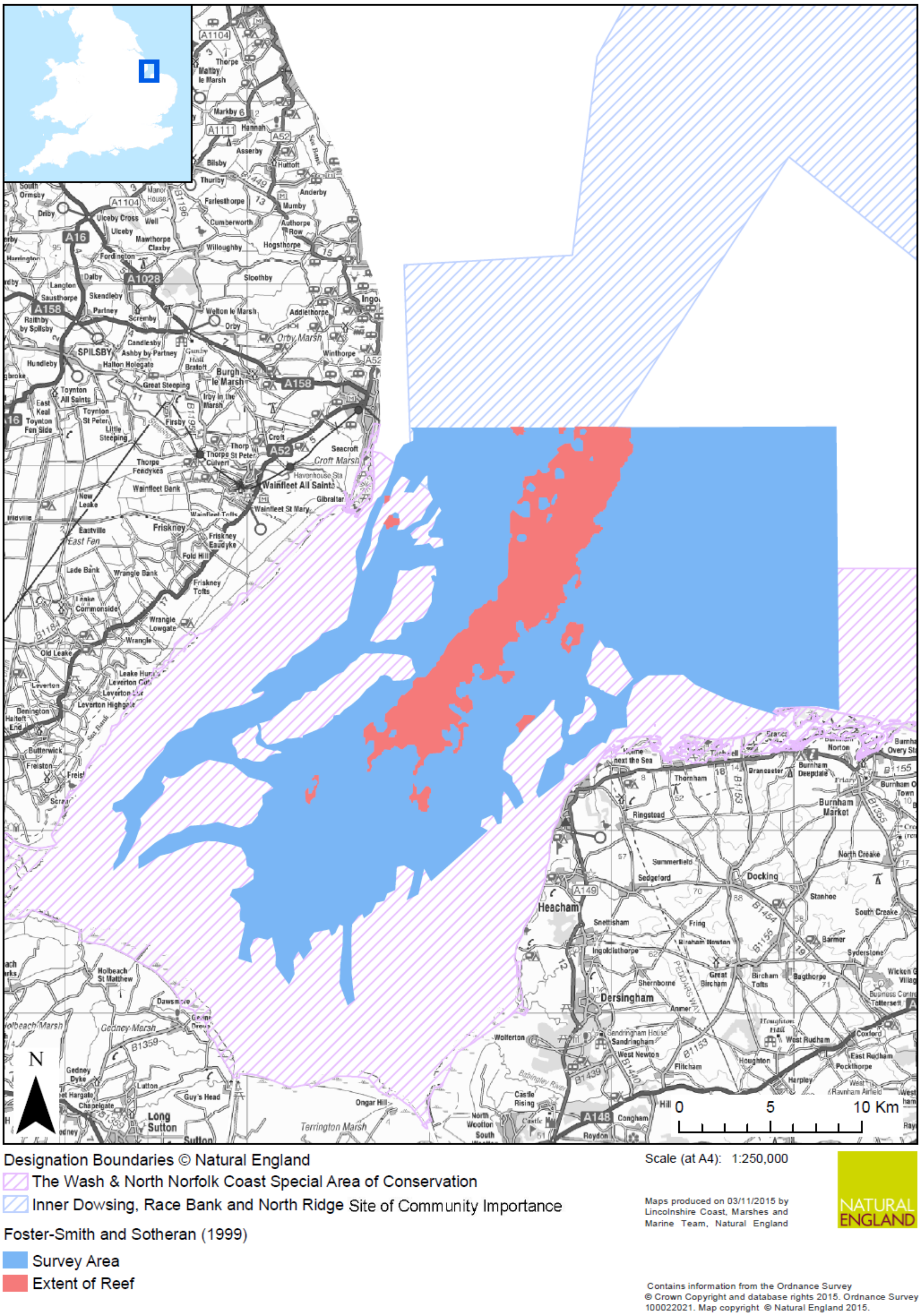



**Figure A** Foster-Smith and Sotheran (1999) survey area and reef extent

# Appendix 1.2 FOSTER-SMITH, R.L. 2000

### Data source (report title):

FOSTER-SMITH, R.L. 2000. Establishing a monitoring baseline for The Wash subtidal sandbanks.

### Year data collected:

1999

### Data summary:

This survey aimed to establish a baseline for monitoring in the Wash, focusing on sandbanks. The survey was therefore designed with the feasibility of continuation in subsequent years in mind. It therefore prioritised temporal resource availability over optimal techniques. It was targeted according to previous survey results, and comparisons were made with previous data. As a high level baseline, the survey aimed to produce broadscale predictive maps rather than accurate biotope extents, and so neither the acoustic survey or ground truth sampling were sufficiently intense to produce higher accuracy data. No Gubbay (2007) scores were applied, so although high abundance of *S. spinulosa* was mapped, there is no reef data as such and it does not appear reef was found. Bussell & Saunders recommend Fig 4.1 is scanned and geo-referenced to produce an effort layer.

The 200kHz RoxAnn ™ AGDS was used to survey four transects (four tracks, 120m spacing, giving 360m width); positions were based on previous data in order to represent the variety of ground types in the Wash. dGPS was used for positioning. Ground truthing was not extensive; rapid ground truthing was undertaken using video and day grabs with sediment sampled and conspicuous species being noted. Eight stations were chosen for a second ground truth survey, comprising triplicate grabs for infaunal analysis, one for sediment sampling, as well as three 200m chain dredge tows being carried out on three of the transects (outermost was too stony).

Standards – Methods produced by the UKHO were used to provide depth corrections. The data was cleaned using an automatic procedure to flag points for potential deletion. E1 and E2 readings from >40m were all removed and those between 35-40m inspected as RoxxAnn ™ was set for shallower water.

Data were also examined for standardisation and confidence purposes. Ground truth sites were given biotope codes based on BMP report and UK marine biotope classification, although these could vary with different interpretations of videos, so species abundance was analysed using PCA.

GI data – AGDS track point data was interpolated to give a continuous coverage. Maximum likelihood analysis used to interpret sediment type / biotope classification from the AGDS data. Large display and search distances were used in the interpolation method, although this ensured that if a buffer with a radius of 50m was created around each ground truth point then this would fall well within the transect zone. All of the acoustic values within the GT buffers were selected and an acoustic signature for that sediment / life form type was determined.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: RoxAnn™ AGDS. **MESH - 1.5**
- Coverage: AGDS track spacing was 120m apart and surveyed an area of moderate heterogeneity (central Wash). **MESH - 1**
- Positioning: Used differential global positioning system (dGPS). **MESH - 3**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH - 2**
- Age: Data collected in 1999 and therefore over 15 years old. **MESH - 1**

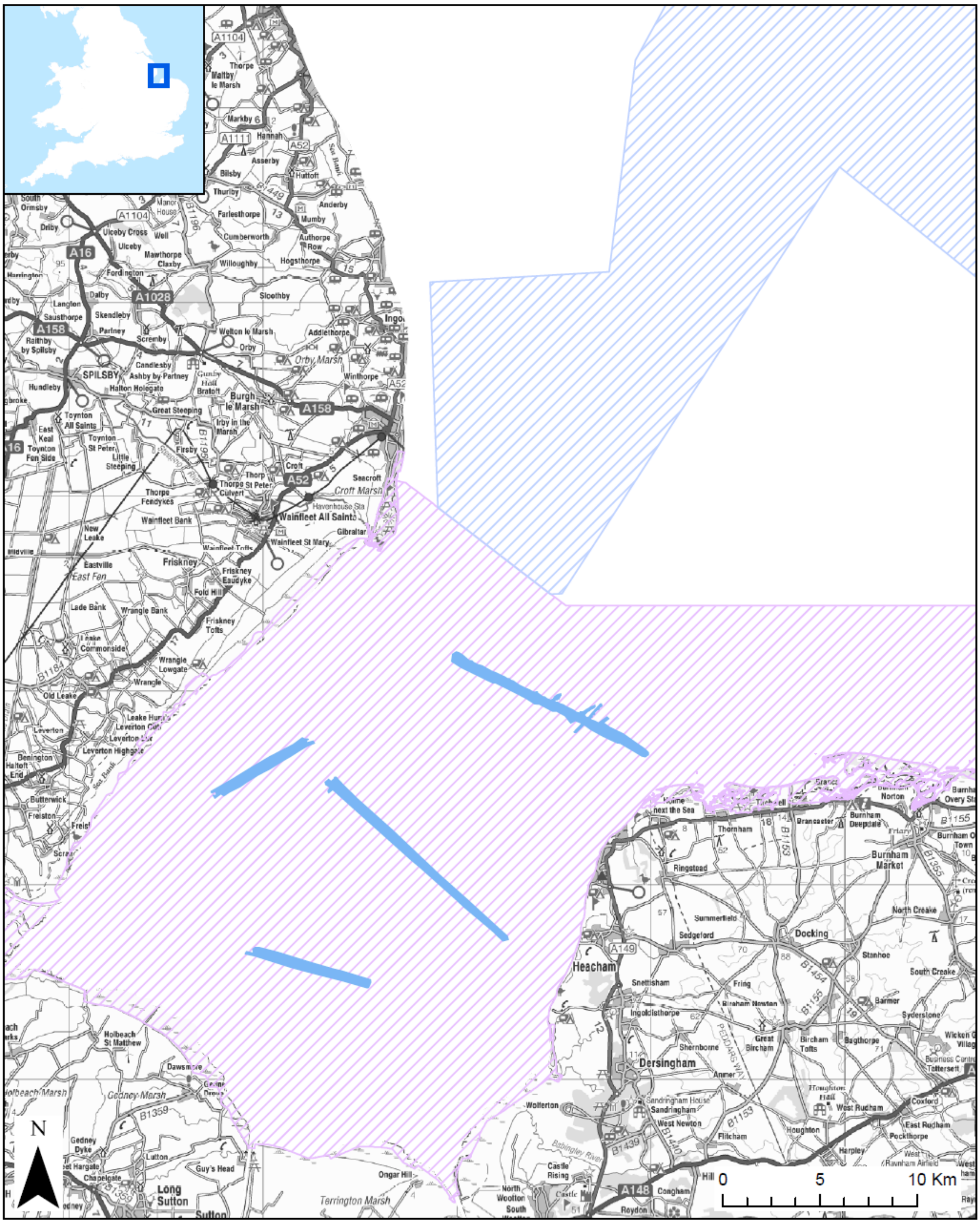
**Ground truthing:**

- Technique: Ground truthing consisted of day grabs, dredge and video tow. While no reef was found and the report does not explicitly discuss the methods it followed for reef identification, *S. spinulosa* density was recorded and it is likely that reef extent was assessed using RoxAnn. **MESH-1**
- Positioning: dGPS used. **MESH - 3**
- Density: Eight locations were selected for monitoring on each of the four transects. At each sample station three grab samples were taken for infaunal analysis and one for sediment analysis. Tows, video and rapid GT phase were also conducted. GT regime was broadscale. **MESH – 2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH – 2**
- Age: Data gathered in 1999 and therefore over 15 years old. **MESH - 1**

**Data interpretation:**

- Ground truthing interpretation: Expert interpretation and we have the data that was used to inform their reef assessment. **MESH – 3**
- Remote sensing interpretation: Ground Truthing used to inform maximum likelihood analysis. **MESH – 3**
- Detail level: Report does not explicitly discuss the methods it followed for identifying reef, *S. Spinulosa* density was recorded and it is likely extent of reef would have been assessed using RoxAnn™. Survey was conducted pre Gubbay criteria. **MESH – 1**
- Map accuracy: Natural England commissioned the report. Data analysis was contracted to SeaMap, assuming internal QA, followed by external QA. **MESH – 3**

**MESH Confidence Score: 65**




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Foster-Smith (2000)

Survey Area

Extent of Reef

Scale (at A4): 1:250,000

Maps produced on 03/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure B** Foster-Smith (2000) survey area and reef extent

# Appendix 1.3 FOSTER-SMITH, R.L. and WHITE, W.H. 2001

### Data source (report title):

FOSTER-SMITH, R.L and WHITE, W.H. 2001*.* *S. spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part I, mapping techniques and ecological assessment. A report for the Eastern Sea Fisheries Joint Committee and English Nature. English Nature Research Report Number 545.

### Year data collected:

2000

### Data summary:

The report assessed the relative merits of using AGDS and sidescan sonar for mapping the distribution of *S. spinulosa* reef. The report also compared two types of AGDS units, QTC and RoxAnn. In addition, ground truthing was conducted in the form of videos and day grabs (twenty two video samples and five stations of five replicate grab samples were taken). The data was collected as knowledge of what constitutes reef was evolving and the presence of *S. spinulosa* reef was recorded in ground truthing through video sample observations. Data was gathered from two areas: Long Sands within The Wash and aggregate extraction Area 107 in The Greater Wash (Figure 2 on p. 18 shows survey effort). Track spacing is variable but not reported. AGDS was gathered at a broad scale level, with targeted AGDS and SSS within this where reef was detected. No reef was detected in Long Sands despite anecdotal evidence of previous video footage from ESFJC data earlier in the year but techniques were considered to be fallible due to high turbidity and high currents etc. Direct observation using video confirmed that reefs existed in Area 107 in locations where it was previously observed in 1997. However, while the SSS image for Area 107 also suggested the presence of reef, the extent of the feature could not be delineated from surrounding seabed features (see Figure 9).

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: AGDS (QTC and RoxAnn™) and SSS. Report does not state the frequency of SSS used. **MESH-2**
- Coverage: Not reported but variable. AGDS was gathered at a broad scale level, with targeted AGDS and SSS (figures 5 and 8 suggest 100% coverage) within this where reef was detected. Survey located in the central Wash therefore given heterogeneity value of moderate. **MESH-1**
- Positioning: Not reported. GPS assumed. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2000 therefore over 12 years old. **MESH-1**

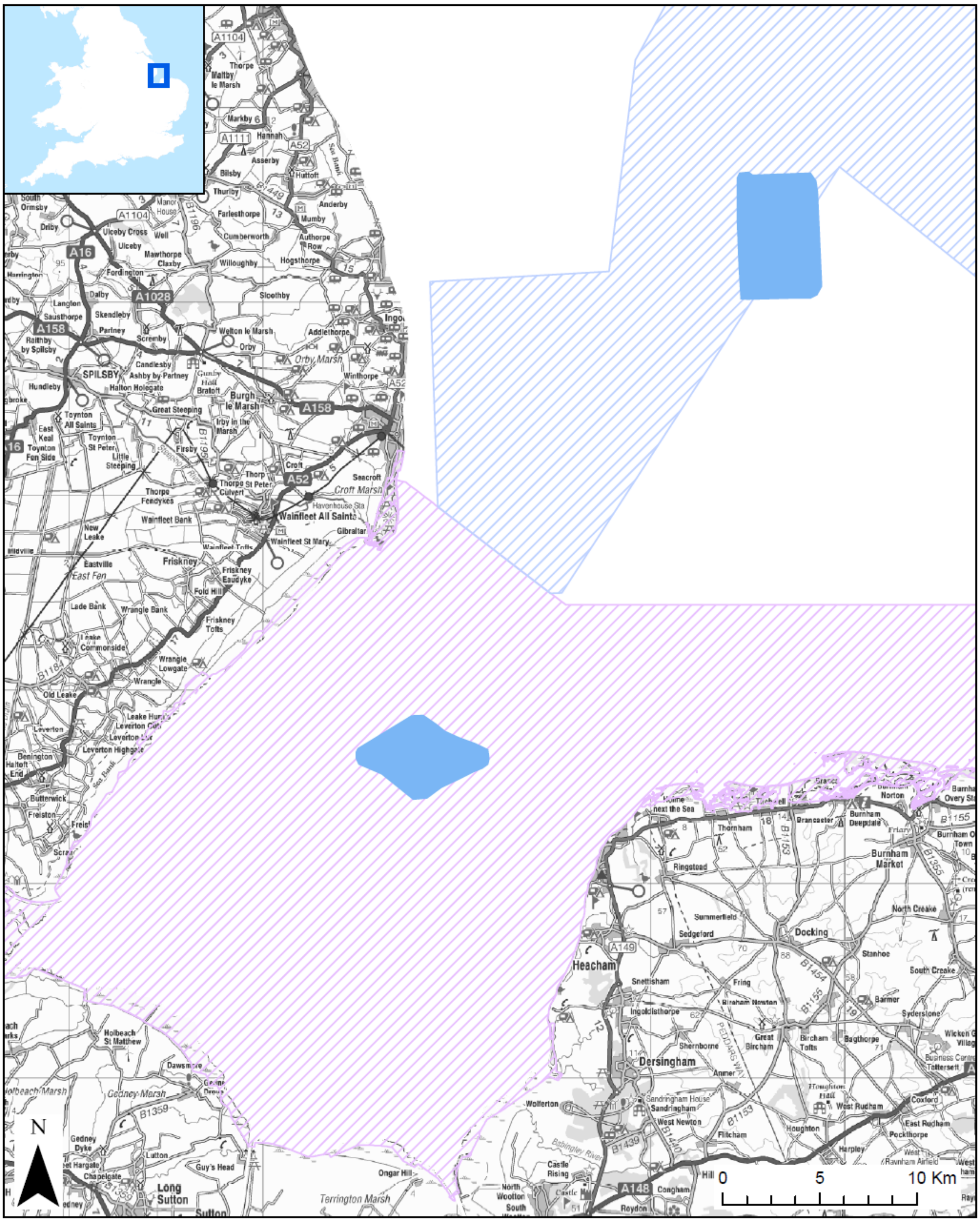
**Ground Truthing:**

- Technique: Ground truthing consisted of Video and day grabs. No specific Gubbay (2007) criteria applied, *S. spinulosa* identified via visual identification of video samples**. MESH-1**
- Positioning: Not reported. GPS assumed. **MESH-2**
- Density: Every habitat class in the habitat maps was ground truthed at least 3 times. **MESH-3**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2000 therefore over12 years old. **MESH-1**

**Data interpretation:**

- Ground truthing interpretation: GT interpreted by scientific organisation but data used for reef assessment not provided. **MESH-2**
- Remote sensing interpretation: SSS has been interpreted using round truthing but raw ground truthing data not provided. Ground truthing used in supervised classification of interpolated AGDS map. **MESH- 2.5**
- Detail: Survey conducted prior to Gubbay (2007) criteria. Survey inferred reef from direct observation using video. **MESH-1**
- Map accuracy: Report received external QA. **MESH-3**

**MESH Confidence Score: 56**




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Foster-Smith and White (2001)

Survey Area

Extent of Reef

Scale (at A4): 1:250,000

Maps produced on 03/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure C** Foster-Smith and White (2001) survey area and reef extent

# Appendix 1.4 FOSTER-SMITH, R.L. 2001

### Data source (report title):

FOSTER-SMITH, R.L. 2001. *Sabellaria spinulosa* reef in The Wash and North Norfolk Coast cSAC and its approaches: Part II, fine scale mapping of the spatial and temporal distribution of reefs and the development of techniques for monitoring condition.

### Year data collected:

2001

### Data summary:

This survey aimed to identify the distribution of *S. Spinulosa* in selected survey boxes along a transect running from the Inner Wash to further offshore outside the SAC. In addition, it aimed to test techniques by assessing the application of different acoustic survey and ground truthing methods for identifying and measuring *S. spinulosa* reefs at different stages in development.

The survey design was based on stratified and nested sampling of selected sites based on broad scale predictive maps from the BMP project and more recent surveys. RoxAnn™ was used as a real-time prospecting tool to identify particular ground types, the purpose of the classification of the remote data was to interpret using supervised classification techniques and not define the acoustic characteristics of biotope ground. SSS was used alongside the AGDS.

Using historic broadscale surveys, areas likely to support *S. spinulosa* were identified. Sites were placed along a transect from the inner Wash to Long Sands/Lynn Deeps to outside the cSAC boundary. Areas were re-surveyed using RoxAnn™ to refine the selection and positioning of box sampling areas. Sampling was stratified within the boxes. Remote sensing techniques were used to detect spatial structures at a fine scale within super-quadrats.

The super-quadrats had sides of 1km. Ten grab samples were collected randomly from selected stations (but accurately located within 50m) within the boxes which were assessed visually for reef development. Grab sample stations were also sampled with drop down video which could not only assess the physical scale of reef development but also be used to gauge the patchiness of the biotopes at a broader scale than the grab sample. Acoustic techniques were also used to try and obtain broad coverage of the boxes (AGDS and sidescan).

### MESH Confidence Assessment:

#### Remote sensing:

- Technique: AGDS and sidescan run together, sidescan frequency not reported. **MESH-2**
- Coverage: AGDS Track spacing was 200m and surveyed an area of moderate heterogeneity (central Wash). **MESH-1**
- Positioning: dGPS used. **MESH-3**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2001 therefore over 12 years old. **MESH-1**

#### Ground truthing:

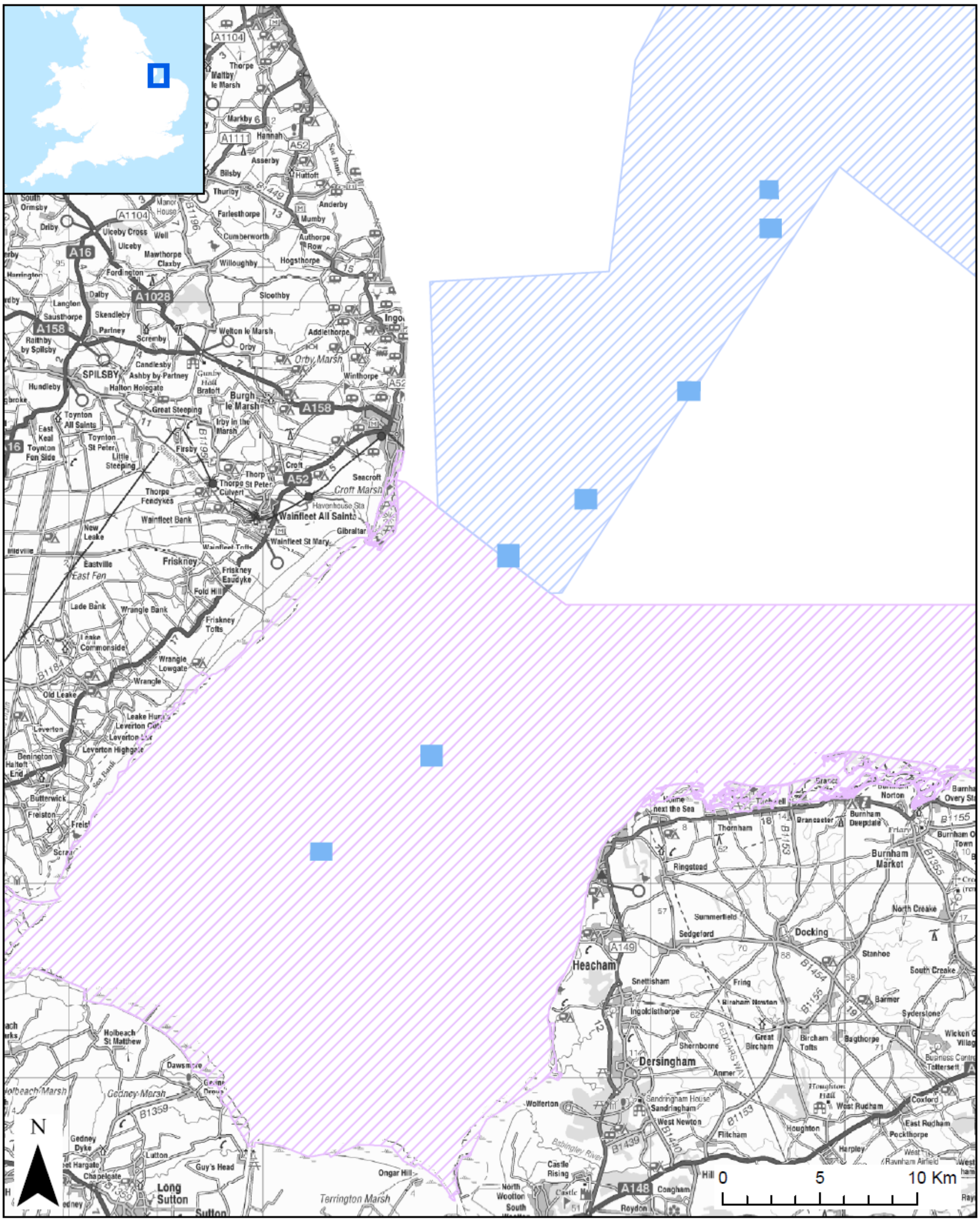
- Technique: Day grab samples (n=10 per box) and video (23- minute tow) used, pre Gubbay (2007) but *S. spinulosa* density provided. **MESH-1**
- Positioning: dGPS. **MESH-3**
- Density: Every habitat class in the map classification was sampled. **MESH-2**

- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2001 therefore over 12 years old. **MESH-1**

**Data interpretation:**

- Ground truthing interpretation: Evidence of expert interpretation and data for reef assessment is provided. **MESH-2**
- Remote interpretation: Ground truthing used to inform Maximum likelihood analysis of AGDS data. Sidescan interpreted using ground truthing data which was provided. **MESH-3**
- Detail: Reef defined using less than three Gubbay (2007) criteria. **MESH-1**
- Map accuracy: Natural England commissioned report therefore subject to external QA. **MESH-3**

**MESH Confidence Score: 64**




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Foster-Smith (2001)

Survey Area

Extent of Reef

Scale (at A4): 1:250,000

Maps produced on 03/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure D** Foster-Smith (2001) survey area and reef extent

# Appendix 1.5 JESSOP, R.W. and STOUTT, J. 2006

### Data source (report title):

JESSOP, R.W. and STOUTT, J. 2006. Broad scale *Sabellaria spinulosa* distribution in The central Wash (Southern North Sea) as predicted with AGDS RoxAnn$^{TM}$.

### Year data collected:

2005

### Data summary:

The survey aim was to produce a broadscale map of *S. spinulosa* in the central Wash using AGDS supported by grab samples. The report assessed data from both a targeted survey, and additional routine surveys. The additional data was of lower confidence and required separate MESH score assessment.

A targeted survey was conducted; 71km$^2$ of seabed were covered using RoxAnn™ AGDS, and 50 targeted 0.1m$^2$ day grabs taken. Track data was analysed using Excel (for cleaning), MapInfo (display) and Vertical Mapper (nearest neighbour interpolation). AGDS predicted *S. spinulosa* in 22% of the survey area (based on previous work indicating likely E1/E2 values) from which twenty samples stations were selected. Only 0.1m$^2$ day grabs were used for GT, due to poor visibility. Ten of these were sampled three times, and ten twice (A 3$^{rd}$ sample was deemed unnecessary due to consistent reef findings). Grab sampling confirmed *S. spinulosa* presence at 85% of sample stations. Those samples which contained *S. spinulosa* were scored on quality (1-4), based on quantity and size of *S. spinulosa* (ratio, height, size of clumps). However, the criteria for 1-4 were not defined any further. Reef height in the samples varied from 1cm to 6.5 cm, and surface coverage with <25% - 100% patchiness.

Data from additional routine surveys included a 117km$^2$ area of AGDS tracks which was analysed using the same methods. This additional data can be seen alongside the targeted data in figure 8 of the report. Ground truthing was not as reliable, and the data on amount and location of the ground truthing was not available, resulting in lower MESH confidence. Figure 10 suggested a couple of areas were verified by day grab to contain *S. spinulosa* reef but insufficient data is available to support an independent decision.

An intertidal *S. spinulosa* reef was identified by ESFJC officers in 2004, and its extent plotted in 2005. It is 1300m long and 90m wide, and covers 11ha. There is approximately 30% coverage of the area, the average height is 8-0cm, and some of the larger communities were 12-15cm.

### MESH Confidence Assessment:

**<u>Targeted survey</u>**

**Remote sensing:**

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: Track spacing not reported. **MESH – 1**
- Positioning: Assumed GPS. **MESH – 2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2005 therefore 9 years old. **MESH – 2**

**Ground truthing:**

- Technique: Ground truthing consisted of day grabs. Reef assessed based on extent (interpolated Ground truth data), elevation, patchiness. No video used. Data collected pre

Gubbay (2007) and report is unclear about the respective characteristic thresholds that were used to define reef. **MESH – 1**

- Positioning: Assumed GPS. **MESH – 2**
- Density: Twenty stations sampled fifty times using day grab. Survey was broadscale. **MESH -2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2005, therefore 9 years old. **MESH -2**

**Data interpretation:**

- GT interpretation: Expert interpretation by ESFJC. Data used for reef assessment provided. **MESH - 3**
- Remote interpretation: Nearest Neighbour interpolation of AGDS data used to infer reef extent. **MESH – 2**
- Detail level: Reef assessed based on extent (interpolated GT data), elevation, patchiness, using day grabs. Data collected pre Gubbay (2007), report is unclear about the respective thresholds that were used to define reef. **MESH – 1**
- Map accuracy: Internal QA by ESFJC. **MESH – 2**

**<u>Additional data</u>**

**Remote sensing:**

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: AGDS Track spacing not reported. **MESH – 1**
- Positioning: Assumed GPS. **MESH – 2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2005, therefore 9 years old. **MESH -**

**Ground truthing:**

- Technique: Type, amount and location of Ground Truthing unknown. Data used for reef assessment is not provided. **MESH – 0**
- Positioning: Assumed GPS used. **MESH – 2**
- Density: Amount and location of Ground Truthing is unknown. **MESH – 0**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2005, therefore 9 years old. **MESH -2**

**Data interpretation:**

- GT interpretation: Expert interpretation by ESFJC. Data used for reef assessment is not provided. **MESH - 3**
- Remote interpretation: Nearest neighbour interpolation of AGDS data used to infer reef extent. **MESH – 2**
- Detail level: Method used to define reef unknown. **MESH – 0**
- Map accuracy: Internal QA by ESFJC. **MESH – 2**

### MESH Confidence Score:

**Targeted survey = 60**

**Additional data = 49**

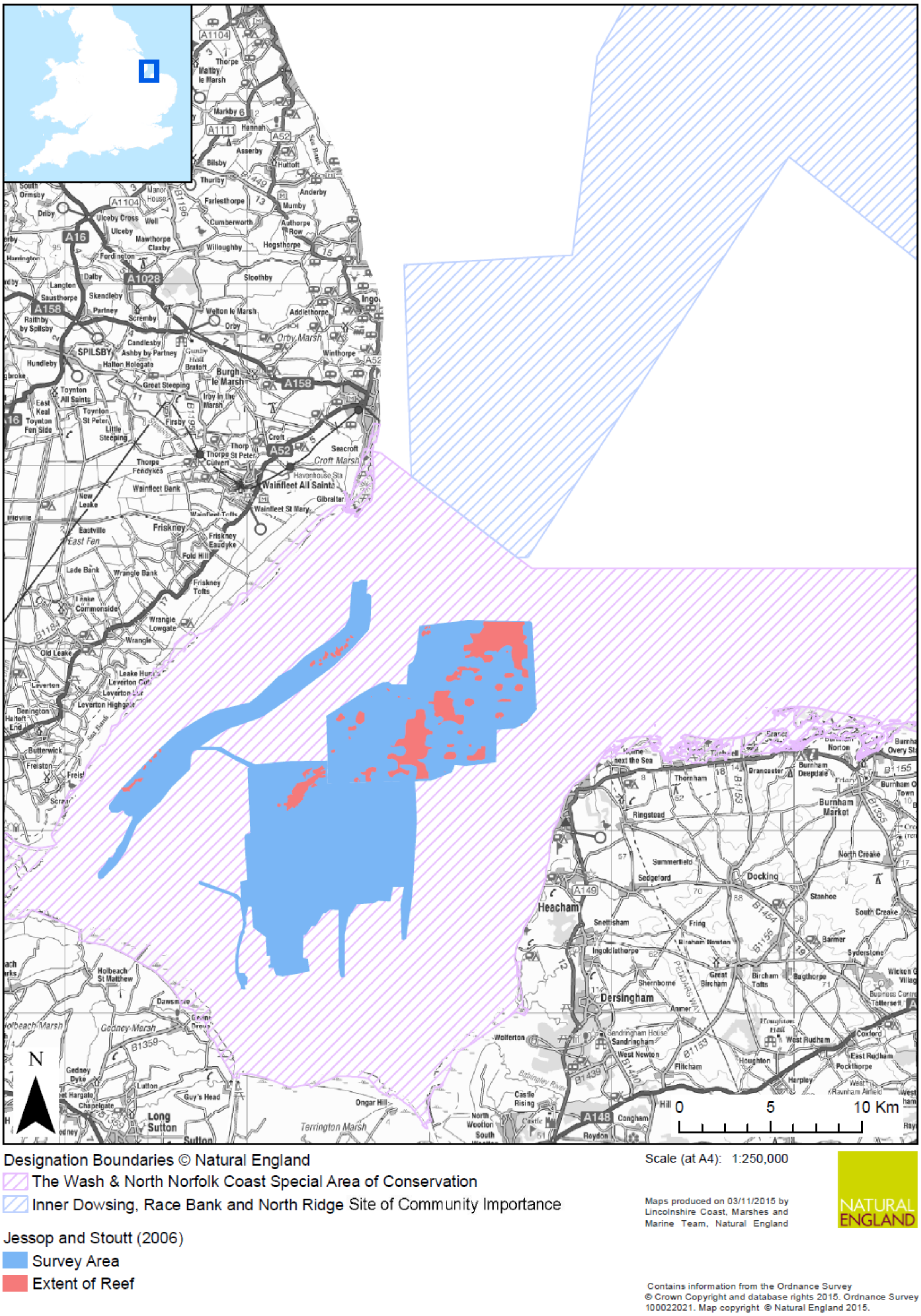



**Figure E** Jessop and Stoutt (2006) survey area and reef extent

## Appendix 1.6 JESSOP, R.W., GRAVES, K.M. and WOO, J.R. 2006

### Data source (report title):

JESSOP, R.W., GRAVES, K.M. and WOO, J.R. 2006. Eastern Sea Fisheries Joint Committee Research Report 2006.

### Year data collected:

2006

### Data summary:

The study aimed to create a broad-scale map of *S. spinulosa* distribution, to inform the management of towed shrimp fisheries within the Wash and North Norfolk Coast SAC and the Wash SSSI. The survey was a continuation of ESFJC and NE 2005 monitoring of *S. spinulosa* spatial coverage in the site.

Surveys were conducted throughout 2006, with the majority of these occurring within October-December, restricted to weather conditions that allowed for reasonable signal quality.

Vessel speed was approx 6kt during the AGDS survey and the distance between transects varied from 150-500m due to the spatial coverage of the defined survey 'box'; larger areas invited wider transect separation.

RoxAnn™ interpretation was conducted using Microplot7TM in real time to optimise decision on ground truthing targets; consisting of day grabs and VideoRay™ ROV on occasion.

For mapping of reef, data was cleaned in Microsoft Excel and transferred to GIS program MapInfo for spatial analysis, Nearest Neighbour Interpolation was applied using Vertical Mapper to predict the likely position of *S. spinulosa* reefs.

### MESH Confidence Assessment:

**<u>The Well</u>**

**Remote sensing:**

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: AGDS survey boxes covered 99km2, using tracks at a distance of 150-500m apart. **MESH-1**
- Positioning: GPS assumed with AGDS. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2006 therefore 8 years old. **MESH-2**

**Ground truthing:**

- Technique: Ground truthing consisted of five Day Grabs, VideoRay™ Only extent of the Gubbay (2007) criteria used. **MESH-1**
- Density: Forty three grabs deployed, ROV deployed on five occasions. Ground Truthing interpolated to infer reef extent. Survey was broad-scale. **MESH-2**
- Positioning: Assumed GPS used. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: data gathered in 2006 therefore eight years old. **MESH-2**

**Data interpretation:**

- GT interpretation: Expert interpretation by EFICA, we don't have the data used to inform reef assessment. **MESH- 2**
- Remote sensing interpretation: Nearest neighbour interpolation of Ground truth sites used to infer reef extent. **MESH-2**
- Detail level: Extent was the only characteristic used define reef but was inferred through interpolating Ground Truth data. **MESH-1**
- Map accuracy: Internal ESFJC QA assumed. **MESH-2**

**MESH Confidence Score: 57**

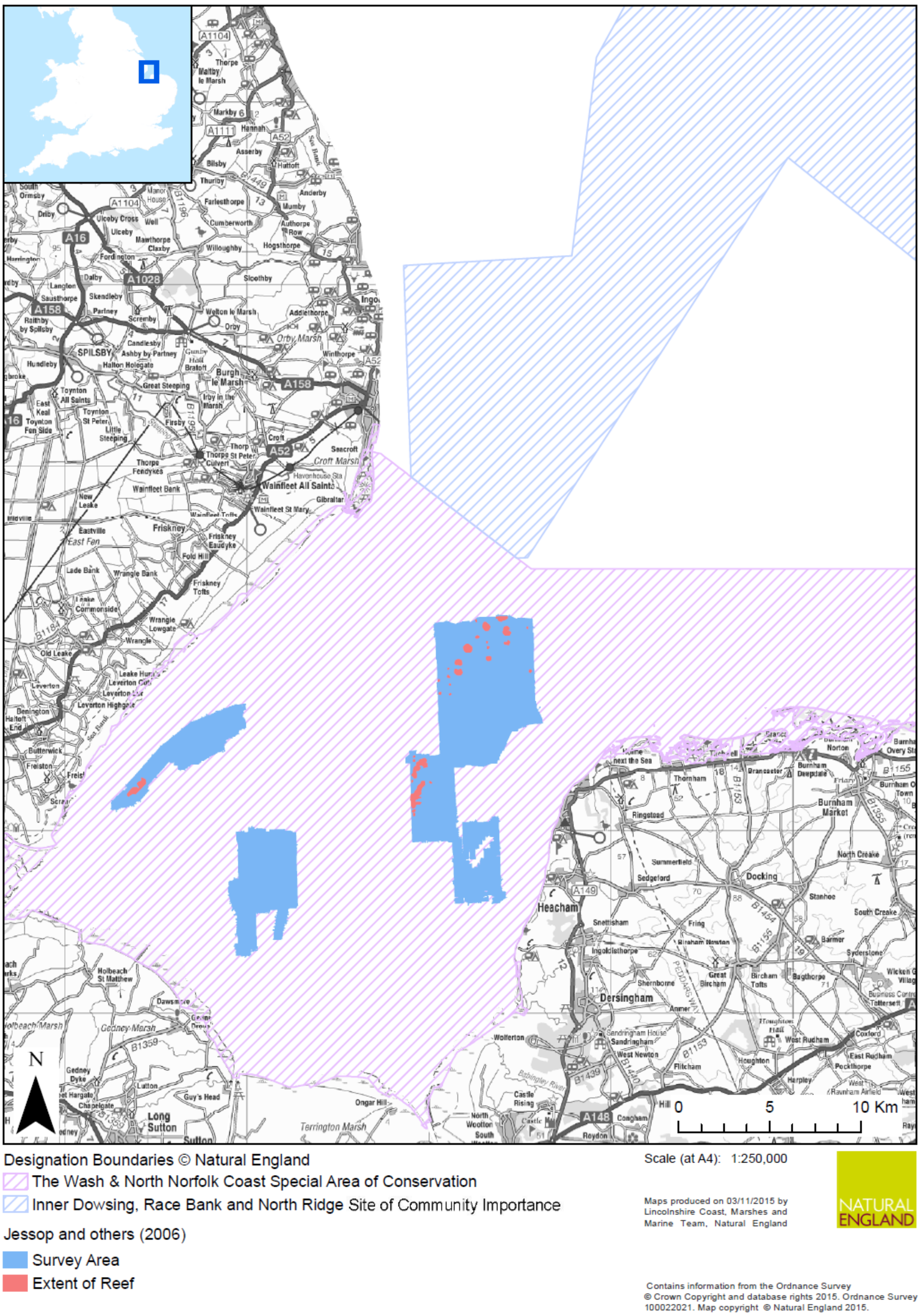



**Figure F** Jessop, Graves and Woo (2006) survey area and reef extent

## Appendix 1.7 WOO, J.R. 2008

### Data source (report title):

WOO, J.R. 2008. The “reefiness” of *S. spinulosa* in The Wash: a report on the results of the 2007 AGDS survey. Eastern Sea Fisheries Joint Committee, King’s Lynn.

### Year data collected:

2007

### Data summary:

The 2007 survey covered three predicted *S. Spinulosa* colonies: Lynn Knock, the Well and Lynn Deeps (surveyed from 2005-07 inclusive) and an area east of roger sand called Box 48 or East Roger.

Surveys were only conducted on days where conditions and sea state were suitable to get reasonable signal from the AGDS. The boat travelled at 6kt approx, and tracked back and forth along north south transect lines at distance of between 150m and 500m apart within the discrete survey area (box). The spacing depended on a combination of the spatial coverage needed and the level of detail required. In Lyn Deeps/Well 500m separation was used due to it being a large area; elsewhere 150 or 200m was more suitable.

RoxAnn™ AGDS signal was displayed in real time using Microplot 7 mapping software enabling decisions to be made on where to target Ground Truthing after completion of the transects. Ground Truthing consisted of 37 day grabs and 26 ROV flights.

Day Grab samples and ROV footage was used to score reefiness of predicted reef zones in MapInfo. Scoring protocol of Hendrick and Foster-Smith (2006) and Gubbay (2007) were used to assess reefiness. As ESFJC did not have the capacity to measure density (% occupancy of tubes), community composition or species diversity for this survey, scoring was based on data collected about physical attributes, including elevation, percentage consolidation of sediment by the *S. spinulosa* tubes, spatial coverage of the feature and patchiness.

The ROV was deployed at most sites to help determine how representative the grab sample was of the surrounding reef/crust allowing an estimation of “patchiness” of reef to be made as well as comprehensive description of the nature of the *S. spinulosa*.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: Track spacing between 150-500m, moderate heterogeneity. **MESH-2**
- Positioning: GPS assumed. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2007 therefore seven years old. **MESH -2**

**Ground truthing:**

- Technique: Used grabs, video and three primary Gubbay (2007) characteristics: extent, elevation and patchiness. **MESH-3**
- Positioning: Assumed GPS. **MESH-2**
- Density: Thirty seven day grabs and twenty six ROV flights. Comparative density of Ground Truthing not discussed therefore survey assumed to be broad-scale. **MESH-2**

- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2007 therefore seven years old. **MESH-2**

**Data interpretation:**

- Ground truthing: Expert interpretation by ESFJC but data for reef assessment not provided. **MESH-2**
- Remote sensing interpretation: Nearest neighbour interpolation of AGDS data used to infer reef extent. **MESH-2**
- Detail: Reef defined using three primary Gubbay (2007) characteristics: extent, elevation and patchiness. **MESH-3**
- Map accuracy: Internal ESFJC QA assumed. **MESH-2**

**MESH Confidence Score: 72**

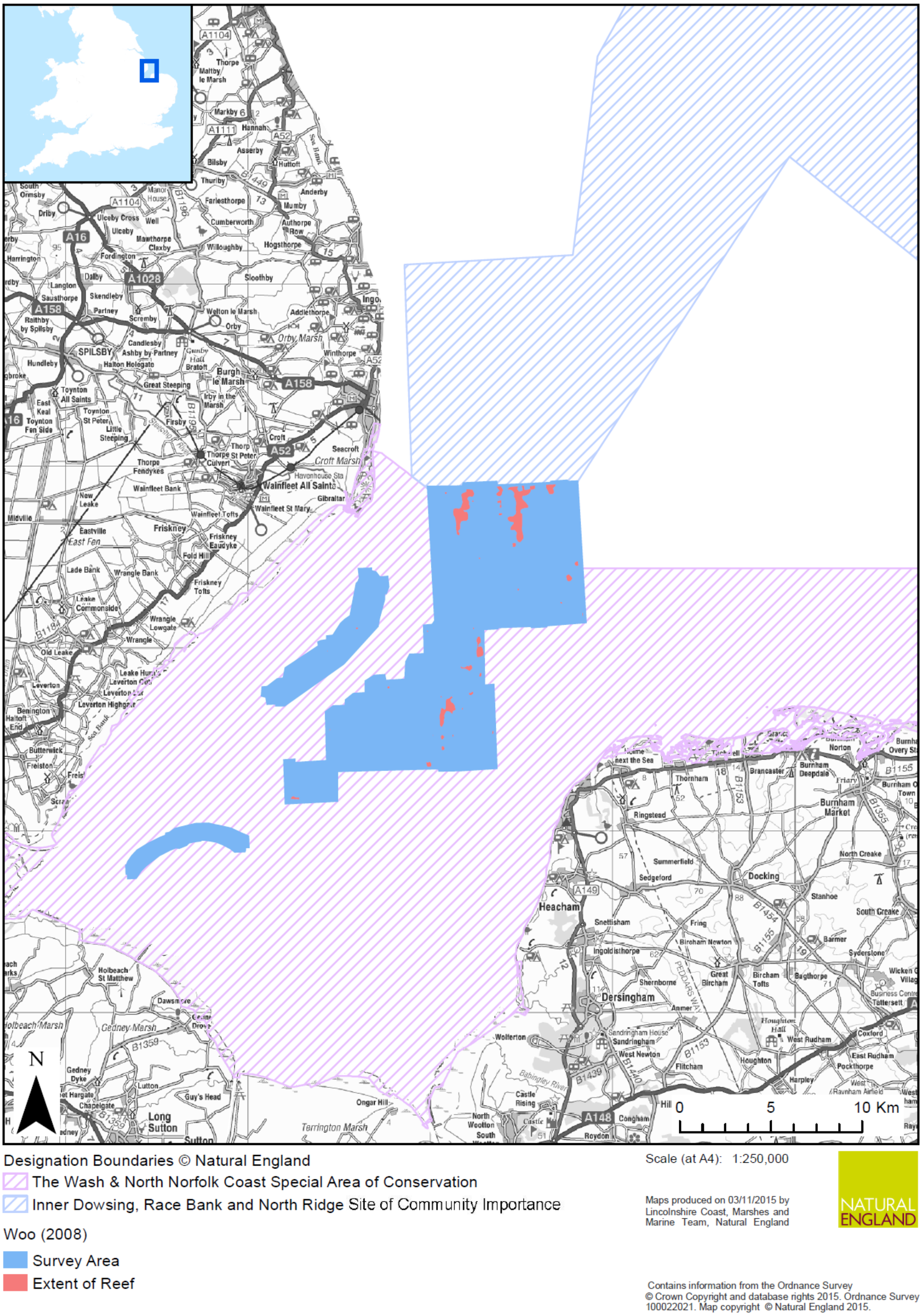



**Figure G** Woo (2008) survey area and reef extent

# Appendix 1.8 JESSOP, R.W., WOO,J.R. and HARWOOD, A.J.P. 2008

### Data source (report title):

JESSOP, R.W., WOO, J.R. and HARWOOD, A.J.P. 2008. Eastern Sea Fisheries District Research Report 2008. King's Lynn. ESFJC.

### Year data collected:

2008

### Data summary:

The survey focused on the intertidal of The Wash (for example intertidal cockle and mussel beds), with no specific reef survey being conducted. AGDS surveys of the Lincolnshire coast were undertaken in search of sublittoral mussel beds to inform fisheries. However, as mussel beds and *S. spinulosa* reef have similar acoustic signatures ground truthing was used to determine which seabed features were. This is therefore low confidence data that was not mapped for the purpose of identifying *S. spinulosa* reef, so much as indicating that it was not mussel.

Roxann™ AGDS – detected the presence of 'seabed features' which were then ground truthed using a combination of grabs, dredges, and underwater camera footage. Roxann™ data was interpreted using Vertical Mapper™ in order to create interpolated models of the estimated distributions of mussel beds and *S. spinulosa* reef.

*S. spinulosa* was found on the survey, which the report states was confirmed through ground truthing (grab, dredge, video) to be reef. However, no further information is given. The AGDS Mapinfo files give a *S. spinulosa* reefiness score of 0-2. 0 indicates no reef, while 1 indicates possible reef, and 2 was used to make mapping easier. The raw data gives more information than the MapInfo Ground Truthing files. Bussell & Saunders (2011) concluded it likely that 8 of the 25 stations were in *S. spinulosa* reef areas, and 4 of them were medium reef (based on comparison of excel sheet and raw data). Bussell & Saunders (2011) reviewed the drop down video work and found no reef.

The AGDS MapInfo file provides survey effort. There is a shapefile of interpreted reef but no associated methods / clarity on how it was obtained. It is assumed it used the same methods as other years.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: Track spacing unreported so assume poor. **MESH-1**
- Positioning: GPS used. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2008 therefore six years old. **MESH-2**

**Ground truthing:**

- Technique: grab, dredge and video, but no reference to reef characteristics that were assessed. **MESH-1**
- Positioning: GPS used. **MESH-1**
- Density: Amount and location of Ground Truthing is unreported. **MESH-1**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**

- Age: 2008. **MESH-2**

**Data interpretation:**

- GT interpretation: Expert interpretation provided ESFJC but data used for reef assessment is not provided. **MESH-2**
- Remote sensing interpretation: Nearest neighbour interpolation of Ground Truthing sites used to infer reef extent but survey was not designed to target the identification of reef. **MESH-1**
- Detail level: Characteristics used to define reef are unknown. **MESH – 1**
- Map accuracy: Internal Assumed internal ESFJC QA. **MESH – 2**

## MESH Confidence Score: 52

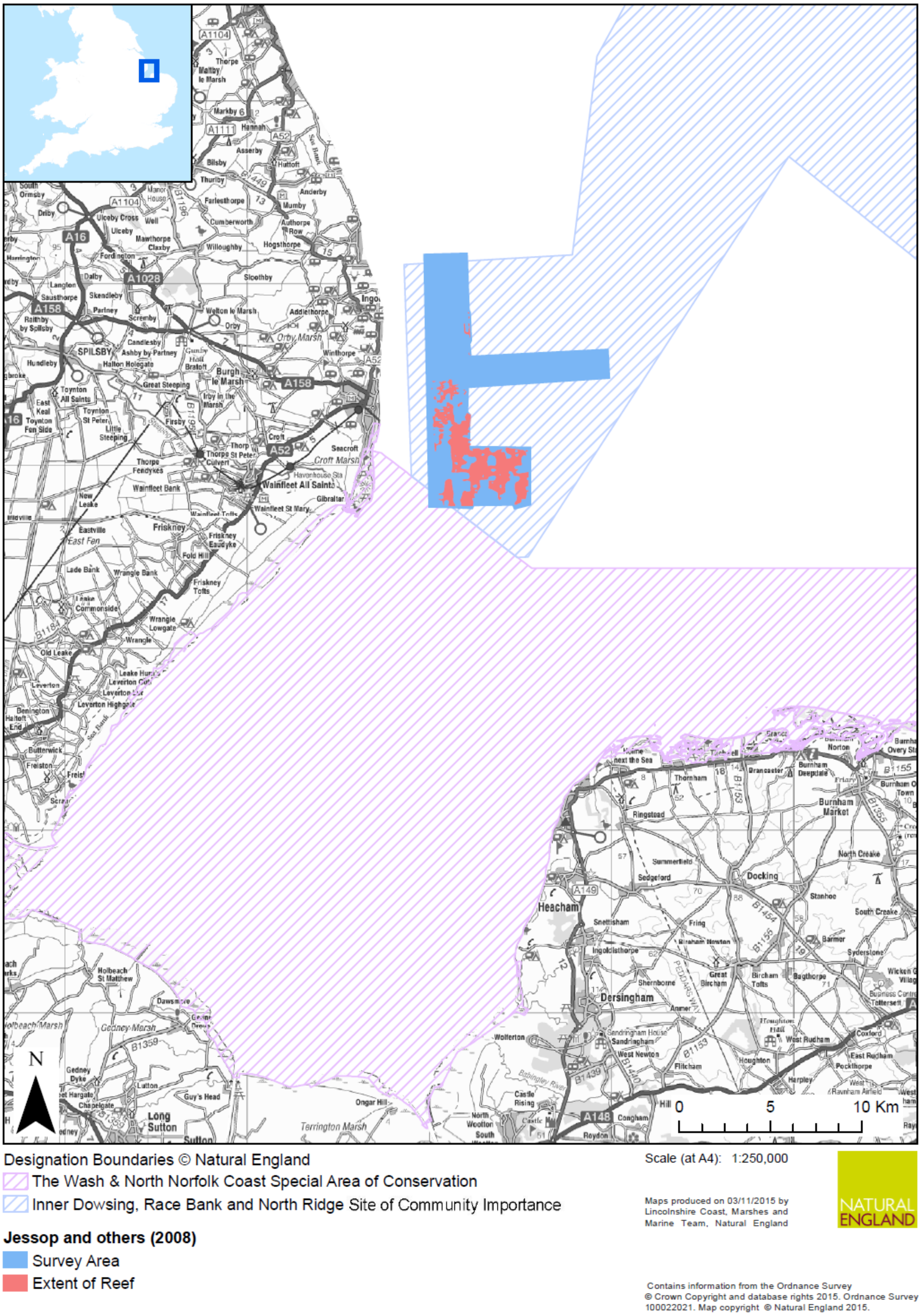



**Figure H** Jessop, Woo and Harwood (2008) survey area and reef extent

# Appendix 1.9 JESSOP, R.W., HARWOOD, A.J.P. and WOO, J.R.2009

### Data source (report title):

JESSOP, R.W., HARWOOD, A.J.P. and WOO, J.R. 2009. Eastern Sea Fisheries Joint Committee Research Report 2009

### Year data collected:

2009

### Data summary:

This year was a much more targeted survey with significantly more ground truthing than previous ESFJC *S. spinulosa* surveys. This method differs from all previous ESFJC and related surveys in that it uses ground truth techniques as the primary method of reef detection. Five areas were surveyed: West Lynn Knock, East Lynn Knock, East Dogs Head, South Well and Seal Sand. AGDS (RoxAnn™) was used with a track spacing of 150m (the one exception being Dogs Head - 300m) while travelling at speeds of between 6-8Kt with survey being restricted to reasonably calm sea state conditions.

Ground truth locations were selected in a three stage process. The first phase occurred after processing of ADGS data using MapInfo and Vertical Mapper GIS Software creating seabed models which were used to assign semi-stratified ground truth stations based on expected distribution of *S. spinulosa* reef from AGDS. Day grabs were then assessed for reefiness and this data was interpolated in Vertical Mapper to show predicted reef extent based on grab samples. This extent was then used to determine further grab sample locations which were again assessed for reefiness and also used to delineate the edge of reef. At this stage phase 1 and 2 data were pooled and interpolated so that video could then be used to assess patchiness in phase 3 ground truthing. Overall 341 grabs and 36 ROV flights were deployed. Poor weather meant the ROV flights conducted were delayed too long for the data to be included in the report. Instead the data from the ROV flights could only be used to verify the Day grab data regarding reef elevation and consolidation.

Two sets of maps using different thresholds for defining *S. spinulosa* communities were produced for each site. The first defines *S. spinulosa* communities in terms of crust and elevated reef using the following criteria.

**Table A**

| Criteria | *S. spinulosa* crust | Elevated reef |
|---|---|---|
| Sediment consolidation | >5% | >5% |
| Elevation | <5cm | >5cm |

The second defines *S. spinulosa* communities in terms of the not reef, low, medium, high reefiness parameters defined by Gubbay (2007). Reefiness is defined using the criteria elevation, sediment consolidation, spatial extent, and temporal stability.

A summary of how each reefiness criteria was detected is as follows.

**Table B**

| Characteristic* | Method of detection |
|---|---|
| Elevation (mm) | Day Grab, verification by ROV footage. |
| Consolidation | Day Grab, verification by ROV footage. |
| Spatial Extent | Boundary of reef defined by interpolating Day Grab data. |
| Temporal stability | Past survey data and anecdotal evidence |

*The survey attempted to quantify reef patchiness but poor weather meant the ROV flights conducted at this site were delayed too long for the data to be included in this report.

The data is then further separated out into areas:

**West Lynn Knock:** Track spacing 150 m. 50 grabs collected in first phase; 29 were predicted to have reef but only 12 had med-high with the remaining 17 supporting low grade reef/crust. At 21 stations reef was not expected but 4 of these detected elevated reef and 8 crust, which gives an indication of data reliability. Data was interpolated and a further 30 stations selected. The data was pooled and re-interpolated. Figure 5.4 of the annual report shows the distribution of reef based on Gubbay criteria and matches the GIS data fairly well in MedReef_WGS84.shp.

**East Lynn Knock:** 18 AGDS tracks spaced 150 m apart were collected. 54 grabs were collected in Phase 1. As the AGDS suggested, the first phase of ground truthing did not show much *S. spinulosa*. Only one of 23 stations where *S. spinulosa* was expected found reef with 14 stations showing crusts. Of the 31 grabs where reef was not expected, 8 had crust and the rest nothing. The second phase used a further 6 stations to try and delineate reef edge. Figure 5.9 of the annual report shows this assessed against Gubbay (2007) criteria. The area of medium reef in Figure 5.9 seems to correspond well with the digitised areas in GIS but the low reef is not similar.

**East Dog's Head:** this area was actually surveyed using AGDS in Nov 2008. 300m track spacing was used over 8 tracks 60km long. 80 grabs were collected in the first phase of ground truthing. 23 of the grab stations were expected to contain reef but only 3 did, with 4 finding crust. Of the remaining 57 stations, 5 were found to support elevated reef and 13 crust. 20 further day grabs used to map reef edges were pooled with earlier data and re-interpolated. Figure 5.15 of the annual report shows Gubbay (2007) interpretation of this data (elevation and extent only). This data seems to correspond well with the digitised data in GIS. This survey block extends all the way up into Lynn Knock.

**Seal Sand:** AGDS was collected over 25km with track spacing of 150-220m. Phase 1 ground truthing samples were not stratified, but selected to give uniform coverage. 6 out of 46 samples found reef, while 12 found crust. The second phase of ground truthing added 14 samples. Figure 5.21 of the annual report shows the Gubbay (2007) assessment of the ground truth data and matches well with the digitised data we hold.

**South Well:** The AGDS failed, so only grab sampling was used. In the absence of current AGDS data, survey data from 2007 were used to target 20 phase 1 grabs in a semi-stratified manner. 12 of these 20 grabs contained *S. spinulosa*. Grabs were interpolated and then a further 21 were collected and the data was pooled. Data in Figure 5.28 of the annual report shows this model, and matches our digitised data in GIS.

## MESH Confidence Assessment:

### Remote sensing:

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage:

1) West Lynn Knock – AGDS track spacing 150m, low heterogeneity. **MESH-2**
2) East Lynn Knock – AGDS track spacing 150m, low heterogeneity. **MESH-2**
3) East Dog's Head – AGDS track spacing 300m, moderate heterogeneity. **MESH-1**
4) Seal Sand – AGDS track spacing 150-220m, low heterogeneity. **MESH-2**
5) South Well – AGDS track spacing 500m, (used data from 2007 survey), moderate heterogeneity. **MESH-1**

- Positioning: Assumed GPS. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age:

1) West Lynn Knock – Data gathered in 2009 therefore five years old. **MESH-3**
2) East Lynn Knock – Data gathered in 2009 therefore five years old. **MESH-3**
3) East Dog's Head – Data gathered in 2008 therefore six years old. **MESH-2**
4) Seal Sand – Data gathered in 2009 but also used survey data from 2007 to inform ground truthing. **MESH-2**

### Ground truthing:

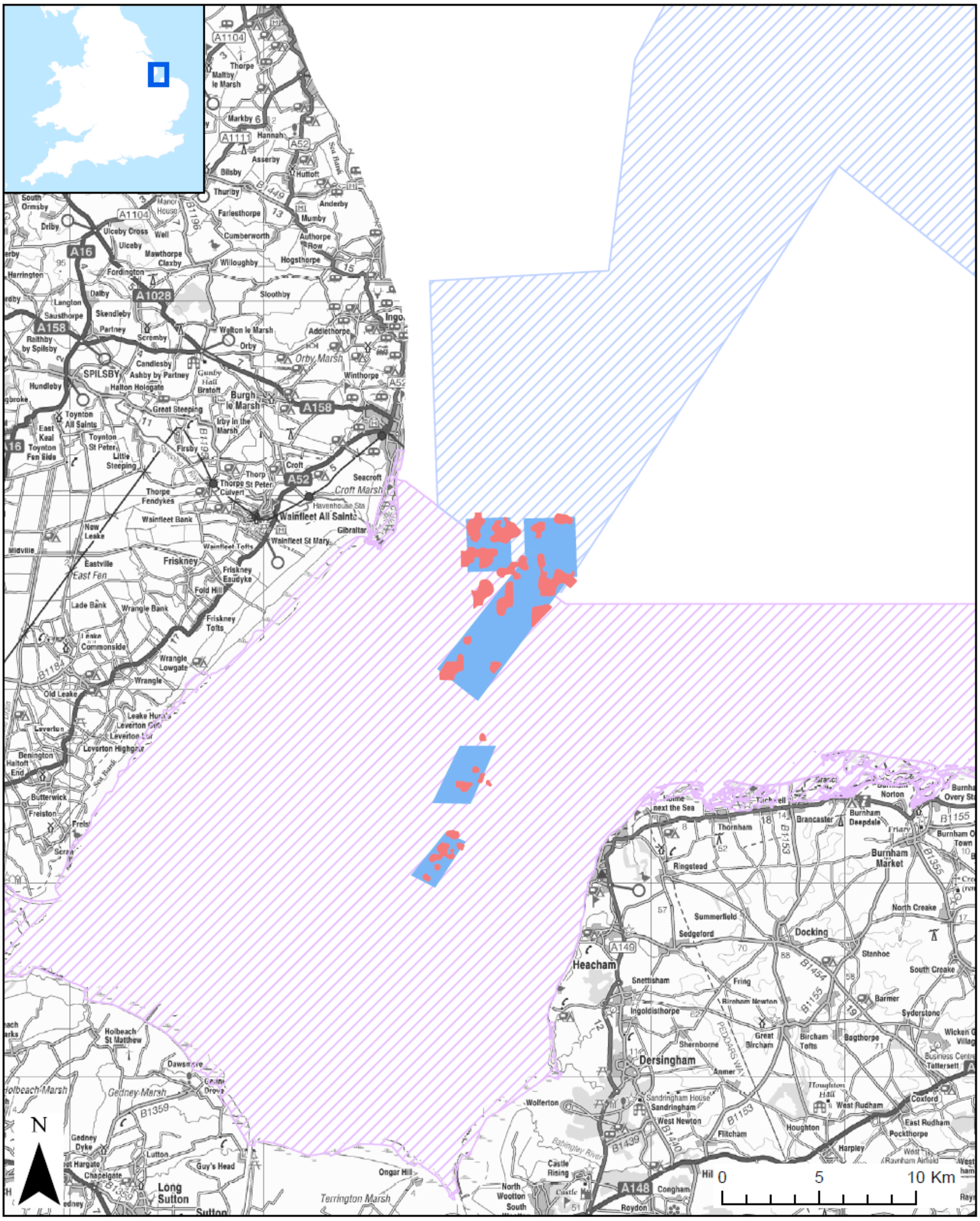
1) Technique: Two Phases of Day Grab Ground Truthing were conducted for each survey area, but there was insufficient time for ROV video Ground Truthing to be analysed as part of report. Elevation, sediment consolidation, extent and longevity were assessed. **MESH-2**
2) Positioning: Assumed GPS. **MESH-2**
3) Density: 341 Day grabs and 36 ROV flights, survey conducted at comparatively fine scale compared to previous EIFCA surveys. **MESH- 3**
4) Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
5) Age: Data gathered in 2009 for all survey sites, therefore five years old. **MESH-3**

### Data interpretation:

- Ground truthing interpretation: Expert interpretation assumed data used for reefiness assessments is provided. **MESH-3**
- Remote sensing interpretation: AGDS used to inform the Ground Truthing locations; Ground Truth data then interpolated to produce maps of *S. spinulosa* reef extent. **MESH-2**
- Detail: Elevation, sediment consolidation, extent and longevity were assessed. **MESH-2**
- Map Accuracy: Internal QA by EFJCA. **MESH-2**

## MESH Confidence Score:

- West Lynn Knock – 74
- East Lynn Knock – 74
- East Dog's Head – 70
- Seal Sand – 74
- South Well – 70




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Jessop and others (2009)

Survey Area

Extent of Reef

Scale (at A4): 1:250,000

Maps produced on 03/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure I** Jessop, Harwood and Woo (2009) survey area and reef extent

## Appendix 1.10 EMU. 2009

### Data source (report title):

EMU. 2009. Docking Shoal and Race Bank Offshore Wind farms. Additional geophysical survey areas in the Wash for Centrica Energy

### Year data collected:

2009

### Data summary:

This survey is an additional area to Emu's 2008 report of 2005/2006 dataset. The survey was designed to detect *S. spinulosa* reef, particularly in Area 2, but none was found. dGPS was used with an accuracy of +/- 5m. The methodology included the use of Swath Bathy (100%) to provide detailed topographical information for the identification of seabed features and Side Scan Sonar (full coverage) to supplement and verify AGDS interpretation when identifying *S. spinulosa* reef*.* AGDS RoxANN™ was utilised to determine biotope types and sediment classes, further informed by ground truthing with DDV and day grabs.

DDV ground truthing was carried out at the sites with the maximum probability of *S. spinulosa* reef being present. Where DDV footage was insufficient Day grabs were carried out (n=84); only 15 of these were processed. In areas of *S. spinulosa* clumps or crust a greater number of DDV drops were required and low visibility video was deployed. Appendix J gives the biotope report. A low number of good videos were obtained due to poor visibility but based on video only the presence of *S. spinulosa* reef was ruled out. Gubbay (2007) criteria were not used in the classification of reef, since none was located.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: AGDS and SSS both high and low frequency. **MESH- 2.5**
- Coverage: 100% coverage. **MESH- 3**
- Positioning: DGPS. **MESH-3**
- Standards: Assumed internal standards, carried out by EMU scientific organisation. **MESH-2**
- Age: Data gathered in 2009 therefore five years old. **MESH-3**

**Ground truthing:**

- Technique: Used DDV and Day Grabs, would have used Gubbay (2007) if applicable. **MESH-2**
- Positioning: DGPS. **MESH-3**
- Density: Every class in the map classification was sampled. **MESH-2**
- Standards: followed JNCC UK Project Handbook for the biological monitoring of marine SACs. **MESH-3**
- Age: Data gathered in 20009 therefore five years old. **MESH-3**

**Data interpretation:**

- Ground truthing: Expert interpretation assumed, provided all data, reef assessment not applicable. **MESH-3**
- Remote sensing interpretation: Acoustics interpreted using GT and data provided. **MESH-3**
- Detail: Did not find reef, stated Gubbay (2007) would have been used if reef found. **MESH-2**
- Map accuracy: Assume external QA as produced for client. **MESH-3**

**MESH Confidence Score: 88**

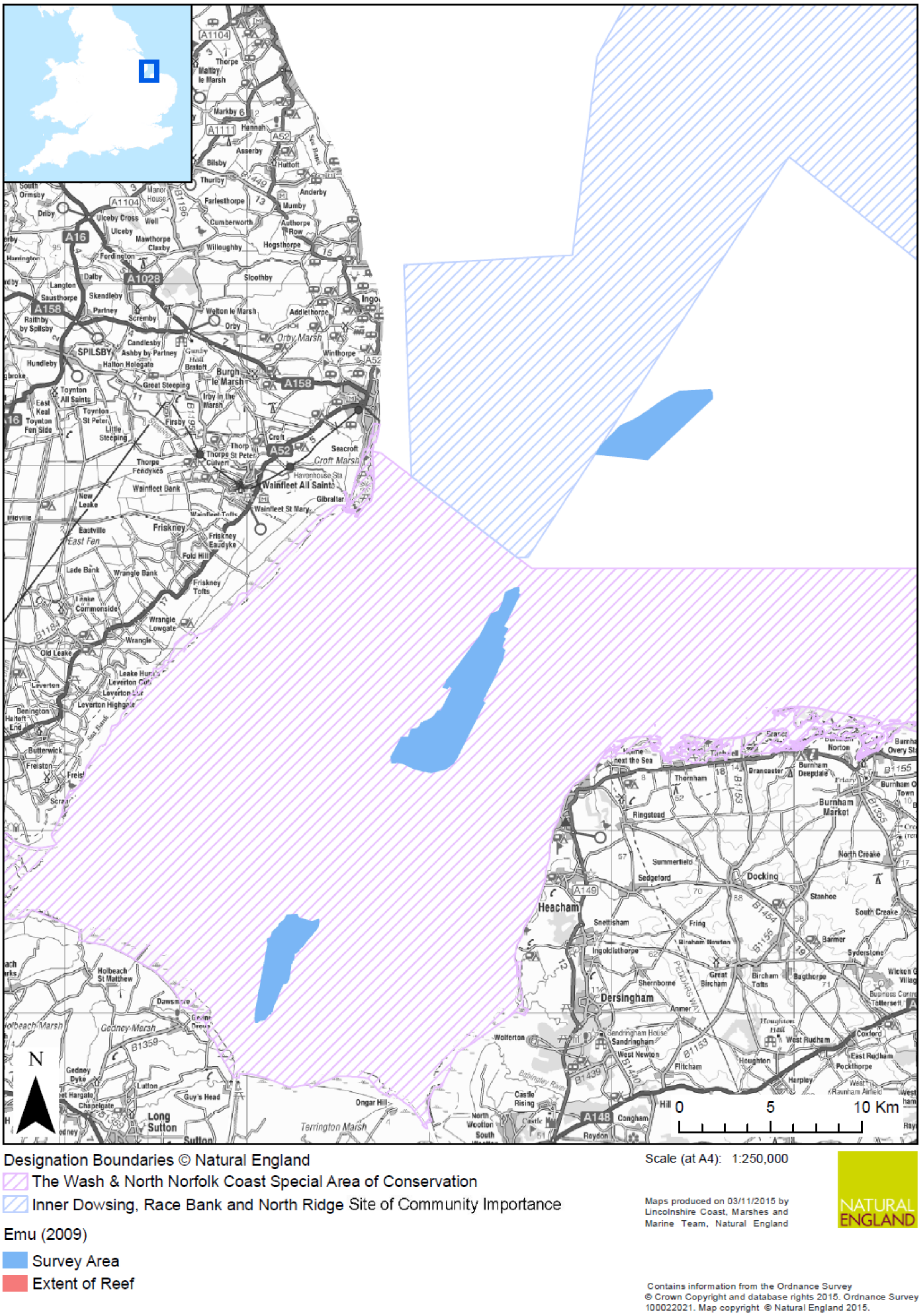



**Figure J** Emu (2009) survey area and reef extent

## Appendix 1.11 JESSOP, R.W., HINNI, S., SKINNER, J. and WOO, J.R. 2010

### Data source (report title):

JESSOP, R.W., HINNI, S., SKINNER, J. and WOO, J.R. 2010. Eastern Sea Fisheries Joint Committee Research Report 2011. Eastern Sea Fisheries Joint Committee

### Year data collected:

2010

### Data summary:

The survey programme was divided spatially into two main areas comprising five sites within The Wash and four sites along the Lincolnshire coast near the Lynn and Inner Dowsing OWFs. Time constraints meant that slightly different methodologies were used for the two survey areas.

Lincolnshire Coast site
RoxAnn™ AGDS tracks were conducted across the four sites, the data from which were then processed to create models depicting the hardness and roughness of the seabed within the areas. These models were then used to inform the location of semi stratified ground truth positions.

Within each area, parallel AGDS tracks were conducted between 200-250 meters apart. Tracks were conducted at a speed of approximately 6-8 knots. AGDS models of seabed hardness and roughness were then used to predict where reef structures might be located, and thus to inform where to assign ground-truth stations in a semi-stratified manner. Ground truthing was conducted using a mixture of Day grabs and underwater video camera footage taken from a Remotely Operated Vehicle (ROV). Ground truthing was conducted in three phases and a single sample was collected from each ground-truth station from which the following details were recorded:

- Predominant sediment types
- Height range of clumps
- Percentage volume of shell
- Occupancy of *S. spinulosa* tubes (zero, low, moderate or high)
- Percentage volume of *S,spinulosa* fragments
- Presence of faunal turfs
- Percentage coverage of *S. spinulosa* clumps
- Presence of other macro-faunal species present

At each survey area Day grabs were used exclusively during phase one, using the pre-determined semi-stratified patterns that had been assigned following analysis of the track data. These models were then used to inform the second phase of ground truthing, in which further Day grab samples were collected to more precisely chart the extent of the reef features identified in the first phase. Data collected during the second phase were pooled with those data collected during phase one and the Vertical Mapper interpolated models re-created using the additional data. Areas of predicted *S. spinulosa* reef were selected from these models as sites for the third phase of ground truthing, in which the ROV video camera was used to verify the grab data and to estimate the patchiness of the reef.

**The Wash sites**

The survey of the Wash sites were conducted in a similar way to the Lincolnshire Coast sites except time constraints meant it was not possible to conduct RoxAnn™ survey tracks for these areas. Semi-stratified ground truth positions were therefore derived from interpolated models of the *S. spinulosa* reefs created from the 2009 ESJFC ground truth data.

AGDS from 2009 was used to inform ground truth stations.

**Mapping**

Maps produced showing the distribution of *S. spinulosa* reef for each site by interpolating the ground-truth data using the thresholds defined by Gubbay (2007). Gubbay (2007) thresholds were assigned using the criteria reef elevation and sediment consolidation only. Patchniess could not be estimated from single grabs and video.

## MESH Confidence Assessment:

**Remote sensing:**

- Technique: RoxAnn™ AGDS used to inform Lincs coast sites. AGDS from 2009 used for The Wash. **MESH-1.5**
- Coverage: AGDS Track spacing 150m-500m spacing across all survey sites. Moderate heterogeneity. **MESH-1**
- Positioning: Assumed GPS. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2011 for Lincolnshire Coast sites therefore 4 years old. Data gathered in 2009 for Wash sites therefore 5 years old. All data under 6 years. **MESH-3**

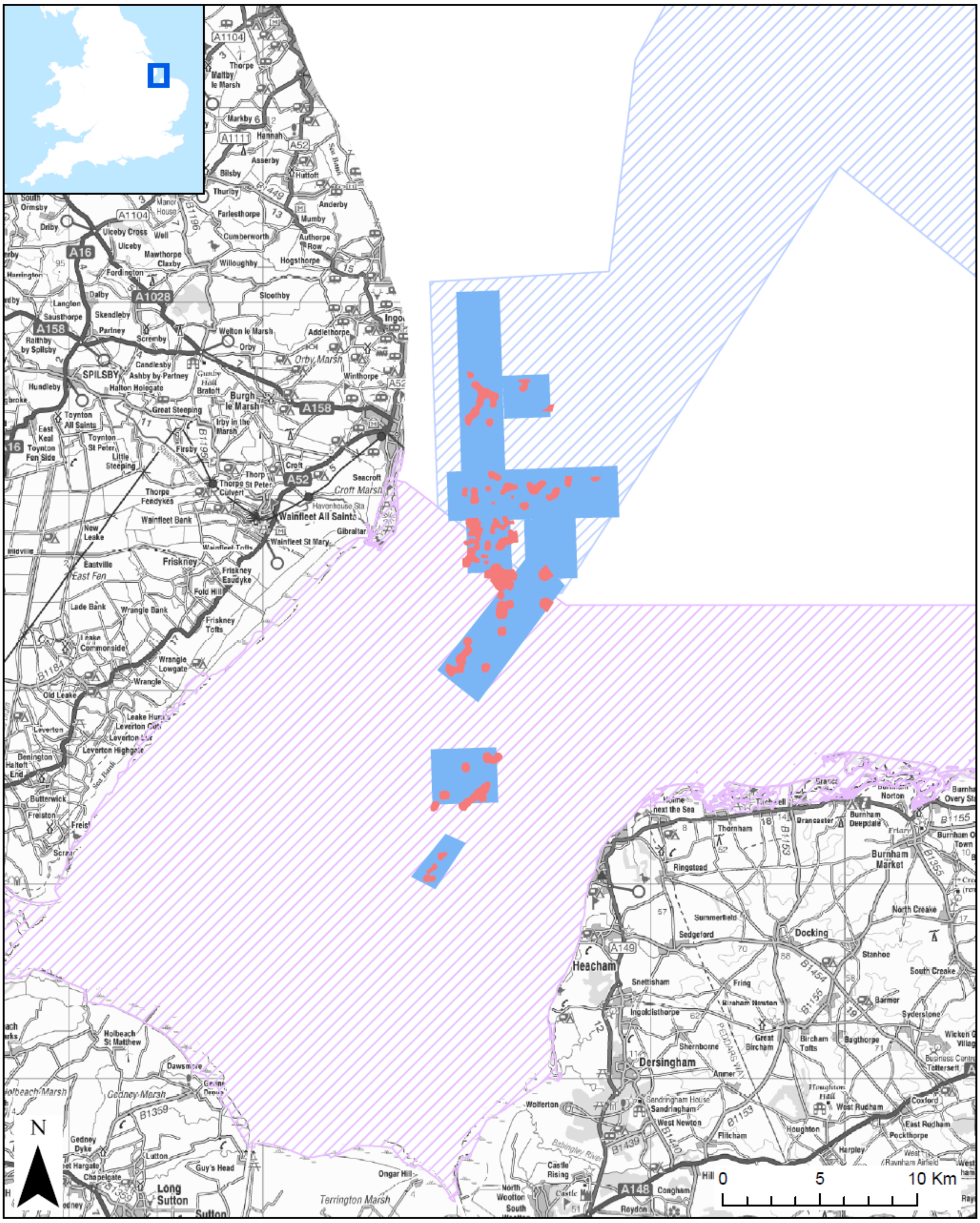
**Ground truthing:**

- Technique: Two phases of day grab sampling, one of video, Gubbay (2007) criteria used reef patchiness not verified by video so two criteria. **MESH-2**
- Positioning: Assumed GPS.
- Density: One sample collected at each ground truth site, every class in map was sampled. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2011 therefore four years old. **MESH-3**

**Data interpretation:**

- GT interpretation: Expert interpretation by EIFCA but the data used to inform reef assessment is not provided. **MESH-2**
- Remote sensing interpretation: Nearest neighbour interpolation of GT sites used to infer reef extent. **MESH 2**
- Detail level: Reef extent (inferred through interpolating GT data), elevation and sediment consolidation characteristics used to define reefiness. **MESH-1**
- Map accuracy: Internal EIFCA QA assumed. **MESH-2**

## MESH Confidence Score: 66




Designation Boundaries © Natural England

The Wash & North Norfolk Coast Special Area of Conservation

Inner Dowsing, Race Bank and North Ridge Site of Community Importance

Jessop and others (2010)

Survey Area

Extent of Reef

Scale (at A4): 1:250,000

Maps produced on 03/11/2015 by Lincolnshire Coast, Marshes and Marine Team, Natural England

NATURAL ENGLAND



**Figure K** Jessop, Hinni, Skinner and Woo (2010) survey area and reef extent

# Appendix 1.12 JESSOP, R.W. and MAXWELL, E. 2011

### Data source (report title):

JESSOP, R.W. and MAXWELL, E. 2011. Eastern Inshore Fisheries and Conservation Authority Research Report 2011. IFCA.

### Year data collected:

2011

### Data summary:

The survey programme was divided spatially into two main areas comprising West Lynn Knock and East Lynn Knock. The method used was similar to the 2010 methodology. RoxAnn AGDS was not conducted, instead 2010 ADGS data was used along with ground truthing data from 2010 to inform ground truthing during the 2011 survey.

Stratified positions were derived from interpolated models of 2010 ground truth data. A single sample was taken from each site in order to minimise disturbance. 95 grab samples were taken from the West Lynn Knock site and 45 from the East Lynn Knock site.

Poor weather conditions meant that ground truthing was confined to semi-stratified sampling using day grab to identify areas of reef. There was no phase 2 or 3 grab sampling.

Data from grab sampling were plotted using MapInfo GIS and interpolated using Vertical Mapper producing maps depicting sediment distribution and *Sabellaria* reef within the survey areas.

Gubbay (2007) thresholds were assigned using the criteria reef elevation and sediment consolidation only. Patchiness could not be estimated from single grabs.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: AGDS used from 2010 survey **(1.5)**
- Coverage: 150m spacing, East and West Lynn Knock heterogeneity = low **(1)**
- Positioning: GPS assumed **(2)**
- Standards: EIFCA report therefore it is assumed that internal standards were followed **(2)**
- Age: Data gathered in 2011 for Lincolnshire Coast sites therefore 4 years old. AGDS data from 2010, both under 6 years old **(3)**

**Ground truthing:**

- Technique: One phase of day grab sampling. Extent (inferred through interpolating GT data), sediment consolidation and reef elevation assessed **(1)**
- Positioning: GPS assumed **(2)**
- Density: West Lynn Knock was sampled 95 times and East Lyn Knock 45 times. One phase of GTing conducted. The survey was targeted at specific areas of reef indicating and therefore took place at a comparatively fine scale **(3)**
- Standards: EIFCA report therefore it is assumed that internal standards were followed **(2)**
- Age: Data gathered in 2011 for all sites therefore 4 years old **(3)**

**Data interpretation:**

- GT interpretation: Interpretation by EIFCA but the data used for the reef assessment is not provided **(2)**

- Remote sensing interpretation: Nearest neighbour interpolation of GT sites used to infer reef extent **(2)**
- Detail level: Extent (inferred through interpolating GT data), sediment consolidation and reef elevation used to define reefiness **(2)**
- Map accuracy: Internal EIFCA QA assumed **(2)**

**MESH Confidence Score: 66**

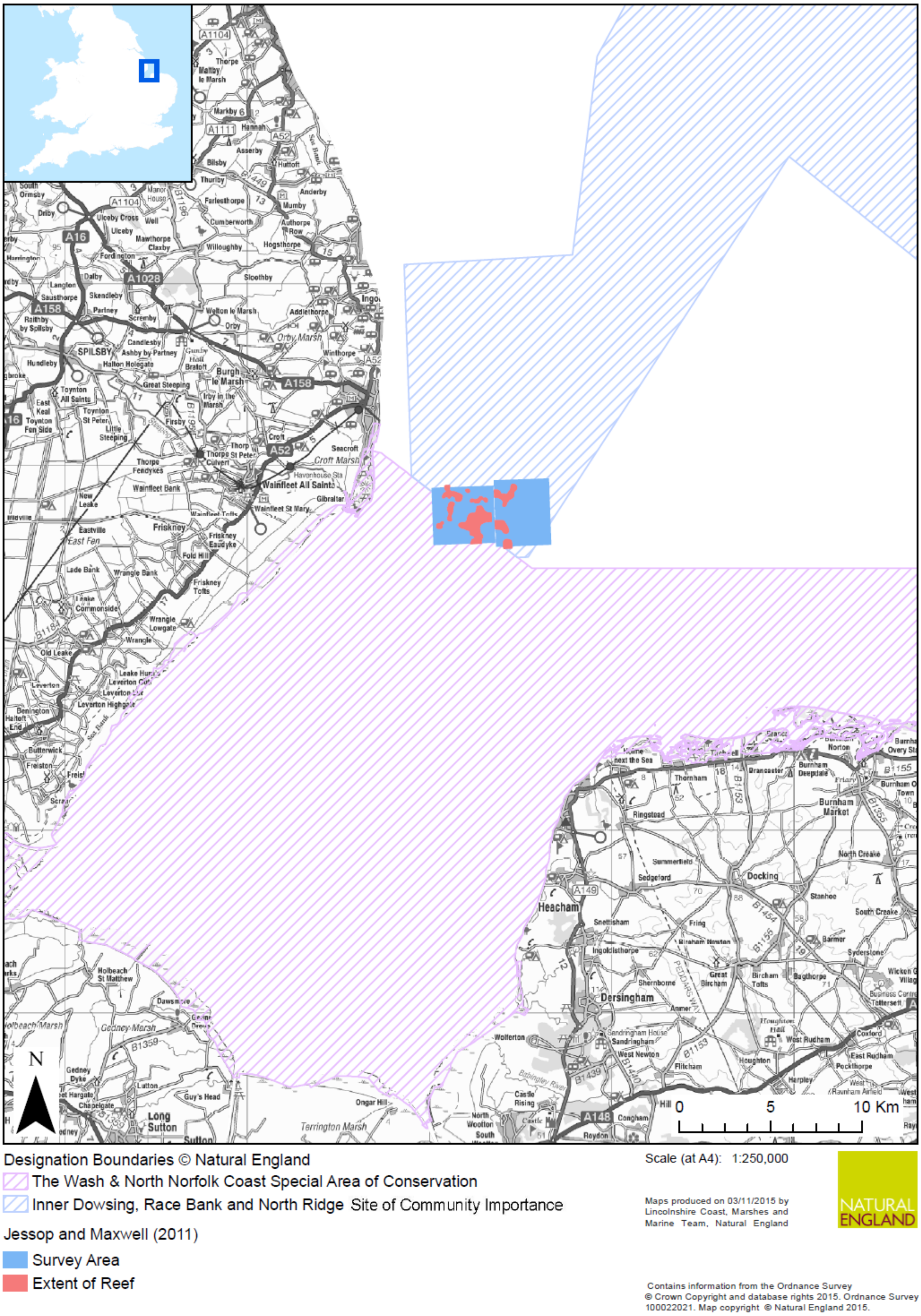



**Figure L** Jessop and Maxwell (2011) survey area and reef extent

# Appendix 1.13 JESSOP, R.W., ÅKESSON.O and SMITH, L.M. 2012

### Data source (report title):

JESSOP, R.W., ÅKESSON, O. and SMITH, L.M. 2012. Eastern Inshore Fisheries and Conservation Authority Research Report 2012. IFCA.

### Year data collected:

2012

### Data summary:

The aim of the survey was to concentrate on discreet areas that previous surveys had already identified as supporting *S. spinulosa* reef to improve resolution and therefore allow greater increased confidence in management decisions arising from a potential *S. spinulosa* byelaw. The sites surveyed were Lynn Knock, North Well and South Well.

RoxAnn™ AGDS was used to inform an intensive semi-stratified ground-truth programme. AGDS tracks were conducted 250m apart. The AGDS data was cleaned up using Excel and interpolated using Vertical Mapper Software. These interpolated models were used to inform the position of ground-truth stations. Ground truthing was done in two phases. Phase-1 day grab samples were taken from stations arranged in semi-stratified patterns around potential features. Data from phase-1 was used to create interpolated models of reef distribution. These models were used to inform phase-2 ground truthing where further grab samples was used to fine tune these models. To minimise sea bed disturbance a single sample was collected from each ground truth station and the following details recorded:

- Percentage volume of *S. spinulosa* fragments, height range of clumps, occupancy of *S. spinulosa* tubes (zero, low, moderate, high), % coverage of *S. spinulosa* clumps.

Photos were also taken of day grab samples and a third phase of ground truthing planned using an ROV camera to verify the results of the grab samples however poor weather prevented this stage. 150 stations were sampled by day grab at Lynn Knock, 63 in the North Well, 108 in the South Well.

Grab sample data plotted using MapInfo GIS and interpolated using Vertical Mapper. Used Gubbay (2007) criteria for assessing reef characteristic, specifically elevation and sediment consolidation as determining patchiness requires multiple grabs or clear video, neither of which was practical for this survey.

### MESH Confidence Assessment:

#### Remote sensing:

- Technique: RoxAnn™ AGDS used. **MESH-1.5**
- Coverage: AGDS Track spacing of 250. Moderate heterogeneity. **MESH-1**
- Positioning: GPS used. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2012, therefore two years old. **MESH-3**

#### Ground truthing:

- Technique: Grabs only were used. Extent (inferred through interpolating GT data), sediment consolidation and reef elevation assessed. **MESH-1**
- Positioning: GPS used. **MESH-2**

- Density: 150 stations were sampled by day grab at Lynn Knock, 63 in the North Well, 108 in the South Well. Comparatively broad scale compared to 2009-2011 surveys. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data gathered in 2012, therefore two years old. **MESH-3**

**Data interpretation:**

- Ground trothing: Expert interpretation by EIFCA, however data used to inform the reefiness assessment is not provided. **MESH-2**
- Remote sensing interpretation: Nearest neighbour interpolation of GT sites used to infer reef extent. **MESH-2**
- Detail: Extent (inferred through interpolating GT data), sediment consolidation and reef elevation used to define reefiness. **MESH-2**
- Map accuracy: Internal EIFCA QA assumed. **MESH-2**

**MESH Confidence Score: 64**

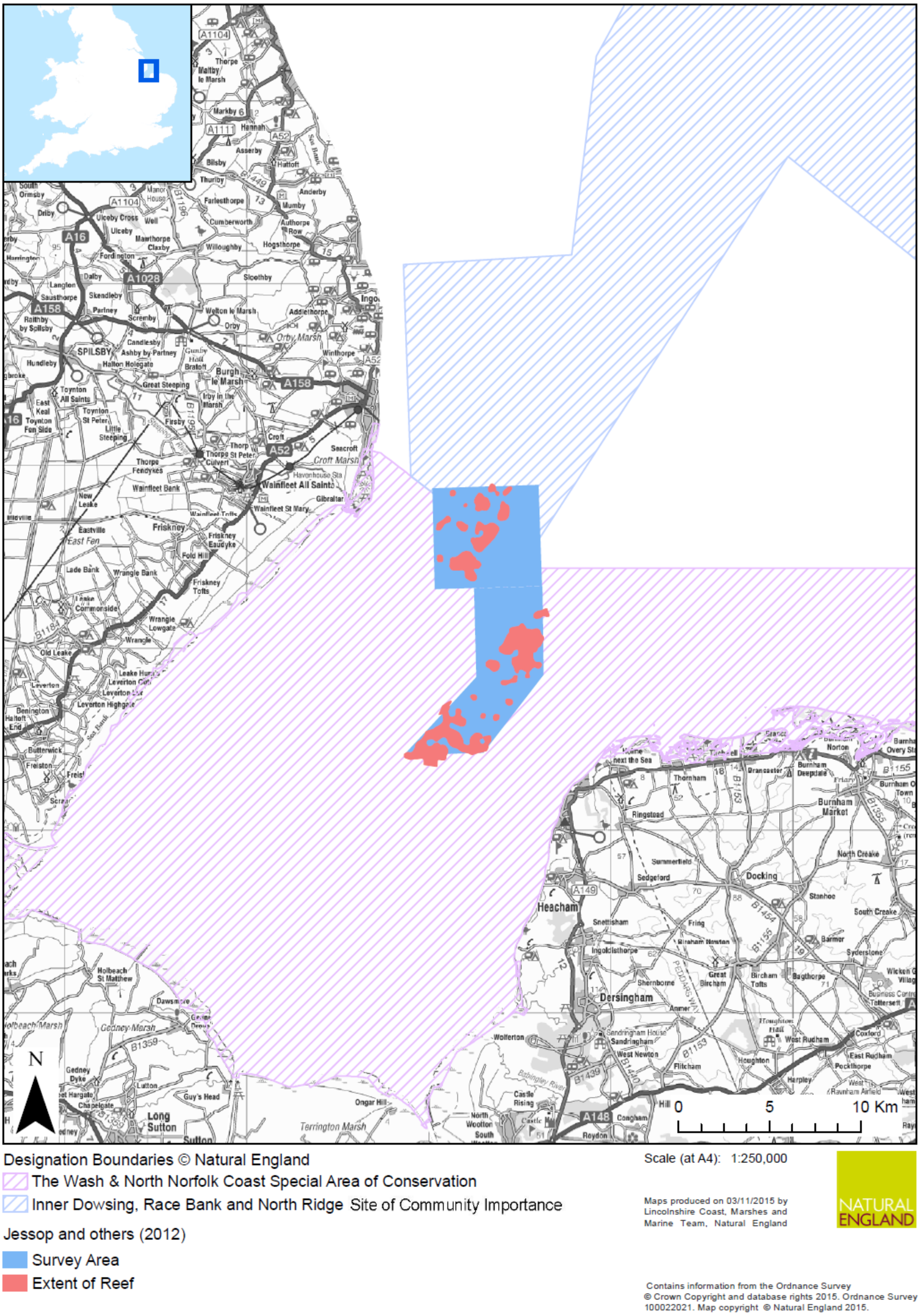



**Figure M** Jessop, Akensson and Smith (2012) survey area and reef extent

# Appendix 1.14 MEADOWS, B. and FROJÁN, C.B. 2012

### Data source (report title):

MEADOWS, B. and FROJÁN, C.B. 2012. Baseline Monitoring Survey of Large Shallow Inlet and Bay for The Wash and North Norfolk Coast SAC. Cefas.

### Year data collected:

2011

### Data summary:

Locations for potential survey were determined according to the availability of data to Natural England (NE) from other sources, and the likelihood of reef being present, as informed by the knowledge of the Eastern Inshore Fisheries and Conservation Authority (EIFCA) and Natural England. The final areas were then selected according to vessel time and cost necessary for survey them.

The four survey areas were two in the Well, one in Boston Road, and one in Boston Deep.

All field activities were carried out in accordance with the following recommendations:

- Biological monitoring: General Guidelines for Quality Assurance document (ICES, 2004)
- Quality Assurance in Marine Biological Monitoring (Addison, 2010)
- Recommended operating guidelines for underwater video and photographic imaging techniques (MESH)

An Edgetech 4200MP sidescan sonar system running with Edgetech DISCOVER acquisition software was used for acoustic survey. Positional data was provided through a Furuno GP36/37 GPS with IALA differential corrections. A marked umbilical was used to tow the system, providing layback information. The speed of the tow was varied according to the weather conditions in order to acquire the best possible quality data. Rapid assessments of ground type were made using the waterfall sonar record, and used to reduce the survey time over featureless or mobile sandy seabed. 50% coverage was used when isonifying the seabed.

An assessment of ground type based on the acoustic data was used to inform the ground truthing, with 30 stations being selected. Ground truthing took the form of underwater video and still photography, and grab samples for faunal extraction and particle size distribution analysis (PSA).

A Kongsberg camera and flash were used to acquire the underwater video and stills photography. This was mounted on a lightweight aluminium frame that could be used either as a sledge or a drop-down, depending on the seabed. During video-sampling the MESH ‘Recommended operating guidelines for underwater video and photographic imaging techniques’ were followed. The vessel was allowed to drift on the current while the camera was deployed, and 10 minutes of footage were recorded at each site. Tow length was adjusted according to visibility and the interest of the features observed (for example barren seabed or biogenic reef). Photographs were taken at one minute intervals as well as of features of interest.

Seabed samples were acquired using a mini-Hamon grab (0.1$m^2$ sample area). Samples with a volume of over 4 litres were deemed suitable. 500ml of these samples was taken for PSA, and the remainder was washed over a 1mm mesh sieve, and the infauna fixed in buffered 4% formalin solution. Grab samples were not taken at locations where hard substrate had been identified during the video footage.

Video footage was watched repeatedly in order to record changes in biotope across each transect, and quantify characteristic epifauna according to the MNCR SACFOR abundance scale. Physical features such as inclination and stability were also recorded. Epifauna from a maximum of three photographic stills of each biotope were also quantified according to the SCAFOR scale. MNCR habitat recording forms were used, and data was entered into marine recorder.

Faunal samples were processed by a specialist sub-contractor, participating in the National Marine Biological Analytical Quality Control Scheme and following the Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites. PRIMER software was used to conduct analyses on the resulting taxon-by-sample matrix. Standard metrics per sample, such as number of species, were calculated, and multivariate analyses were performed to identify patterns in community composition and structure.

### MESH Confidence Assessment:

#### Remote sensing:

- Technique: Sidescan sonar, frequency not specified. **MESH-2**
- Coverage: 50% Sidescan coverage. Moderate heterogeneity in the centre of the Wash. **MESH - 2**
- Positioning: GPS with IALA differential corrections used. **MESH – 3**
- Standards: External standards applied. **MESH – 3**
- Age: Data gathered in 2011. Therefore three years old. **MESH – 3**

#### Ground truthing:

- Technique: Hamon grab, video and still photography. Density of *S. spinulosa* was reordered but no reef was detected. However, methodology does not state how *S. spinulosa* reef was defined and detected during the survey. **MESH – 1**
- Positioning: GPS with IALA differential corrections used. **MESH – 3**
- Density: Every habitat class in the habitat maps was ground truthed at least 3 times. **MESH-3**
- Standards: MESH video and still photography standards were followed. **MESH -3**
- Age: Data gathered in 2011. Therefore three years old. **MESH – 3**

#### Data interpretation:

- GT interpretation: Expert interpretation and we have the data that was used to inform sediment and biotope classification. **MESH-3**
- Remote sensing interpretation: Acoustics interpreted using Ground Truthing, Ground Truthing provided. **MESH – 3**
- Detail level: Does not state how *S. spinulosa* reef was defined and detected during the survey. **MESH – 1**
- Map accuracy: Report received external QA. **MESH – 3**

### MESH Confidence Score: 83

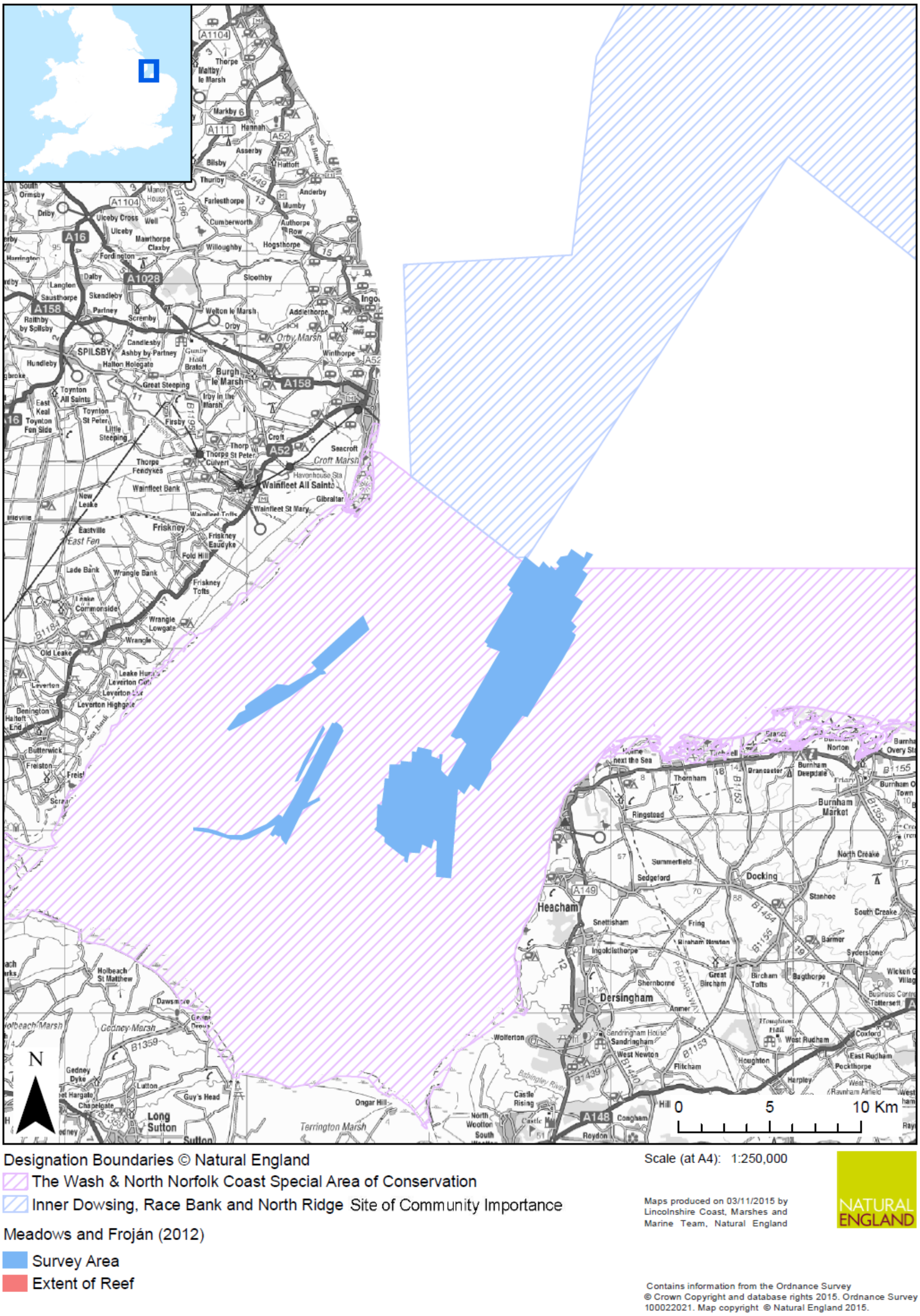



**Figure N** Meadows and Froján (2012) survey area and reef extent

## Appendix 1.15 EMU. 2008

### Data source (report title):

EMU. 2008. Acoustic surveys for the proposed Lincs wind farm sites for Centrica (Linc) Limited on behalf of Centrica Renewable Energy Limited.

### Year data collected:

2008

### Data summary:

Emu Ltd were commissioned to undertake a geophysical and hydrographic survey of the proposed Lincs Wind Farm area located east of Skegness. The survey aim was to determine the nature and distribution of sediment types and other features of interest throughout the wind farm site and cable route. Notably, the survey aimed to report on the presence or absence of biogenic reefs across the site.

The survey used:

- Swath bathymetry (100% coverage)
- Side scan sonar (200% coverage)
- AGDS
- Ground truthing with seabed samples and video (mini-hammon grabs)

High resolution dual frequency (100kHz/500kHz) Klein 3000 Sidescan sonar unit was used to map tracks of 100m providing coverage of 200%.

AGDS RoxAnn (100% coverage) was used with ground truthing to determine benthic habitats (notably reefs) bathymetry and subsurface geology.

Drop down video surveys were conducted at sites presenting seabed features or change in sediment composition as shown by side scan sonar. The use of low visibility system ensured that all sites were surveyed. Grab samples were taken using 0 .1 m2 Day grabs. Grabs were not taken if mussel beds, *S.spinulosa* reef or munitions were perceived on the video. *S.spinulosa* reef presence was determined by height (>2cm high), extent and patchiness. The method was developed through discussion with Natural England.

dGPS was used throughout the duration of the survey.

As part of Emu's quality assurance, the survey underwent a comprehensive review on completion.

GIS analysis included all data collected.

### MESH Confidence Assessment:

**Remote sensing:**

- Technique: High resolution dual frequency 100kHz/500kHz Klein 3000 Sidescan Sonar unit was used. **MESH-2.5**
- Coverage: SSS Operated at a range of 100m to give 200% SSS coverage and 100% bathymetry. Moderate heterogeneity. **MESH-3**
- Positioning: dGPS used. **MESH- 3**
- Standards: EMU internal3 standards were followed. **MESH-2**
- Age: Data gathered in 2008. **MESH-3**

**Ground truthing:**

- Technique: Video, grabs and three primary Gubbay Criteria used. **MESH- 3**
- Positioning: dGPS used. **MESH-3**
- Density: Every class in the mpa was sampled. **MESH-2**
- Standards: EMU internal standards were followed. **MESH-2**
- Age: Data gathered in 2008 therefore six years old. **MESH-3**

**Data interpretation:**

- Ground truthing interpretation: Expert data interpretation, Data used in reef assessment provided in Appendix H. **MESH-3**
- Remote sensing interpretation: Acoustics interpreted using GTing and GT data is provided. **MESH-3**
- Detail: reef has been defined using all three of the Gubbay (2007) primary reef characteristics. **MESH-3**
- Map accuracy: high accuracy, proven by internal accuracy assessment. **MESH- 2**

**MESH Confidence Score: 90**

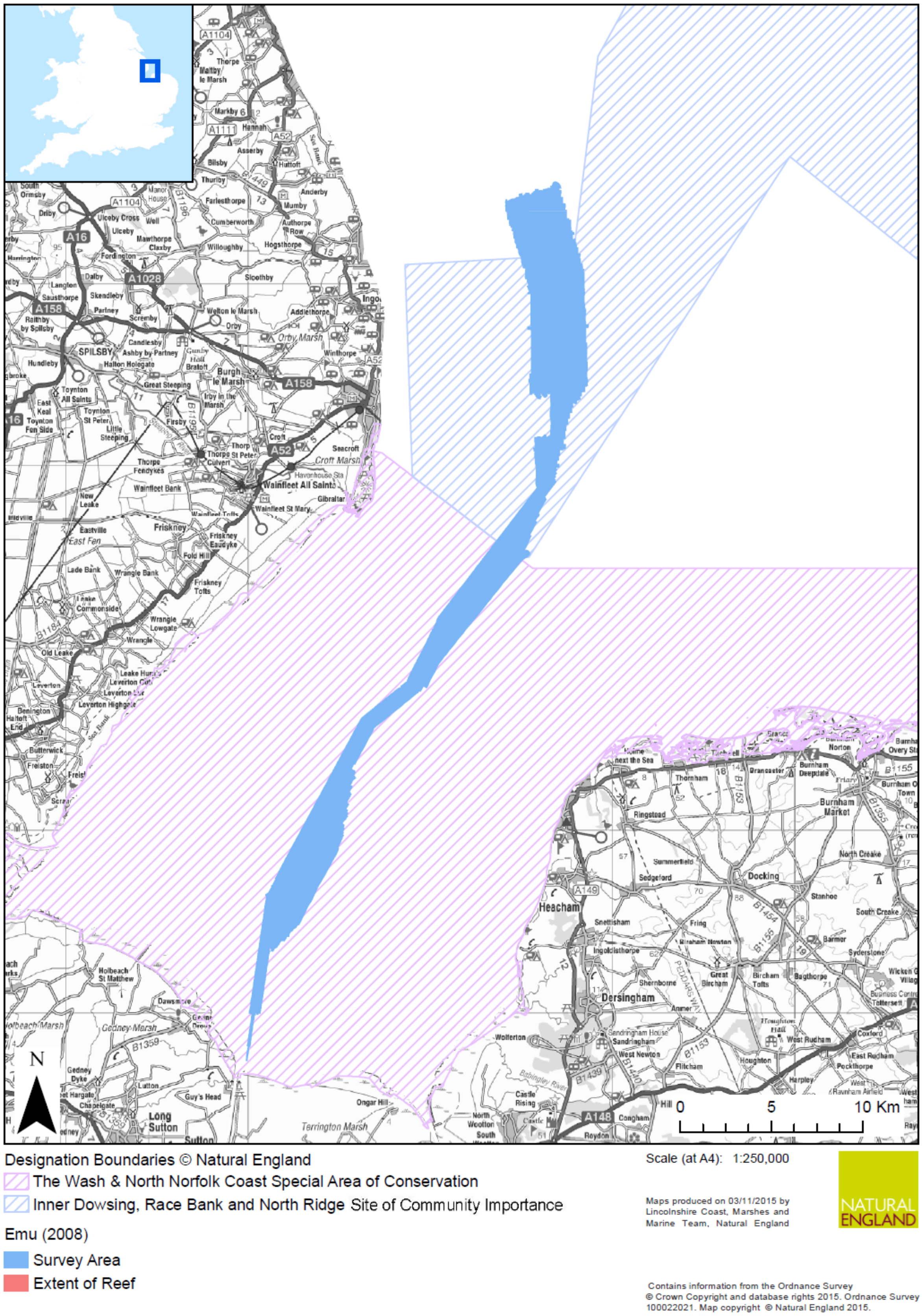



**Figure O** Emu (2008) survey area and reef extent

# Appendix 1.16 OSIRIS PROJECTS and EMU LTD. 2008

### Data source (report title):

OSIRIS PROJECTS and EMU LTD. 2008. Centrica energy and AMEC geophysical investigation at the proposed race bank and docking shoal wind farm sires with associated cable route corridors, Section 4, Greater Wash area cable route survey report.

### Year data collected:

2005-2006

### Data summary:

The report was commissioned by Centrica Energy for Emu Ltd and Osiris Projects to carry out high definition over the Round 2 proposed Wind Farms in the Race Bank/Docking Shoal areas and the associate cable routes using the following:

- Swath bathymetry (near 100% coverage, some small gaps are interpolated)
- Seismic reflection (Boomer Seismic system)
- Magnetometer
- Acoustic ground discrimination (single beam echo sounder-results not presented as not considered to add to other methods)
- High resolution side-scan sonar (75-100m, positional accuracy +-10m)

It was not a specific Annex I survey but aimed to provide information on the seabed habitats, bathymetry, sedimentology and geology of the area as well as locate possible metallic targets to assess the area for the potential wind farm construction and to provide information to engineers for this purpose.

In the main reference *S.spinulosa* reef was not located, however data from grab samples (n=34) and drop down video (n=38) from a 2006 survey used to inform Lincs Offshore Wind farm and Environmental Statement (below) suggested potential *S.spinulosa* reef found at three locations, stations 9, 25 and 37. Height was suggested to be 5-10cm, the patchiness was not quantified but suggested well consolidated compared to other areas (station 4) with high *S.spinulosa* abundance.

Appenidx 18 RACE BANK & DOCKING SHOAL PROPOSED WIND FARMS Macro-benthic Ecology Surveys of the Associated Cable Route Corridor Technical Report February 2007 Report No. 06/J/1/03/0885/0627:

### MESH Confidence Assessment:

#### Remote sensing:

- Technique: Sidescan sonar used. **MESH-2.5**
- Coverage: Coverage of 100% and moderate heterogeneity. **MESH-3**
- Positioning: Assume GPS used. **MESH-2**
- Standards: No standards reported therefore, as scientific organisation carried out the survey; it is assumed that internal standards were followed. **MESH-2**
- Age: Data collected in 2005-2006 therefore eight years old. **MESH-2**

#### Ground truthing:

- Technique: Bussell and Saunders cite pre-Gubbay (2007) therefore full Gubbay (2007) assessment not possible. No *S.spinulosa* found and lacks Ground thruth data only appears in Annex 18. **MESH-**
- Positioning: Assumes GPS. **MESH-2**

- Density:
- Standards:
- Age: Data collected 2005-06 therefore eight years old. **MESH-2**

**Data interpretation:**

- Ground truthing: Possible expert interpretation but no *S.spinulosa* found to interpret. **MESH**
- Remote sensing interpretation: Unknown ground truthing and lack of data. **MESH**
- Detail:
- Map accuracy: Unsure on level of QA. **MESH**

### MESH Confidence Score:

This survey was not designed to detect *S. spinulosa* reef, and as such there is a risk that it was under reported. There is insufficient data available to comprehensively assess the MESH confidence criteria.

**85** given by Bussell & Saunders previously

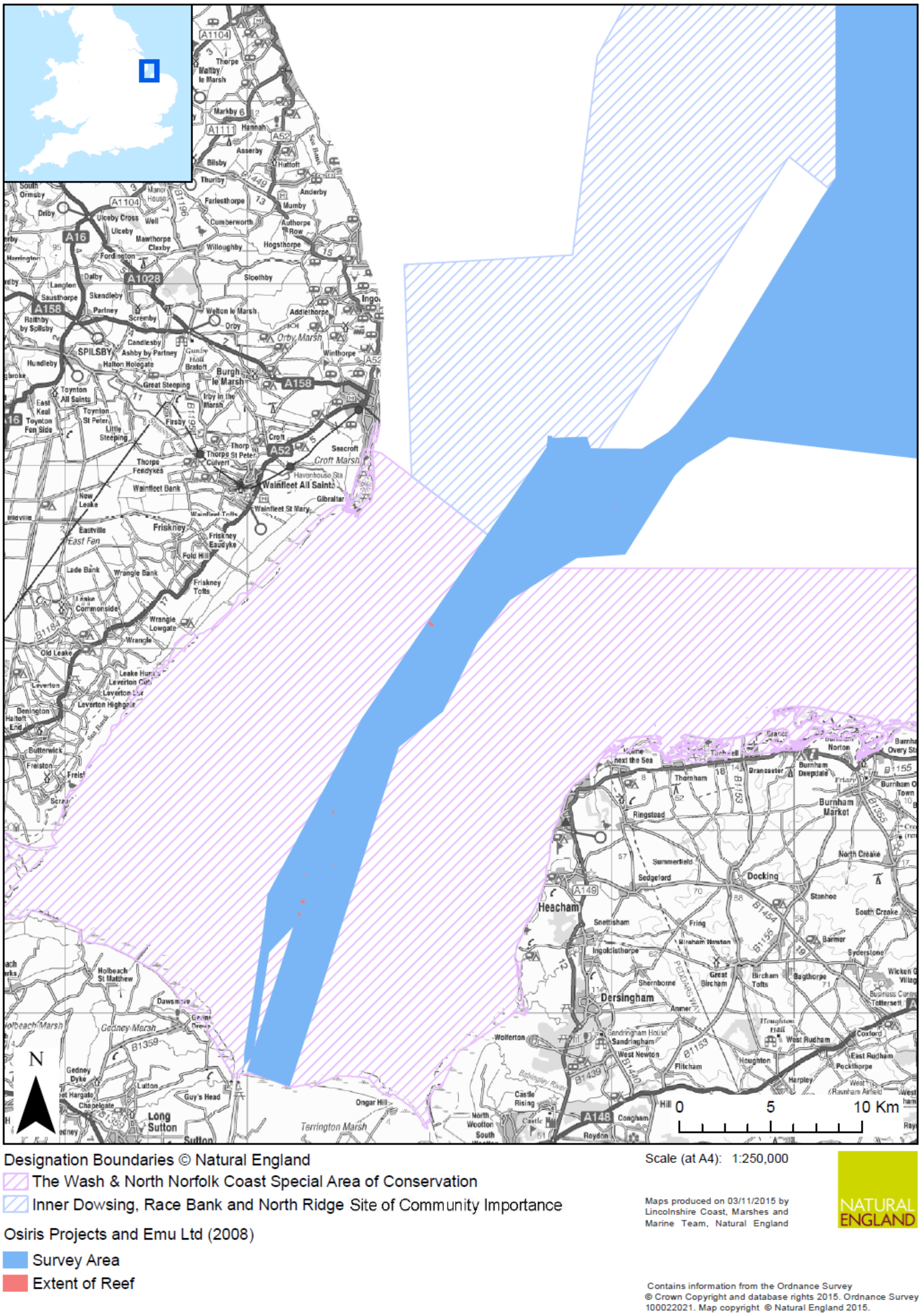



**Figure P** Osiris Projects and Emu Ltd (2008) survey area and reef extent

# Appendix 2 Survey Templates not used in the synthesis

## Appendix 2.1 FOSTER-SMITH, R.L., SOTHERAN,I. and WALTON,R.1997

**Data source (report title):**

FOSTER-SMITH, R.L., SOTHERAN, I. and WALTON, R. 1997. Broad-scale mapping of habitats and biota of the sub-littoral seabed of The Wash. English Nature Report no 238.

**Year data collected:**

1996

**Data availability:**

No digital data and no raw data available.

**Data summary:**

This report details a habitat mapping project that was not specifically designed to identify *S. spinulosa* reef. It was used to train ESFJC in AGDS and supplemented with towed video sledge (12), day grabs (25) and trawls (4). Side Scan Sonar (SSS) was used but not as a main technique and was not fully analysed. Ground truth sites were selected by distinct areas in microplot not after an in depth analysis. Extent covers all of The Wash but way below 100% (see for example Map 1 on p.17) with a significant amount of interpolation but exact Figures not stated. No reef assessment was made but the following observation was made: 'Tube reefs were patchy and low-lying and did not form substantial reefs. They are widely distributed with highest abundance at entrance to The Wash.'

**MESH Confidence Assessment:**

As no reef assessment was made with low coverage of data and small amount of data presented the 1996 ESFJC Survey was **excluded** from the synthesis, and it was not confidence assessed.

**MESH Confidence Score: N/A**

# Appendix 3 MESH Criteria and Scoresheet

The question "How appropriate were the sampling techniques to determining the biological nature of the seabed?" was believed to be sufficient to capture the information needed for assessing reef and prevented sampling technique from being over-weighted in the MESH scores. The question "How appropriate were the sampling techniques in determining the geophysical nature of the seabed?" was therefore excluded from the current project's confidence assessment.

The question "What level of information is contained" was adapted to evaluate how many of the Gubbay (2007) criteria were considered when interpreting the survey data. The criteria were split into primary and secondary criteria (Appendix 4).

| | RemoteTechnique | RemoteCoverage | RemotePositioning | RemoteStdsApplied | RemoteVintage | BGTTechnique | PGTTechnique | GTPositioning | GTDensity | GTStdsApplied | GTVintage | GTInterpretation | RemoteInterpretation | DetailLevel | MapAccuracy | Remote score | GT score | Interpretation score | **Overall score** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foster Smith 1999 | 1.5 | 1 | 3 | 2 | 1 | 1 | | 3 | 3 | 2 | 1 | 3 | 3 | 1 | 3 | 56.67 | 61.11 | 83.33 | **67** |
| Foster Smith 2000 | 1.5 | 1 | 3 | 2 | 1 | 1 | | 3 | 2 | 2 | 1 | 3 | 3 | 1 | 3 | 56.67 | 55.56 | 83.33 | **65** |
| Foster Smith and White 2001 | 2 | 1 | 2 | 2 | 1 | 1 | | 2 | 3 | 2 | 1 | 2 | 2.5 | 1 | 3 | 53.33 | 55.56 | 70.83 | **60** |
| Foster Smith 2001 | 2 | 1 | 3 | 2 | 1 | 1 | | 3 | 2 | 2 | 1 | 2 | 3 | 1 | 3 | 60.00 | 55.56 | 75.00 | **64** |
| Jessop and Stoutt 2006 (targeted) | 1.5 | 1 | 2 | 2 | 2 | 1 | | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 56.67 | 55.56 | 66.67 | **60** |
| Jessop and Stoutt 2006 additional | 1.5 | 1 | 2 | 2 | 2 | 0 | | 2 | 0 | 2 | 2 | 3 | 2 | 0 | 2 | 56.67 | 33.33 | 58.33 | **49** |
| Jessop Graves and Woo 2006 Well | 1.5 | 1 | 2 | 2 | 2 | 1 | | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 56.67 | 55.56 | 58.33 | **57** |
| Jessop Graves and Woo 2006 Rest | 1.5 | 2 | 2 | 2 | 2 | 1 | | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 63.33 | 55.56 | 58.33 | **59** |
| Jessop Woo Harwood 2008 | 1.5 | 1 | 2 | 2 | 2 | 1 | | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 56.67 | 50.00 | 50.00 | **52** |
| Woo 2008 | 1.5 | 2 | 2 | 2 | 2 | 3 | | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 63.33 | 77.78 | 75.00 | **72** |
| Jessop and others. 2009 W. Lynn Knock | 1.5 | 2 | 2 | 2 | 3 | 2 | | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 70.00 | 77.78 | 58.33 | **69** |
| Jessop and others. 2009 East Lynn Knock | 1.5 | 2 | 2 | 2 | 3 | 2 | | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 70.00 | 77.78 | 58.33 | **69** |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jessop and others. 2009 East dog's head | 1.5 | 1 | 2 | 2 | 2 | 2 | | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 56.67 | 77.78 | 58.33 | **64** |
| Jesssop and others. 2009 Seal Sands | 1.5 | 2 | 2 | 2 | 3 | 2 | | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 70.00 | 77.78 | 58.33 | **69** |
| Jessop and others. 2009 South Well | 1.5 | 1 | 2 | 2 | 2 | 2 | | 2 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 56.67 | 77.78 | 58.33 | **64** |
| Emu 2009 | 2.5 | 3 | 3 | 2 | 3 | 2 | | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 90.00 | 83.33 | 91.67 | **88** |
| EIFCA 2010 | 1.5 | 1 | 2 | 2 | 3 | 2 | | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 63.33 | 72.22 | 58.33 | **65** |
| EFICA 2011 | 1.5 | 1 | 2 | 2 | 3 | 1 | | 2 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 63.33 | 66.67 | 66.67 | **66** |
| EIFCA 2012 | 1.5 | 1 | 2 | 2 | 3 | 1 | | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 63.33 | 61.11 | 66.67 | **64** |
| Meadows and Froján 2012 | 2 | 2 | 3 | 3 | 3 | 3 | | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 86.67 | 100.00 | 83.33 | **90** |

| **Confidence field** | **Confidence group** | **Confidence question** | **S.spinulosa Reef** |
|---|---|---|---|
| Remote Technique | How good is the remote sensing? | Were the techniques used appropriate for the ground type? | Expected effectiveness of sampling method in detecting reef extent from Limpenny and others. (2010), Best methods for identifying and evaluating *S. spinulosa*:<br><br>AGDS=Poor-Moderate<br>Multibeam backscater=Poor<br>Multibeam bathymetry=Moderate-Good<br>Sidescan Sonar High=Moderate-Good<br>Sidescan Sonar Low=Moderate<br><br>1=Poor<br>1.5=Poor-Moderate<br>2=Moderate<br>2.5=Moderate-Good<br>3=Good<br><br>If AGDS and SS are gathered use SS score.<br>If SS frequency is not discussed, assume low. |

<table>
<tr><td>Remote Coverage</td><td>How good is the remote sensing?</td><td>Was the ground covered appropriately?</td><td>An assessment of the coverage of the remote sensing data including consideration of heterogeneity of the seabed: (See Coverage x Heterogeneity matrix to the right)<br><br>Coverage scores – use these to determine coverage then combine with heterogeneity assessment to derive final scores<br>3 = good coverage; 100% (or greater) coverage or AGDS track spacing <50m<br>2 = moderate coverage; swath approx 50% coverage or AGDS track spacing <100m<br>1 = poor coverage; large gaps between swaths or AGDS track spacing >100m<br><br>Final scores<br>3 = good coverage OR moderate coverage + low heterogeneity<br>2 = moderate coverage + moderate heterogeneity OR poor coverage + low heterogeneity<br>1 = moderate coverage + high heterogeneity OR poor coverage + moderate or high heterogeneity<br>Limpenny and others. (2010) state that detailed AGDS surveys have track spacing of 25-100m.<br>Use Foster-Smith and Sotheran (1999) to define heterogeneity of survey area (Lynn Knock = low, Well = moderate, Surrounding Wash = low).<br>If survey area covers areas of different heterogeneity, use highest heterogeneity value for survey.
<table>
<tr><td></td><td></td><td colspan="3">Heterogeneity</td></tr>
<tr><td></td><td></td><td>Low</td><td>Moderate</td><td>High</td></tr>
<tr><td rowspan="3">Coverage</td><td>Poor</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Moderate</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Good</td><td>3</td><td>3</td><td>3</td></tr>
</table></td></tr>
<tr><td>RemotePositioning</td><td>How good is the remote sensing?</td><td>How were the positions determined for the remote data?</td><td>An indication of the positioning method used for the remote data:<br>3 = differential GPS<br>2 = GPS (not differential) or other non-satellite ‘electronic’ navigation system<br>1 = chart based navigation, or dead-reckoning</td></tr>
</table>

| | | | |
|---|---|---|---|
| RemoteStdsApplied | How good is the remote sensing? | Were standards applied to the collection of the remote data? | An assessment of whether standards have been applied to the collection of the remote data. This field gives an indication of whether some data quality control has been carried out:<br>3 = remote data collected to approved standards<br>2 = remote data collected to 'internal' standards<br>1 = no standards applied to the collection of the remote data<br><br>If scientific organisation complete work but do not much mention the standards that were followed assume internal standards were followed. |
| RemoteVintage | How good is the remote sensing? | How recent are the remote sensing data? | An indication of the age of the remote data:<br><br>Whilst it is true to say that the confidence in reef being present in a particular year wouldn't change, it is still useful to reduce the confidence as data gets older, as a reflection that reef is less likely to be present in that area with time.<br><br>Protocol E defines three levels of confidence for detecting habitat FOCI with high temporal variability (for example *S. spinulosa* reef) presence based on age of evidence:<br><br>High = data less than 6 years old<br>Moderate = 6-12 years old<br>Low = older than 12<br><br>Boundaries were chosen to reflect the six year reporting cycle of Marine and Coastal Access Act 2009. Six years is also the N2K condition assessment reporting cycle.<br><br>3 = ≤ 6 years old<br>2 = 7 - 12 years old<br>1 = >12 years old |

| Confidence field | Confidence group | Confidence question | S.spinulosa Reef |
|---|---|---|---|
| BGTTechnique | How good is the ground-truthing? | How appropriate were the sampling techniques to determining the biological nature of the seabed? | In order to assess the characteristics that Gubbay (2007) defines reef by in full a combination of grabs and video must be gathered to ground truth acoustic data, therefore:<br><br>3 = Grabs and video used AND all three primary Gubbay (2007) reef characteristics are assessed.<br>2 = Grabs and video used AND three primary/secondary Gubbay (2007) reef characteristics are assessed.<br>1 = Grabs AND/OR video AND less than three Gubbay (2007) reef characteristics are assessed.<br><br>See the Interpretation criteria Detail Level for the definition of primary/secondary reef characteristic.<br><br>For surveys that did not detect reef but state in their methodology that they would have assessed reef using Gubbay (2007) approach score 2. If they also state that three primary Gubbay (2007) criteria would have been assessed then award 3. |
| PGTTechnique | How good is the ground-truthing? | How appropriate were the sampling techniques to determining the geophysical nature of the seabed? | Not applicable to *S. spinulosa* reef. |
| GTPositioning | How good is the ground-truthing? | How were the positions determined for the ground-truth data? | An indication of the positioning method used for the ground-truth data:<br>3 = differential GPS<br>2 = GPS (not differential) or other non-satellite ‘electronic’ navigation system<br>1 = chart based navigation, or dead-reckoning |
| GTDensity | How good is the ground-truthing? | Was the density of sampling adequate? | An assessment of what proportion of the polygons or classes (groups of polygons with the same ‘habitat’ attribute) actually contain ground-truth data:<br><br>3 = Every class in the map classification was sampled at least 3 times<br>2 = Every class in the map classification was sampled<br>1 = Not all classes in the map classification were sampled (some classes have no ground-truth data)<br><br>For surveys which interpolated GT data to identify reef extent, if the GT regime is described as being broad scale score, if fine scale score 3. ALSO if there are 3 phases of GTing score 3 and if less than 3 score 2. |

| | | | |
|---|---|---|---|
| GTStdsApplied | How good is the ground-truthing? | Were standards applied to the collection of the ground-truth data? | An assessment of whether standards have been applied to the collection of the ground-truth data. This field gives an indication of whether some data quality control has been carried out:<br>3 = ground-truth samples collected to approved standards<br>2 = ground-truth samples collected to ‘internal’ standards<br>1 = no standards applied to the collection of ground-truth samples<br>If scientific organisation complete work but do not much mention the standards that were followed assume internal standards were followed. |
| GTVintage | How good is the ground-truthing? | How recent are the ground-truth data? | Whilst it is true to say that the confidence in reef being present in a particular year wouldn’t change, it is still useful to reduce the confidence as data gets older, as a reflection that reef is less likely to be present in that area now.<br>Protocol E defines three levels of confidence for detecting habitat FOCI with high temporal variability (for example *S. spinulosa* reef) presence based on age of evidence:<br><br>High = data less than 6 years old<br>Moderate = 6-12 years old<br>Low = older than 12<br><br>Times were chosen to reflect 6 year reporting cycle of Marine and Coastal Access Act 2009.<br>6 years is also the N2K condition assessment reporting cycle.<br>3 = ≤ 6 years old<br>2 = 7 - 12 years old<br>1 = >12 years old |

| Confidence field | Confidence group | Confidence question | S.spinulosa Reef |
| --- | --- | --- | --- |
| GTInterpretation | How good is the interpretation? | How were the ground-truthing data interpreted? | An indication of the confidence in the interpretation of the ground-truthing data.<br><br>3 = Evidence of expert interpretation; data used for reef assessment provided.<br>2 = Evidence of expert interpretation, but data used for reef assessment not provided.<br>1 = No evidence of expert interpretation; limited description of reef assessment provided.<br><br>Expert defined as scientific organisation.<br>Reef assessment in this instance is whatever methods they used to define/identify reef and not necessarily the Gubbay (2007) reef assessment. |
| Remote Interpretation | How good is the interpretation? | Were the remote data appropriately interpreted? | "Appropriate technique" will differ between the remote sensing sampling methods utilised.<br><br>Sidescan Sonar<br>3 = Acoustics interpreted using GTing and GT data is provided.<br>2 = Acoustics interpreted using GTing but GT data is not provided.<br>1 = No GT data is used to interpret acoustics.<br><br>AGDS<br>3 = GTing used to inform maximum likelihood supervised classification of images derived from interpolation of AGDS track data.<br>2 = AGDS used to inform the GTing locations; GT data then interpolated to produce maps of S. spinulosa reef extent (for example ESFJC/EIFCA surveys) OR interpolation of AGDS data without any supervised classification.<br>1 = GTing used but GT data is not provided.<br><br>Average the score if two types of interpretation were used |

<table>
<tr>
<td>DetailLevel</td>
<td>How good is the interpretation?</td>
<td>What level of information is contained?</td>
<td>Gubbay (2007) identify 7 defining characteristics of S. spinulosa reef. (Annex 4.1) Of these Gubbay (2007) identified three characteristics as being primary considerations when defining reef: elevation, area and patchiness<br><br>3 = reef has been defined using all three of the Gubbay (2007) primary reef characteristics.<br>2 = reef has been defined using three of the Gubbay (2007) reef characteristics, primary or secondary.<br>1 = reef has been defined using less than 3 of the Gubbay (2007) reef characteristics, primary or secondary OR did not use Gubbay (2007) reef assessment.<br><br>If reef extent is inferred through interpolation of GT data record as primary characteristic but note method of assessment.<br><br>Patchiness can only be properly assessed through multiple grabs or video.<br><br>For surveys that did not detect reef but state in their methodology that they would have assessed reef using Gubbay (2007) approach score 2. If they also state that three primary Gubbay (2007) criteria would have been assessed then award 3.<br>
<table>
<tr><th>Gubbay (2007) Reef characteristics</th><th>Primary/secondary consideration</th></tr>
<tr><td>Elevation (average tube height)</td><td>Primary</td></tr>
<tr><td>Area ($m^2$)</td><td>Primary</td></tr>
<tr><td>Patchiness (% cover)</td><td>Primary</td></tr>
<tr><td>Sab spin population density</td><td>Primary?</td></tr>
<tr><td>Sediment consolidation</td><td>Secondary</td></tr>
<tr><td>Associated biodiversity</td><td>Secondary</td></tr>
<tr><td>Longevity</td><td>Secondary</td></tr>
</table>
</td>
</tr>
<tr>
<td>MapAccuracy</td>
<td>How good is the interpretation?</td>
<td>How accurate is the map at representing reality?</td>
<td>If scientific organisation assume map was subject to internal accuracy assessment.<br>If report has been commissioned then assume map was subject to external accuracy assessment.</td>
</tr>
</table>

# Appendix 4 Gubbay (2007) Reef characteristics

**Table C** Gubbay (2007) Reef characteristics

| Gubbay (2007) Reef characteristics | Primary/secondary consideration |
|---|---|
| Elevation (average tube height) | Primary |
| Area (m2) | Primary |
| Patchiness (% cover) | Primary? |
| Sab spin population density | Primary |
| Sediment consolidation | Secondary |
| Associated biodiversity | Secondary |
| Longevity | Secondary |

# Appendix 5 Moran’s I spatial autocorrelation

## Calculating centroids in ArcGIS

1) In the map document, open the attribute table for the polygon feature class.

2) In the attribute table, navigate to Table Options > Add Field and add two new fields of type Double. Name one 'Latitude' and the other 'Longitude'.

3) Right-click the Longitude field and select Calculate Geometry.

4) In the Calculate Geometry dialog box, select 'X Coordinate of Centroid' from the Property drop-down menu. Click OK.

5) Right-click the Latitude field and select Calculate Geometry.

6) In the Calculate Geometry dialog box, select 'Y Coordinate of Centroid' from the Property drop-down menu. Click OK.

7) Export to a table:

   a) In the attribute table, select Table Options > Export.
   b) Specify a name and location for the new table.

8) Make an XY Event layer:

   a) Navigate to ArcToolbox > Data Management Tools > Layers and Table Views > Make XY Event Layer.
   b) Add the new table (from step 7) as the XY Table.
   c) For the X Field, select the Longitude field.
   d) For the Y Field, select the Latitude field.
   e) Name the new event layer.
   f) Select the spatial reference or coordinate system.
   g) Click OK.

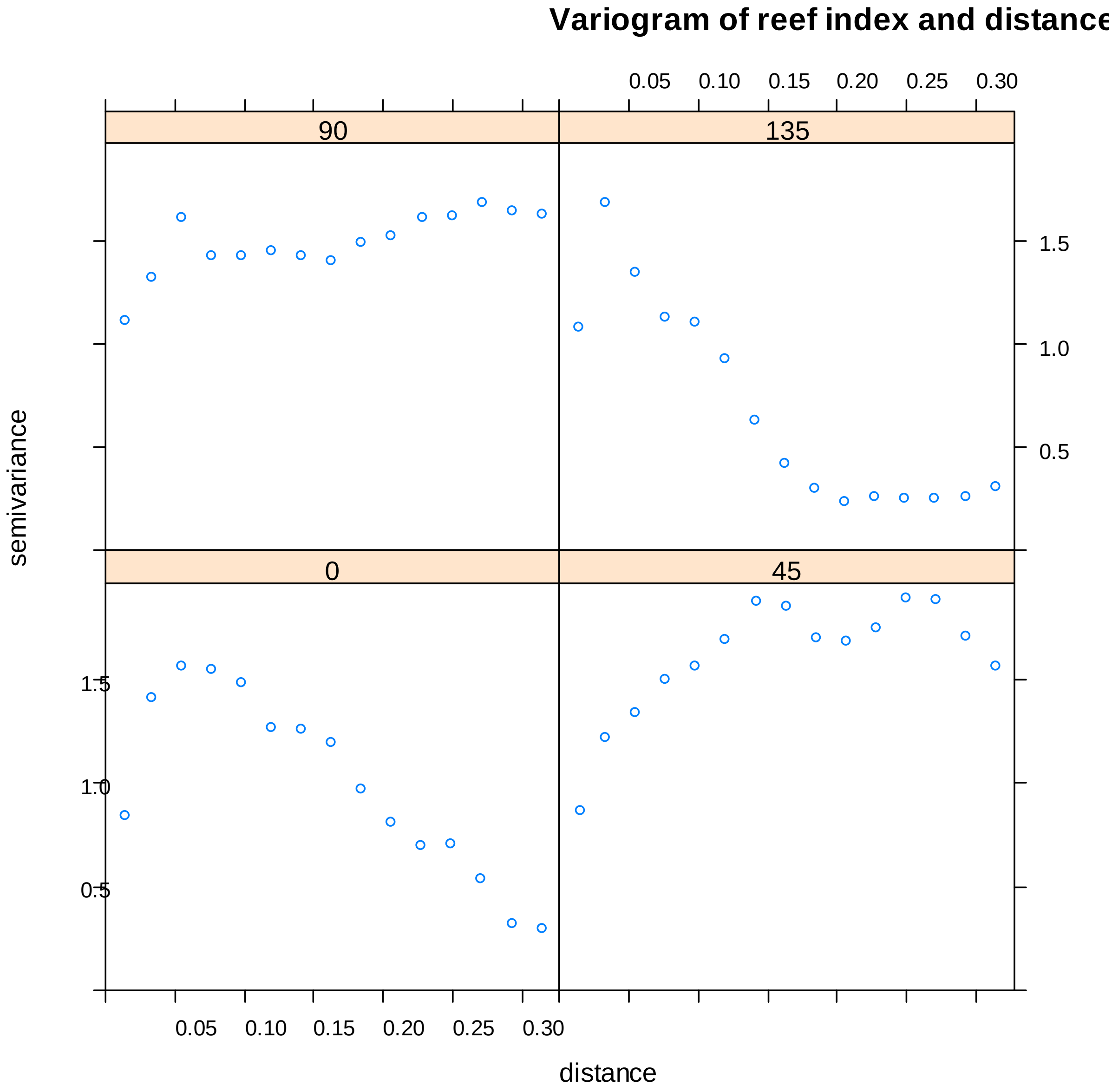



**Figure Q** Variogram showing correlation of distance between random points and reef index in four directions

## 5/3 R. Code for calculation of Moran's I

****** Moran's I autocorrelation coefficient between polygons' reef index value and the inverse distance between polygon (based on the Euclidean distance of centroids calculated from WGS84 latitude/longitude).

```
> library(ape)

> reefdata <- read.table("2014_Synthesis_ReefIndex_XY.txt", sep=",", header=T)

> reef.dists <- as.matrix(dist(cbind(reefdata$X, reefdata$Y)))

> reefs.dists.inv <- 1/reef.dists

> diag(reefs.dists.inv) <- 0

> Moran.I(reefdata$Reef_Index, reefs.dists.inv)
```

****** Moran's I autocorrelation coefficient between the reef index value of 1,000 random unstratified points

```
> Moran.I(reef.random$Reef_Index, reefs.random.dists.inv)
```

116

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