



NAFC Marine Centre
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Highlands and Islands

**Razor clam biology, ecology, stock assessment, and exploitation: a
review of *Ensis* spp. in Wales**

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Razor clam biology, ecology, stock assessment, and exploitation: a review of *Ensis* spp. in Wales

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Executive summary

Razor clams of the genus *Ensis* are the subject of valuable fisheries and are exploited by hand gathering in the intertidal and by vessels using various gear types in the subtidal. Concerns about the sustainability of razor clam harvesting in Welsh waters have recently resulted in the closure of an intertidal area and the need to determine effective measures to assess stocks. The aim of this report is to provide a review of the biology of razor clams in Welsh waters; to map known, and potential, areas of exploitation; and to review and recommend possible stock assessment methodologies for both intertidal and subtidal fisheries.

Of the species of razor clam present in Welsh waters, three are of commercial significance and the fishery has mainly targeted *Ensis siliqua*, with other species of much less significance. There are very few records of the invasive *Ensis directus* which has recently become abundant to fishable levels in areas of continental Europe and on the east coast of England.

Key aspects of the biology of razor clams relating to their assessment and exploitation are that: they have a very patchy distribution; the density of individuals within fished beds is highly variable; there are inconsistent recruitment patterns; populations can extend from the intertidal into the subtidal and are age structured with larger individuals found lower down the shore.

Mapping of known razor clam harvesting areas has been carried out to identify recent fishing activity. Predictive modelling in GIS was undertaken using available data, to identify potential distributions for each of the species of interest.

There are a wide range of potential methods for the assessment of *Ensis* spp. stocks. For intertidal surveys, both hydraulic and manual survey methods were considered with the latter deemed to be most cost effective. A combination of techniques would be recommended in order to ensure that a wide size range of individuals was captured in intertidal sampling. For subtidal sampling, hydraulic dredging is considered to be a reliable and well-studied methodology; however, it was recommended that this be supplemented with a new electrofishing technique involving cameras. This may enable sampling within areas where dredging might not be appropriate, such as marine protected areas. For all suggested assessment methods it is important to determine any potential source of bias in the data collection early in the process so that measures can put in place to reduce it or to incorporate it into the assessment process (e.g., appropriate training for intertidal sampling or quantification of gear efficiency for subtidal sampling).

A range of data gaps and potential methods for collecting additional data were considered and outlined. Consideration of the chosen assessment methods and proposed management structures will influence the data required. It is recommended that surveys for stock assessment are supported by an appropriate fisheries data collection programme and that both fisheries and assessment data are effectively integrated within a clearly defined management plan. The early establishment of management goals will help to inform appropriate data collection and assessment methodologies.

Crynodeb gweithredol

Mae cyllyll môr o'r genws *Ensis* i'w cael mewn pysgodfeydd gwerthfawr a chânt eu hecsbloetio â llaw yn yr ardaloedd rhynglanwol, a gan longau sy'n defnyddio gwahanol fathau o offer yn yr ardaloedd islanwol. Yn ddiweddar, mae pryderon ynglŷn â chynaliadwyedd cynaeafu cyllyll môr yn nyfroedd Cymru wedi arwain at gau ardal rynglanw, a'r angen i bennu mesurau effeithiol i asesu stociau. Nod yr adroddiad hwn yw darparu adolygiad o fioleg cyllyll môr yn nyfroedd Cymru; mapio ardaloedd lle gwyddys eu bod yn cael eu hecsbloetio ac ardaloedd posibl; ac adolygu ac argymhell methodolegau posibl i asesu stociau mewn pysgodfeydd rhynglanwol ac islanwol.

O blith y rhywogaethau cyllyll môr sydd i'w cael yn nyfroedd Cymru, mae tri o bwysigrwydd masnachol, ac mae'r bysgodfa wedi targedu *Ensis siliqua* yn bennaf, gan fod y rhywogaethau eraill yn llawer llai arwyddocaol. Prin iawn yw'r cofnodion am yr *Ensis directus* goresgynnol sydd wedi dod yn doreithiog yn ddiweddar i lefelau pysgotadwy mewn ardaloedd o gyfandir Ewrop ac ar arfordir dwyreiniol Lloegr.

Ymysg yr agweddau allweddol ar fioleg cyllyll môr sy'n ymwneud â'u hasesu a'u hecsbloetio y mae: dosbarthiad tameidiog iawn sydd ganddynt; mae dwysedd yr unigolion mewn gwelyau sy'n cael eu pysgota yn amrywiol iawn; mae'r patrymau recriwtio yn anghyson; gall poblogaethau ymestyn o'r ardaloedd rhynglanw i'r islanw ac maent wedi'u strwythuro yn ôl oedran gydag unigolion mwy i'w cael yn is i lawr y traeth.

Gwnaed gwaith mapio mewn ardaloedd cynaeafu cyllyll môr hysbys i ganfod gweithgaredd pysgota diweddar. Defnyddiwyd proses modelu rhagfynegol mewn GIS gan ddefnyddio'r data a oedd ar gael, i nodi dosbarthiadau posibl ar gyfer pob un o'r rhywogaethau o ddiddordeb.

Ceir ystod eang o ddulliau posibl ar gyfer asesu stociau *Ensis spp.* Ar gyfer arolygon rhynglanw, ystyriwyd dulliau arolygu hydrolig ac â llaw, gyda'r un olaf yn cael ei ystyried yn fwyaf cost-effeithiol. Byddai cyfuniad o dechnegau yn cael ei argymhell er mwyn sicrhau bod ystod eang iawn o unigolion yn cael eu cipio yn y gwaith samplu rhynglanwol. Ar gyfer samplu islanwol, ystyrir bod llusgrwydo hydrolig yn fethodoleg ddibynadwy sydd wedi'i hastudio'n dda; fodd bynnag, argymhellwyd y dylid defnyddio hefyd dechneg electrobysgota newydd sy'n cynnwys camerâu. Gyda'r dechneg hon gall gwaith samplu gael ei wneud mewn ardaloedd lle na fyddai llusgrwydo yn briodol, fel ardaloedd morol a ddiogelir. Gyda phob dull asesu a awgrymwyd, mae'n bwysig pennu unrhyw ffynhonnell ragfarn bosibl yn fuan yn y broses casglu data, er mwyn gallu rhoi mesurau ar waith i'w lleihau neu i'w hymgorffori yn y broses asesu (ee, hyfforddiant priodol i wneud gwaith samplu rhynglanw, neu fesur effeithlonrwydd offer ar gyfer samplu islanwol).

Ystyriwyd ac amlinellwyd ystod o fylchau yn y data a dulliau posibl ar gyfer casglu data ychwanegol. Bydd ystyried y dulliau asesu a ddewiswyd a'r strwythurau rheoli arfaethedig yn dylanwadu ar y data sy'n ofynnol. Argymhellir bod arolygon ar gyfer asesu stoc yn cael eu cefnogi gan raglen casglu data pysgodfeydd briodol a bod data pysgodfeydd a data asesu yn cael eu hintegreiddio'n effeithiol mewn cynllun rheoli sydd wedi'i ddiffinio'n glir. Bydd sefydlu nodau rheoli yn gynnar yn helpu i lywio methodolegau casglu data ac asesu priodol.

1 Background and aims

Razor clams are burrowing marine bivalves that inhabit sandy substrates from the intertidal region to depths in excess of 40 m. Razor clams are traditionally hand gathered at low tide, and are also commercially fished by divers and vessels using a variety of gear types in a number of small-scale European fisheries.

The sustainability of razor clam hand gathering in Wales has been questioned following recent concerns about over-fishing and high-profile cases of mass harvesting on intertidal beds. Due to the concerns about the status of Welsh razor clam stocks in early 2017, a temporary closure of all fishing for razor clams at Llanfairfechan and Penmaenmawr was put in place, in order for a survey to be conducted to assess the health of the stocks. This closure has since been extended to the end of 2018.

Following the increased pressure from hand gathering, and growing interest from commercial fishers to establish a fishery in Wales, this study aimed to inform the Welsh Government before consideration can be given to establishing a sustainable razor clam fishery. The purpose of this report is to:

- Provide details of the biology and ecology of razor clams in Wales, including specific information on the species present through a comprehensive literature review and interviews with key experts and stakeholders.
- Map known areas of razor clam harvesting, based on interviews with enforcement and conservation officers, and map areas where a potential fishery could occur, based on a predictive habitat mapping approach.
- Review razor clam stock assessment methods for the intertidal and subtidal, and provide recommendations on the most cost effective approaches.

2 Biology and ecology of razor clams in Wales

Razor clams, or razorfish, are bivalve molluscs of the Solenidae family which are characterised by their elongate and fragile shells. A number of large razor clam species found in UK waters of the genus *Ensis* are targeted commercially. Due to their restricted distribution, populations of razor clams are vulnerable to over-exploitation and a detailed understanding of their biology and ecology is needed to inform the effective assessment and management stocks.

2.1 Description of relevant razor clam species

Of the native species of razor clams found in Welsh waters, three have been of commercial significance. These are the “common razor shell”, *Ensis ensis* (Linnaeus, 1758), the “pod razor shell”, *Ensis siliqua* (Linnaeus, 1758), and the “curved razor shell”, *Ensis magnus* Schumacher, 1817 (previously known as *Ensis arcuatus*). Of these species, *E. siliqua* and *E. magnus* are more typically targeted by routine harvesting and are more prevalent in UK historical landings (Chapman 2006; Hauton *et al.*, 2011). In the context of recent activity in Wales, *E. siliqua* are of the greatest importance as it has been the target of intertidal hand collection (G. Hughes, pers. comm. 2018) and the most prevalent in commercial trials (e.g., Trundle, 2004). *Ensis siliqua* has also made up the vast bulk of commercial landings from the Irish Sea along the east coast of Ireland (Fahy and Carroll, 2007; Cross *et al.*, 2014).

Ensis spp. have elongate, smooth, fragile shells coloured white on the inside, with reddish-brown and purplish-brown markings on the outside separated by a diagonal line, and an olive green periostracum (Hill, 2006). The left and right valves gape at both the anterior and posterior ends. Species belonging to the genus *Ensis* can be distinguished from other razor clam species by inspection of the hinge teeth, having two teeth in the left valve which fits between one tooth on the right valve (Holme, 1951). Relatively obvious distinguishing details on the most relevant species are given below:

- *Ensis siliqua*: the dorsal and ventral margins of the shell are parallel and almost straight; a white foot with brown lines; and length up to approximately 200 mm.
- *Ensis magnus*: an almost straight dorsal margin and curved ventral margin; with shell width consequently greatest mid length; truncated ends; a white foot with brown lines; and length up to approximately 150 mm.
- *Ensis ensis*: a slender and curved shell (more curved than *E. magnus*); equally curved dorsal and ventral valve margins; rounded ends; a pale red-brown foot; and maximum length up to approximately 125 mm.

These distinguishing characteristics can be imprecise and difficult to identify, especially for smaller animals, in which case there are a number of additional features which can be inspected (for comprehensive reviews, see Holme (1951), Van Urk (1964), and Breen *et al.*, (2011)). There are also genetic tools capable of identifying specific razor clam species (e.g., Fernández-Tajes and Méndez, 2007; Freire *et al.*, 2008).

The key razor clam species and their generalised anatomy are illustrated in Figure 2.1 and have been identified in Welsh waters in a number of studies (e.g., Holme, 1954; Henderson and Richardson, 1994; Coates, 1999; Trundle, 2004). These three key species have also recently been identified in dredge catches during a stock assessment in Liverpool Bay (Aitken and Knott, 2018).

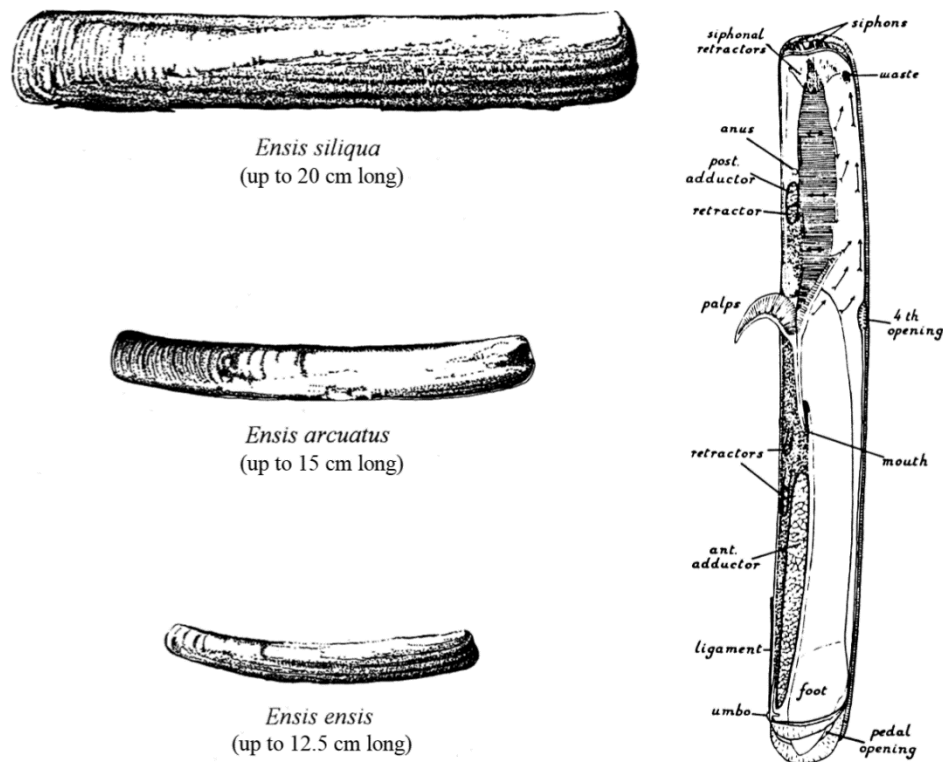


Figure 2.1. Commercially exploited razor clam species (*Ensis* spp.) and generalised anatomy of *Ensis* spp., adapted from Pyke (2002).

In a survey of the Southport area of Liverpool Bay, a “fishable abundance” of the “bean solen” or “egg razor shell”, *Pharus legumen* (Linnaeus, 1758), was identified (Aitken and Knott, 2018) and occasional high abundances recorded off the east coast of Ireland (Fahy and Gaffney, 2001). Similarly, *P. legumen* was reported to be a significant bycatch species in Carmarthen Bay (Trundle, 2004). However, there is little biological information available about this species and it has not previously been targeted in any UK razor clam fisheries. *Pharus legumen* can reach a length of 100 to 130 mm (Coates, 1999, Aitken and Knott, 2018), is almost straight with slightly wider posterior, and can be distinguished by the central position of the hinge. Although *P. legumen* is not known to be recreationally or commercially targeted for the human consumption market, a substantial bycatch of *P. legumen* could be commercially significant as an angling bait product (C. Tundle, pers. comm. 2018).

Other native razor clam species that may be found in Welsh waters are not likely to be commercially significant due to their small size and/or scarcity. This includes the “grooved razor clam”, *Solen marginatus* Pulteney, 1799, which is found around the UK in waters off Wales (Hauton *et al.*, 2011) with reports of isolated individuals in the north west of Carmarthen Bay (Trundle, 2004), and is characterised by a straight shell with parallel margins and length up to 120 mm. There are isolated records of *Ensis minor* (Chenu, 1843) in Wales and elsewhere in the UK (Hauton *et al.*, 2011); however, due to the lack of studies on this species and to its similarity in appearance to *E. siliqua* its prevalence and distribution is not well understood and there are no records of it being of commercial or recreational significance. Similarly, the smaller razor clam species *Phaxas pellucidus* (Pennant, 1777) is common around the whole UK with a maximum length of 40 mm (Neish, 2008) but is not known to be targeted in any recreational or commercial harvesting.

The invasive “American jackknife clam”, *Ensis directus* Conrad, 1844 sensu Abbott, 1954, is thought to have been introduced to Europe in the ballast water of ships from the east coast of the US and there are now established populations on the east coast of England with isolated records in and around Welsh waters (Gollasch *et al.*, 2015). There is no evidence of recreational or commercial interests in the harvesting of *E. directus* in Wales, likely due to its present scarcity.

2.2 Behaviour

Razor clams are normally buried vertically in sediment with only their siphons visible on the surface. In addition to respiration, the siphons are used for suspension feeding on particulate organic matter, principally phytoplankton (Breen *et al.*, 2011). Razor clams use their large “foot” to burrow and to anchor themselves in the sediment. When disturbed, they are capable of rapidly digging to depths in excess of 1 m or of emerging out of their burrows. *Ensis magnus* has been observed to also “swim” horizontally along the bottom of the seabed by flicking the foot and jetting water out of the pedal opening to move forward 3 to 5 m at a time (Pyke, 2002). It has been suggested that this swimming behaviour allows *Ensis* spp. to migrate to more favourable substrate and growing conditions, and may be responsible for the replenishment of exploited intertidal (Coates, 1999) and subtidal (Fahy and Gaffney, 2001) beds. Diver observations of the spouts of sediment and water ejected from the siphons of burrowing razor clams have shown *E. magnus* to be more sensitive than *E. siliqua* in taking immediate evasive burrowing behaviour following human disturbance (Muir, 2003). The burrowing behaviour of *E. siliqua* and *E. ensis* is described in detail in Henderson and Richardson (1994).

2.3 Distribution and habitat preferences

Razor clams can be found on practically every beach in the UK where there is appropriate sediment of sufficient depth and some protection from wave action (Holme, 1954). *Ensis siliqua* and *E. magnus* have a circum-UK distribution while *E. ensis* have a more restricted distribution, being predominately recorded along the English Channel and the coast of Wales (Hauton *et al.*, 2011) although thought to be less common in West Wales (Coates, 1999). *Ensis siliqua* are the dominant species present in the heavily exploited beaches in North Wales (G. Hughes, pers. comm. 2018) and the most commonly observed razor clam species during hydraulic dredging trials in Carmarthen Bay (Trundle, 2004).

In the UK, *E. directus* was first recorded at Southend-on-Sea, Essex, England in 1989 (Howlett, 1990). It is now found on the UK east coast from the Humber and the Wash to the Thames Estuary and English Channel (Palmer, 2003; Palmer, 2004). Isolated records describe the presence of *E. directus* in: the Firth of Forth, Scotland, in 2000; in Angle Bay, Pembrokeshire, South Wales, in 2003; and in several locations of Liverpool Bay in 2011 (Gollasch *et al.*, 2015).

Ensis spp. inhabit sandy substrates from the intertidal to depths generally described as approximately 40 m (e.g., Holme, 1954; Pyke, 2002, Tuck *et al.*, 2000). Peak densities of *E. ensis* were observed at depths of about 10 m (Holme, 1954) and have been recorded at depths of up to 60 m (Holme 1953; Hill, 2006). In contrast, *E. siliqua* are most commonly distributed at extreme low water and just below (Holme, 1954) or at depths of 3 to 7 m (Gaspar and Monteiro, 1998).

Muir (2003) observed that a substantial depth of sand is required for an area to be suitable for razor clams, noting that *Ensis* spp. were not present where the sand depth was less than 30 cm or where there was overlying stones. *Ensis siliqua* are found in clean fine sands (Holme, 1951; Muir, 2003) while *E. magnus* favours more coarse-grained sand but has a relatively wide grain size tolerance (Holme, 1954; Muir, 2003; Hauton *et al.*, 2011). *Ensis ensis* are found in fine, sometimes muddy sand, similar to *E. siliqua* but with a greater tolerance to silt and coarse particles (Holme, 1951; Holme, 1954; Muir, 2003). *Ensis* spp. require some degree of shelter from wave action, depending on the stability of the sediment, and are absent from beaches fully exposed to prevailing winds and swell. However, of the above species *E. siliqua* are the most tolerant of wave exposure with *E. magnus* and *E. ensis* restricted to more sheltered beaches (Holme, 1954). On the exposed west coast of Ireland, *E. magnus* is the dominant species where they are found in the lee of islands, rocks, and reefs where there is shelter from the westerly swell (Fahy *et al.*, 2001). *Pharus legumen* are described as favouring muddy sand at or around the low water mark (Coates, 1999).

High subtidal densities of *Ensis* spp. have been found in areas with relatively strong tidal currents, such as in the centre of tidal channels and around headlands (Bailey *et al.*, 1998) which may be beneficial for their food supply. Similarly, it has been suggested that intertidal razor clam aggregations may concentrate where food accumulates due to tides and wave action (Henderson and Richardson, 1994).

Areas which superficially appear to be ideal habitats can actually be unsuitable for razor clams due to other factors such as: freshwater run-off, organic sediment content, and sediment penetrability (Muir, 2003). It has been observed that *Ensis* spp. are not present in sediments that are black below the surface (indicative of anoxic conditions), nor are they as prevalent in water of reduced salinity such as in estuaries (Holme, 1954).

Due to their particular habitat preferences, it is unusual for different razor clam species to be found living together (Fahy *et al.*, 2001). However, as *Ensis* spp. have some overlapping tolerances, mixed populations have been recorded (Holme, 1951). In mixed razor clam beds on the west coast of Scotland, *E. magnus* was found to consistently be more abundant than *E. siliqua* (Muir, 2003). *Pharus legumen* have previously been observed in abundance with small (< 60 mm) *E. siliqua* in the Irish Sea (Fahy and Gaffney, 2001).

Sampling of large commercially exploited razor clam beds off the east Irish coast found overall densities of 1.45 to 1.52 *Ensis* spp. m⁻², with localised high densities of 20 *Ensis* spp. m⁻² recorded in separate sites (Pyke, 2002). Similarly, studies in Carmarthen Bay have reported densities of 3 to 6 *Ensis* spp. m⁻² in Hauton *et al.* (2011) and up to 9 *Ensis* spp. m⁻² in Trundle (2004). Studies in the Western Isles, Scotland, reported combined densities of *E. magnus* and *E. siliqua* ranging from 2.2 to 14.6 m⁻² (Chapman, 2006). Following settlement, densities of *E. directus* have been reported in excess of 2 000 m⁻² (Palmer, 2004) in the Wash, England, with adult populations measured as high as 200 m⁻² (Palmer, 2003). The variation in observed density is likely related to the highly heterogeneous distribution of *Ensis* spp., even within beds, and effects associated with different survey methods. This has been demonstrated by the failure to find stocks in some studies, including during gear trials in Liverpool Bay (Aitken and Knott, 2018). In the Irish Sea, Fahy and Gaffney (2001) reported that observations from divers suggested some densities of *E. siliqua* exceeding 200 m⁻² but that 1.5 m⁻² was an appropriate figure for the overall bed. In Carmarthen Bay, Coates (1999) describes apparent

densities of *Ensis* spp. (mainly *E. siliqua*) of the order 6 m⁻² in dredge trials and at least 4 to 6 m⁻² in diver observations. Lower densities of 0.5 m⁻² in intertidal beds at Carmarthen Bay have been attributed to the impact of harvesting by anglers for bait (Coates, 1990).

Studies have found that the size distribution of *Ensis* spp. in intertidal beds varies spatially, with smaller individuals found further up the shore and the largest animals found at the extreme low water of spring tides (Henderson and Richardson, 1994). This spatial variation has suggested to be related to down-shore migration of juveniles into adult populations capable of tolerating stronger currents. Shallow areas in razor clam beds could also be more favourable for settlement, with some evidence of higher recruitment densities at the shallowest points of beds (Hernández-Otero *et al.*, 2014c).

2.4 Reproductive biology and growth

Breeding of *Ensis* spp. is annual with gonad development in both sexes during the winter months and spawning during the spring/summer followed by a sexual rest period. Studies in North Wales on *E. ensis*, indicated a spawning period around July with individuals found to be spent in August (Henderson and Richardson, 1994). Other studies have highlighted how environmental conditions, varying geographically and between years, can influence the timing and length of the spawning period (Darriba *et al.*, 2004). Analysis of *E. siliqua* in the Irish Sea from 2011 showed that the first spawning individuals were observed during January with peak spawning in March and continuing through to July; thought to be a consequence of colder than normal temperatures leading to an earlier and longer spawning period (Cross *et al.*, 2014). In Darriba *et al.* (2004) observations of *E. siliqua* in northwest Spain indicated spawning occurred in April to May with a long sexual rest period between summer and autumn. The spawning period of *E. magnus* in northwest Spain has been observed to begin in late January to February and through until May to July (Hernández-Otero *et al.*, 2014b).

Following spawning, fertilised eggs develop into mobile larvae hours after fertilisation, and spend approximately one month as plankton passing through several larval stages (for details see Muir, 2003). The larvae then settle, attaching themselves to sediment by byssal threads, before burrowing into the sand as juveniles at about 0.5 cm in length. In contrast with the regular spawning observed, the successful settlement and recruitment of UK razor clam populations appears to be sporadic in most cases (Woolmer, 2007), with studied populations showing multi-modal size-frequency distributions (Hauton *et al.*, 2011) skewed towards larger size classes (Henderson and Richardson 1994). Juveniles are often found infrequently and at low densities, further indicating intermittent recruitment (Coates, 1999). Settlement also appears to be patchy, leading to dense (commercially viable) beds in some areas (Chapman 2006).

The age structure of razor clam beds indicates negative adult/juvenile interactions, in that beds are often dominated by similarly aged year classes (Woolmer, 2007) and evidence from commercially exploited beds where juveniles are especially abundant in fished areas with reduced adult densities (Del Piero and Dacaprile, 1998). High densities of adult *Ensis* spp. are thought to reduce growth rate and hinder settlement since young razor clams struggle to compete for food and space. Further, adults may be predators of their own eggs and larvae (Hauton *et al.*, 2011).

Native *Ensis* spp. generally have life spans in excess of 10 years (Woolmer, 2007) with individuals up to 18 years recorded in Wales, up to 19 years in Ireland (Fahy and Gaffney, 2001), and in excess of 20 years in Scotland (Breen *et al.*, 2011). In contrast, the invasive *E. directus* appears to be a shorter lived species with few individuals exceeding four years and the largest individuals having an estimated age of seven years (Armonies and Reise, 1999; Palmer, 2004).

Razor clams have separate sexes and the sex ratio is usually found to be equal (e.g., Gaspar and Monteiro, 1998; Darriba *et al.*, 2005) and very low incidence of hermaphroditism is recorded (Cross *et al.*, 2014). In some cases, male razor clams appear to grow at a slightly faster rate than females, which is suggested to explain beds of *E. siliqua* in the Irish Sea where males are larger and more abundant (Fahy and Gaffney, 2001).

Razor clam growth rate has been shown to be sensitive to environmental parameters (Henderson and Richardson, 1954; Hernández-Otero *et al.*, 2014a), for example sediment composition, salinity, temperature, chlorophyll-a concentration, and wave exposure. Muir and Moore (2003) reported that laboratory-reared *E. siliqua* recruits measured three months after spawning were approximately 11 mm long, and found that growth was negligible in the winter. That study also reported a mean length of 33 mm at 1 year 3 months old and 40 mm at two years old. *Ensis* spp. collected in North Wales exhibited similar growth rates but different asymptotic lengths (Figure 2.2). In the same study, an average growth rate of $92.8 \pm \mu\text{m d}^{-1}$ was estimated for surviving animals in the length range 50 to 100 mm (Henderson and Richardson, 1994). Further studies of the growth of *Ensis* spp. in the Orkney Islands was shown to be similar to in North Wales (Robinson and Richardson, 1998). Relevant *Ensis* spp. have relatively similar growth rates but grow to different maximum sizes, given as 130 mm in *E. ensis*, 150 mm in *E. magnus*, and 200 mm in *E. siliqua* (Chapman, 2006).

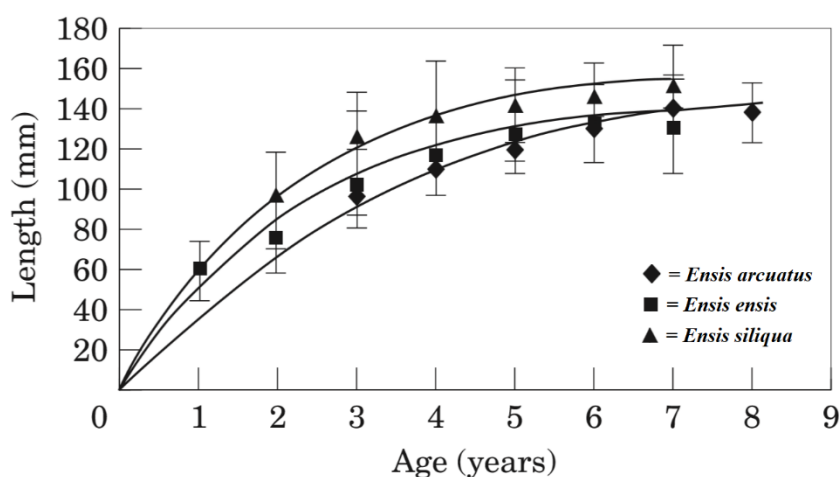


Figure 2.2. Growth curves from *Ensis* spp. collected in North Wales. Curves are fitted using the von Bertalanffy equation. Adapted from Robinson and Richardson (1998) using data derived from Henderson and Richardson (1994).

2.5 Size and age at maturity

It is generally thought that *Ensis* spp. growth rates are similar for both sexes and that they mature at around 100 mm in length at three years old (e.g., Chapman, 2003). Under present EU legislation, a Minimum Landing Size (MLS) of 100 mm length is required for all *Ensis* spp., and 65 mm for *P. legumen* (Aitken and Knott, 2018). However, there are clear size and developmental differences between specific species so the appropriateness of the established MLS in each case varies. For example, results from laboratory studies of *E. siliqua* from the Clyde Sea have indicated that it would take at least four to five years to reach the MLS with the smallest sexual mature individual found to be 118 mm (Muir and Moore, 2003).

Previous work in Wales has also shown that *E. siliqua* are greater than 100 mm in length before reaching maturity and being capable of spawning (Henderson and Richardson, 1994). Similarly, Muir and Moore (2003) reported that the smallest sexually mature *E. magnus* was found to be 73 mm long and that 51% were sexually mature in the category 81 to 90 mm long, while 100% sexual maturity did not occur until 121 to 130 mm long. For *E. siliqua*, Muir and Moor (2003) found that 100% sexual maturity was not reached until 131 to 140 mm in length, suggesting that a distinction should be made between the two species in the application of a MLS and in other management measures. In contrast, in northwest Spain Hernández-Otero *et al.* (2014a) found that 50% of sampled *E. magnus* would reach sexual maturity at a length of 79.5 mm, potentially during its first year of life, with 100% of animals found to be mature at lengths of 100 to 105 mm. Such comparisons further demonstrate the developmental dependencies on environmental conditions, with growth observed to be slower at more northerly latitudes (Muir and Moore, 2003). In Scotland, a MLS of 120 mm for *E. magnus* and 130 mm for the larger and later maturing *E. siliqua* has been suggested to allow all individuals to become sexually mature and spawn at least once (Muir, 2003).

In contrast to observed sexual development of native *Ensis* spp., *E. directus* exhibits a fast rate of growth during the first two years of life and is capable of reproducing as early as two years old (Pyke 2002). It has been suggested that some populations of *E. directus* on the east coast of England would barely exceed the 100 mm MLS by the end of their life and that a lower MLS may be appropriate for this species (Palmer, 2004).

2.6 Mortality

The main predators of adult razor clams are known to include bird species such as eider ducks, *Somateria mollissima* (Linnaeus, 1758), and scoter, *Melanitta nigra* (Linnaeus, 1758) (Aitken and Knott, 2018). Crabs have been observed to feed on exposed razor clams (Murray *et al.*, 2014) including: green crabs, *Carcinus maenas* (Linnaeus, 1758), harbour crabs, *Liocarcinus depurator* (Linnaeus, 1758), common hermit crabs, *Pagurus bernhardus* (Linnaeus, 1758), and velvet swimming crabs, *Necora puber* (Linnaeus, 1767), which have been observed scavenging on disturbed razor clam beds (Robinson and Richardson, 1998; Tuck *et al.*, 2000; Hall *et al.*, 1990). The edible crab, *Cancer pagurus* (Linnaeus, 1758), is thought to be the main predator of razor clams in many areas (Tuck *et al.*, 2000) as it is able to actively excavate them (Hall *et al.*, 1991). Starfish, mainly *Marthasterias glacialis* (Linnaeus, 1758), have been observed extracting *Ensis* spp. from their burrows (Breen *et al.*, 2011). Fish species, such as sand gobies, *Pomatoschistus minutus* (Pallas, 1770), are known to attack exposed razor clams (Robinson and Richardson, 1998; Murray *et al.*, 2014). Demersal fishing methods, such as beam trawling, are known to cause significant razor clam mortality and the foot and siphons

of damaged *Ensis* spp. have been found in the stomachs of whiting, *Merlangius merlangus* (Linnaeus, 1758), in recently trawled areas in the Irish Sea (Kaiser and Spencer, 1994).

Mass mortalities of *Ensis* spp. have been observed intermittently in Wales and generally attributed to adverse weather events, in particular storms, with tens of thousands of razor clams reportedly washed up on beaches in the south of Wales during winter storm events (Coates, 1999). Other explanations of mass mortality incidents relate to unfavourable environmental conditions, and potentially natural post-spawning phenomenon (Hill, 2006). Despite observations of vast numbers of dead razor clams being washed up on beaches in Liverpool Bay, a gear trial study was unable to find exploitable beds in offshore subtidal areas (Aitken and Knott, 2018). Following mass mortality events, herring gulls, *Larus argentatus* (Pontoppidan, 1763), have been observed consuming exposed *E. siliqua* and *E. magnus* in the Clyde Sea (Muir, 2003), and *E. directus* in the Wadden Sea (Cadée, 2000).

2.7 Summary of key species

Further consideration is focussed on species that occur in substantial numbers in Wales and are known to be targeted commercially, or recreationally, in Wales or in nearby waters (*E. siliqua*, *E. magnus*, and *E. ensis*). Other razor clam species, such as *E. directus*, are not included due to their present scarcity and/or small size. A summary of key biological and habitat preference information for key species is given below (Table 2.1 and Table 2.2), with reference only to studies where the species and geographical extent are clearly defined and relevant to Wales. Due to the significant biological and ecological differences detailed below for *Ensis* spp., it is clear that razor clam species should be differentiated for stock assessment and fisheries management purposes. It is also clear that there is conflicting information on some characteristics for particular species, and a lack of information for others. Further management considerations relevant to *Ensis* spp. are discussed in subsequent sections.

Table 2.1. Summary of biological information for relevant razor clam species.

Species	<i>E. siliqua</i>	<i>E. magnus</i>	<i>E. ensis</i>
Max length	200 mm ^{1,2} 233.8 mm ³ 214 mm ⁵ 215 mm ⁷	150 mm ^{1,2} 176.9 mm ³	100 mm ¹ 120 mm ^{2,4}
Size at maturity	Smallest 118 mm, 100% at 131 to 140 mm ³ > 100 mm ⁴	Smallest 73 mm, 51% mature at 81 to 90 mm, 100% at 121 to 130 mm ³ > 100 mm ⁴	
Age at maturity	≥ 3 to 5 years at maturity ³ ≥ 3 years ⁴ Approximately 4 years ⁶	≥ 3 to 5 years at maturity ³	≥ 3 years ⁴
Age at 100 mm	4 to 5 years at 100 mm ³ 2 to 3 years at 100 mm ⁴		2 to 4 years at 100 mm ⁴
Max age	29 years ³ ≥ 19 years ⁶	17 years ³	
Spawning period	Majority spawned from May to June ³ Gonads mature in July and spent in August ⁴ Peak spawning in March to July ⁵ Mid-May to early August ⁶	Majority spawned from April to May ³	Gonads mature in July and spent in August ⁴

¹ Holme (1951), UK

² Coates (1999), South Wales

³ Muir (2003), West Scotland

⁴ Henderson and Richardson (1994), North Wales

⁵ Cross *et al.* (2014), Irish Sea

⁶ Fahy and Gaffney (2001), western Irish Sea

⁷ Trundle (2004), South Wales

Table 2.2. Summary of distribution and habitat preference information for relevant razor clam species.

Species	<i>E. siliqua</i>	<i>E. magnus</i>	<i>E. ensis</i>
Depth preference and range	Low water and shallow sublittoral ¹ Down to 20 m ²	Low water to deeper water ¹ Recorded at 14.5 m, small numbers in deeper waters of continental shelf and occasionally observed at 42 m ²	Only below low water, common in depths of 10 m, with small numbers in deeper waters of continental shelf ² Single specimens found in depths of 58.5 and 60 m ³
Substrate preference	Clean sand ¹ Fairly fine clean sand ² Fine sand ⁴	Course sand or fine gravel ^{1, 2} Coarser grain size but wide tolerance ^{2, 4}	Fine, sometimes muddy, sand ¹ Similar to <i>E. siliqua</i> but with greater tolerance to silt and coarse particles ² Similar but slightly higher tolerance to coarse particles than <i>E. magnus</i> ⁴
Density (animals m⁻²)	2.63 ⁴ In patches exceeding 200 but average 1.5 for the overall bed ⁵ Up to 9 ⁶	4.15 ⁴	
Wave exposure	Only <i>Ensis</i> spp. present on wave-exposed beaches but absent from fully exposed beaches ² Tolerate moderate wave exposure ⁴	Less tolerant to wave exposure, limited to those with at least some shelter from prevailing wind and swell ² Less tolerant to disturbance than <i>E. siliqua</i> ⁴	Less tolerant to wave exposure, limited to those with at least some shelter from prevailing wind and swell ²

¹ Holme (1951), UK

² Holme (1954), UK

³ Holme (1953), English Channel

⁴ Muir (2003), West Scotland

⁵ Fahy and Gaffney (2001), Irish Sea

⁶ Trundle (2004), South Wales

3 The history and status of razor clam fishing in Wales

At present there is no legal commercial razor clam fishery in Wales, and no licenced vessels currently targeting razor clam beds. However, commercial interest in the establishment of a razor clam fishery has recently been growing due to the high prices driven by the increased demand for large *Ensis* spp. from markets in Asia, predominately China (Murray *et al.*, 2014; Fox, 2017). Currently, the harvesting of razor clams in Wales is limited to recreational hand collection on exposed beds at low tides which have come under increased pressure in recent years. However, various trials and surveys with commercial or experimental gear have been conducted in Welsh waters and there are established fisheries in adjacent waters in Scotland and Ireland. The extent of known historical and present razor clam harvesting in Wales by different methods is described below, with information from nearby fisheries referred to as appropriate.

3.1 Intertidal hand gathering

Razor clams have long been collected from sandy beaches in Wales during low spring tides where large and mature *Ensis* spp. are targeted for consumption or for fishing bait. A common hand gathering method is “salting”, where salt or a strong brine solution is poured into the indentations (or “shows”) visible on the sand where razor clams are present, irritating the animal and causing it to emerge from its burrow where it can be collected. Alternatively, skilled collectors can approach and quickly trap razor clams near the surface using their fingers or a tool in the sediment so that they can then be excavated or grabbed and extracted by hand with a slow twisting pull motion. A third method is to use a barbed metal spear, which is inserted into burrows to penetrate and prise out razor clams.

Traditionally, hand gathering activity has been small-scale and thought to be sustainable. However, in recent years beaches in North Wales have come under increased pressure from large travelling groups of up to 200 people harvesting large quantities of mature *E. siliqua*. In addition to the quantity being harvested, authorities were concerned at the uniformity of the animals present in the limited areas targeted as harvested razor clams were all *E. siliqua* with lengths in excess of 130 mm (G. Hughes, pers. comm. 2018). With no evidence of a vast subtidal bed, and no indication of recruitment in the fished areas, it was suggested that the groups may be targeting an important brood stock, and it was thought from anecdotal evidence that the razor clam catch per person was decreasing in the intensely targeted areas (G. Hughes, pers. comm. 2018).

Signs of the over-exploitation of razor clams have previously been recorded in North Wales (Henderson and Richardson, 1994) by the reduction in abundance of large animals in intertidal areas thought to be a consequence of hand collection. Similarly in South Wales, reduced razor clam densities in intertidal beds at Carmarthen Bay have been attributed to the impact of harvesting by anglers for bait (Coates, 1990).

Maps describing the spatial extent of known intertidal razor clam harvesting have been generated with data received during correspondence with local enforcement and conservation officers in Wales. Ordinance Survey maps from each region were annotated to show the known areas of intertidal harvesting. Maps were made available at both a broad- and fine-scale. Once annotated, the maps were digitised into a GIS shapefile format at the two resolutions (Figure 3.1 for broad scale, and Figure 3.2 and Figure 3.3 for fine scale). It is worth noting that it is not easy to accurately annotate maps of known activity and any results from

such work should always be treated with a degree of caution and not be seen as definitive areas but rather an indication of recent known activity.

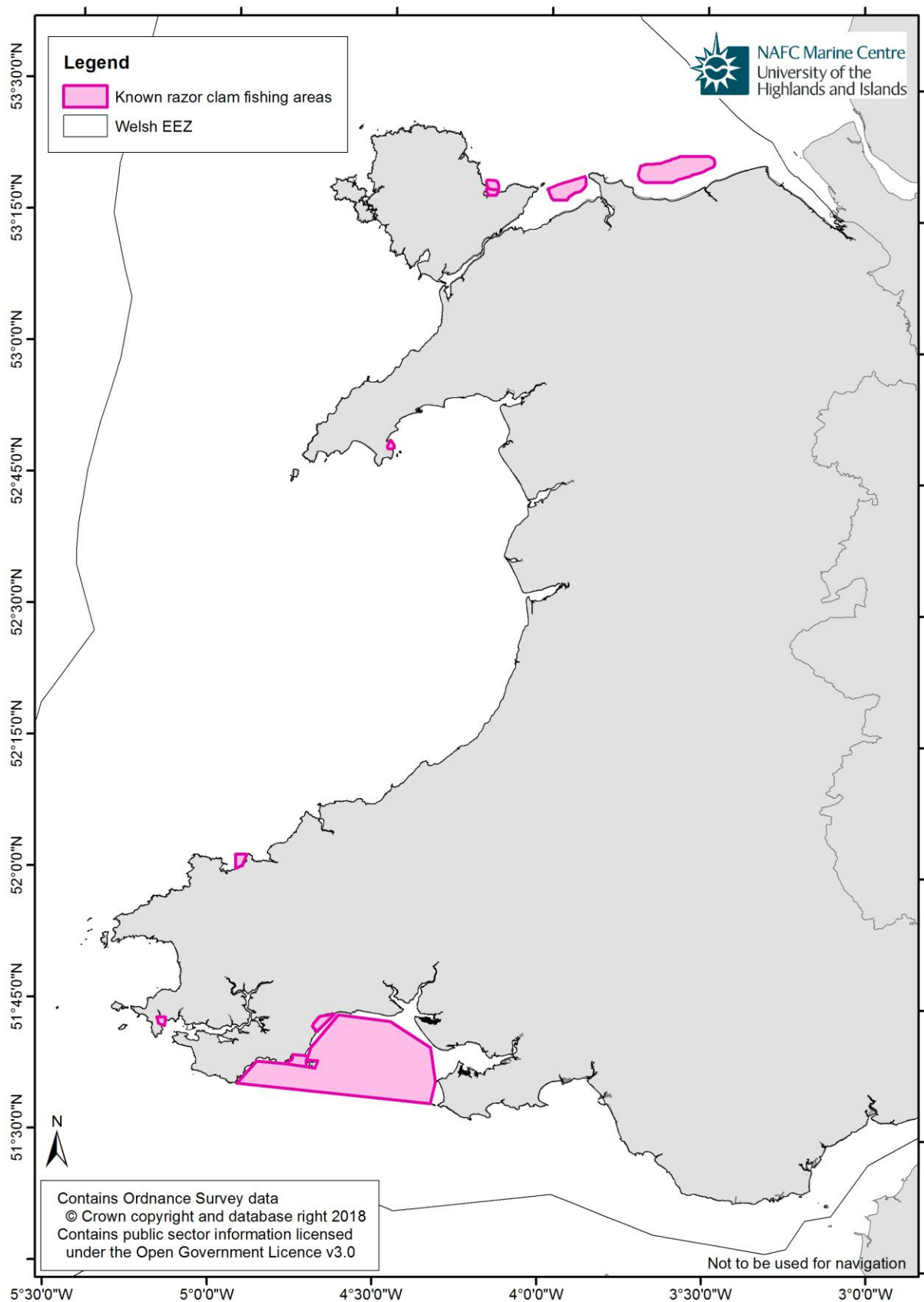


Figure 3.1. An indication of the location of if razor clam fishing activity around Wales mapped using broad-scale Ordnance Survey maps.

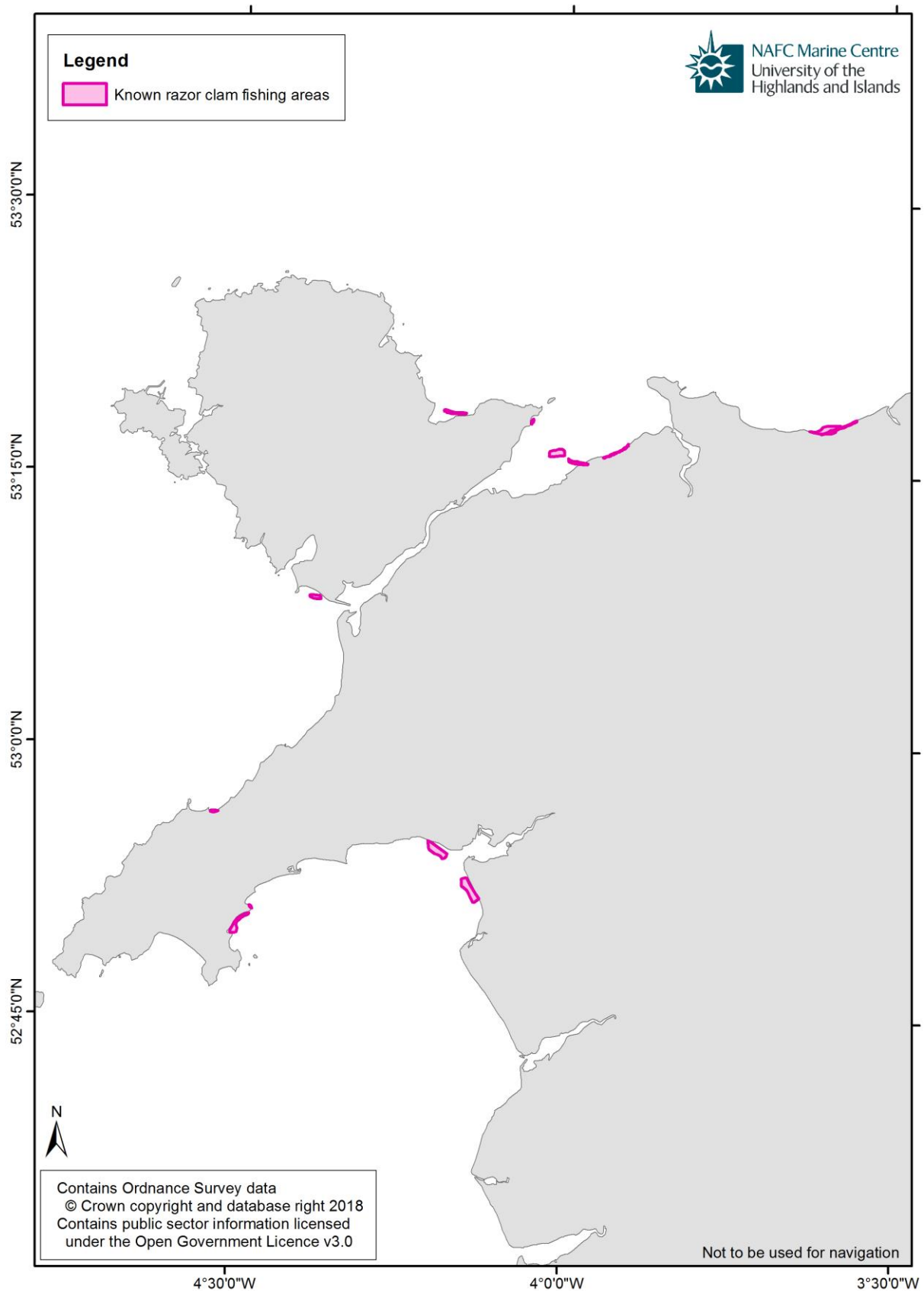


Figure 3.2. An indication of the location of if razor clam fishing activity around northern Wales mapped using fine-scale Ordnance Survey maps.

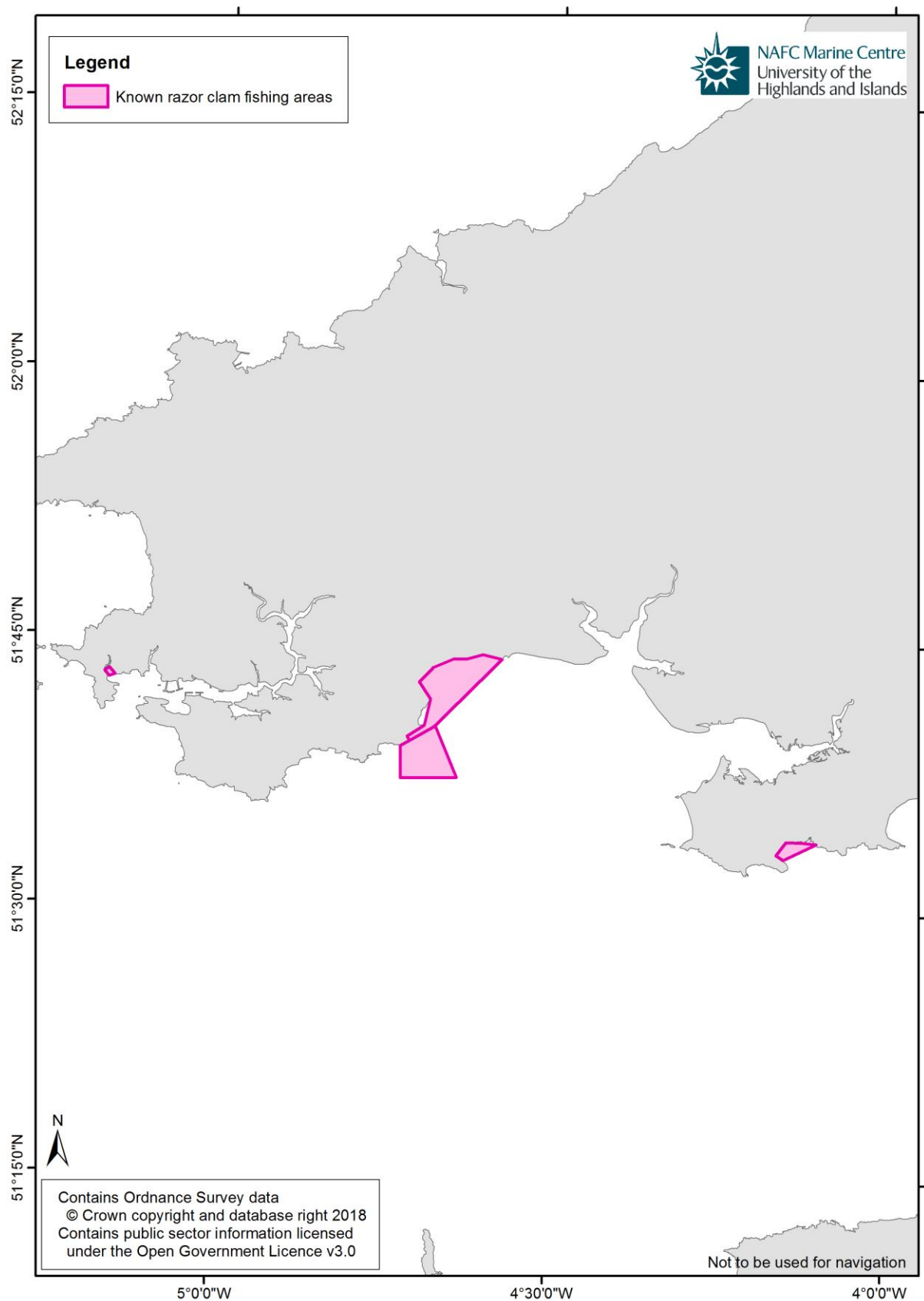


Figure 3.3. An indication of the location of if razor clam fishing activity around southern Wales mapped using fine-scale Ordnance Survey maps.

3.2 Diver gathering

Scuba-divers can target subtidal razor clam beds using similar methods to those used in intertidal hand gathering. Salting and hand-picking by divers have been a major component of the Scottish commercial razor clam fishery (Muir, 2003), with divers capable of collecting 200 to 500 kg day⁻¹ (Pyke, 2002). In Ireland, commercial scuba-diving for shellfish is illegal (Murray *et al.*, 2014) but some stock surveys have been undertaken by diver salting (Fahy *et al.*, 2001). In Wales, there is no evidence of significant historical commercial diver gathering of razor clams. Coates (1999) described how divers counted razor clams by their shows and spouting reactions, with diver observations from Carmarthen Bay indicating the density to be extremely patchy and ranging from at least 4 to 6 m⁻² in the Saundersfoot area. Divers were also used to take observation notes during the electrofishing trials in Carmarthen Bay (described in Woolmer *et al.*, 2011). Since then, there has been one prosecution in South Wales for illegal electrofishing (B. John, pers. comm. 2018) which involved collection by divers.

3.3 Dredging

Dredging methods form a significant component of many subtidal razor clam fisheries, and have the advantage that larger catches are possible than is feasible using diver gathering methods (Murray *et al.*, 2014). Consequently, the efficiency and environmental impacts of dredging have been active areas of research in a number of countries including the UK (e.g., Robinson and Richardson, 1998; Tuck *et al.*, 2000; Hauton *et al.*, 2007).

3.3.1 *Mechanical dredging*

The mechanical removal of razor clams from sediment using dredges with long teeth (up to 40 cm) has been used in Portuguese bivalve fisheries targeting a variety of shellfish including *E. siliqua* (Gaspar *et al.*, 1998; Gaspar *et al.*, 1999). However, high levels of breakage and damage are a commercial limitation of mechanical dredging for *Ensis* spp. (Woolmer *et al.*, 2011). Consequently, these gear types are not commercially employed to target razor clams in the Scottish or Irish razor clam fisheries. Limited success with toothed dredges during trials in the south of Wales is reported in Trundle (2004), but otherwise mechanical dredging for *Ensis* spp. has not been employed in Welsh waters and is not under consideration commercially.

3.3.2 *Hydraulic dredging*

At present, hydraulic dredging is the most studied *Ensis* spp. harvesting method and has been used in Scottish fisheries and is used almost exclusively in Irish fisheries. There is a variety of hydraulic dredge designs operated by individual boats targeting razor clams. In one approach, fluidised sand can be pumped (continuously) aboard the fishing boat with *Ensis* spp. removed by hand on a mesh conveyer belt (Hall *et al.*, 1990; McKay, 1992), an approach which has been reported in the Scottish razor clam fishery and termed “suction dredging” (Robinson and Richardson, 1998; Murray *et al.*, 2014) or “continuous recovery” (Coates, 1999). However, the most common design involves towing a hydraulic dredging rig slowly (at approximately 0.1 knot) along the seabed and pumping seawater down to the dredge from vessel-mounted pumps to fluidise the sediment ahead of a blade which penetrates the sea bed so that razor clams are washed into a collecting cage. This design is termed a “hydraulic batch dredge” (Hauton *et al.*, 2011) or “batch method” (Coates, 1999) and is typically employed with one dredge per vessel for approximately 10 minutes at a time (Hauton *et al.*, 2011). In the razor clam fishery on the east coast of Ireland, commercial vessels use hydraulic

batch dredging and operate in water depths of 4 to 14 m, due to the operational limits of the gear (Marine Institute and Bord Iascaigh Mhara, 2015).

Evidence of over-exploitation in commercial subtidal *Ensis* spp. fisheries by hydraulic dredging has been recorded in Ireland (Fahy and Gaffney, 2001). Pyke (2002) reports that hydraulic dredges can catch 400 to 1 500 kg day⁻¹. Similarly, historical fishing activity in Shetland using hydraulic dredges had catches up to 1 000 kg day⁻¹.

Hydraulic dredging methods are currently banned within the six nautical mile limit in Wales. However, derogations have been put in place for some limited hydraulic batch dredging trials in Welsh waters. During trials in Carmarthen Bay, hydraulic dredging was found to be an effective method to target razor clams, with substantial beds of primarily *E. siliqua* reported which represented a viable fishery (Trundle, 2004). This study provided an estimate of 13 400 tonnes of fishable *Ensis* spp. biomass within the 10 m contour in Carmarthen Bay. The combined length distribution of *E. siliqua* harvested by hydraulic dredge in Carmarthen Bay is shown in Figure 3.4.

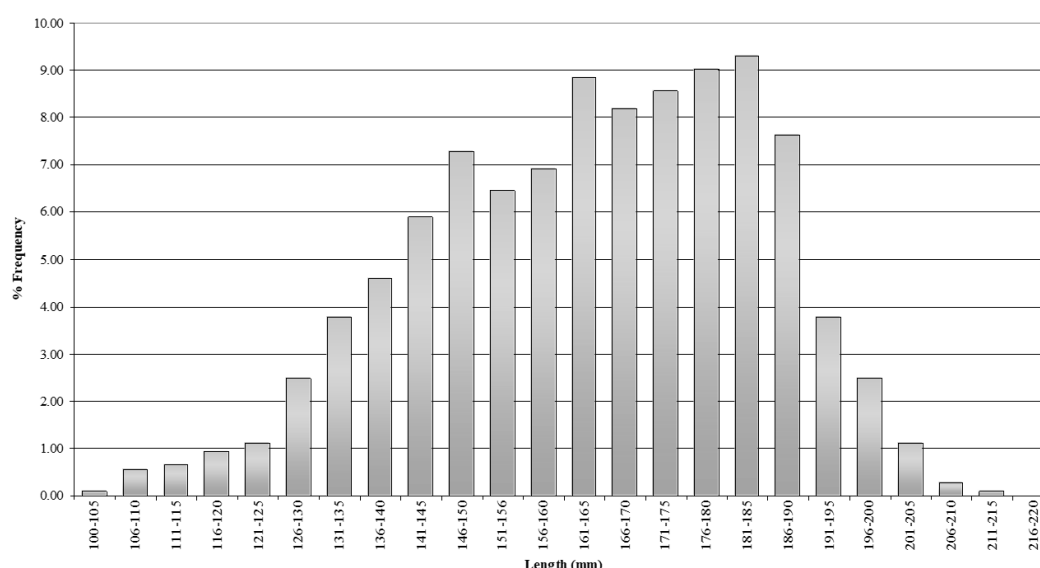


Figure 3.4. Length distribution of *E. siliqua* in Carmarthen Bay from 1 086 measured individuals collected during the hydraulic dredging trial, adapted from Trundle (2004).

In the trial described by Trundle (2004), 29 tows using a hydraulic dredge (dredge width 1.5 m) were undertaken using 15 minute tows at 0.1 knots. Tows were restricted to areas within the 10 m depth contour in the locations shown in Figure 3.5. The greatest abundances were judged to be in the central bay area, with catches of 30 to 50 kg per tow recorded and an estimated density of 9 *E. siliqua* m⁻². In terms of economic viability, the centre and east of Carmarthen Bay was thought to be the most productive as it contained the greatest densities of large *E. siliqua* (in excess of 170 mm in length). In contrast, the Saundersfoot Bay area was described as being generally unsuitable for economically viable fishing due to low razor clam abundance and poor ground, characterised by anoxic mud and debris. The skipper involved in this study felt that the highest densities of razor clams in Carmarthen Bay were concentrated along the 5 m contour (B. Thomas, pers. comm. 2018).

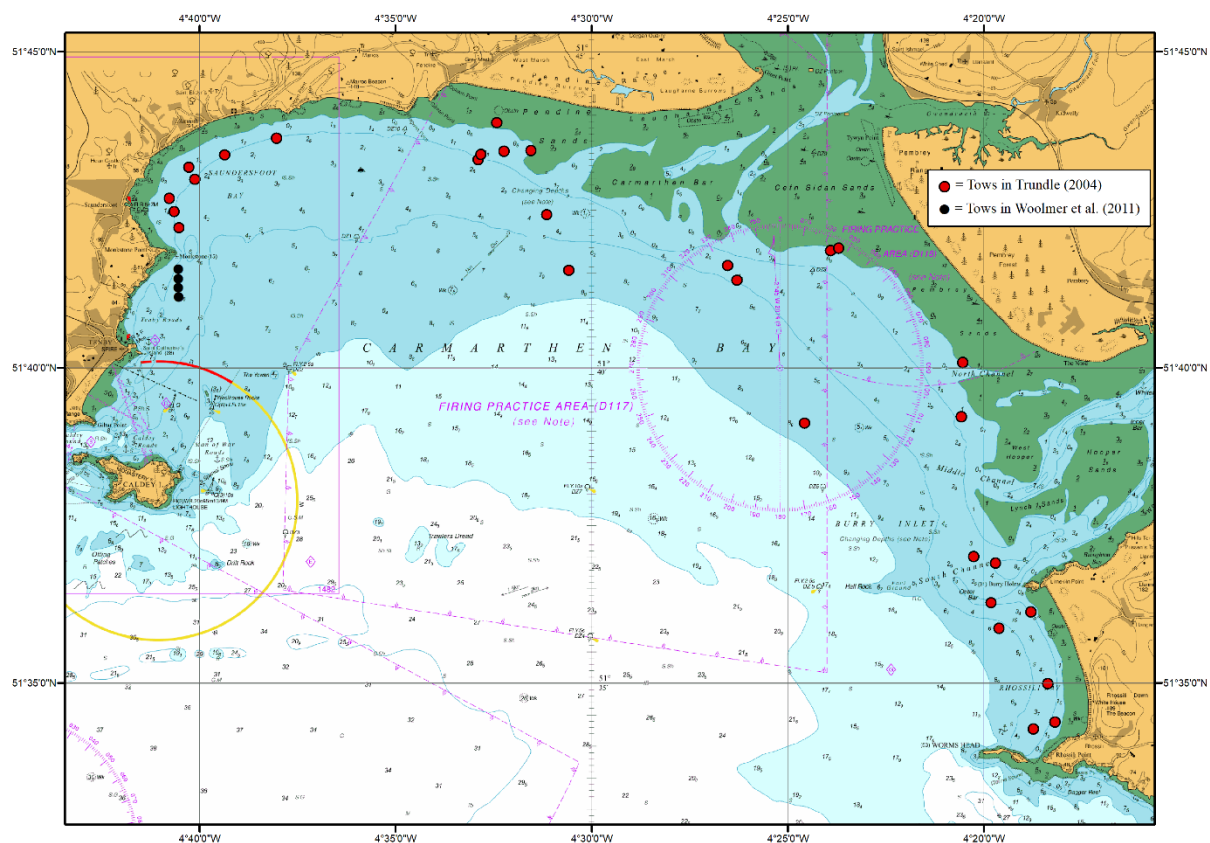


Figure 3.5. Locations of trial subtidal razor clam fishing in Carmarthen Bay. Red circles illustrate the approximate location of hydraulic dredge tows described in the stock assessment study in Trundle (2004) where *E. siliqua* were mostly found. Black circles show the locations of the electrofishing trials in Woolmer *et al.* (2011) which also confirmed the presence of *E. siliqua*. Locations have been estimated by reference to figures in these reports and redrawn on the current map. HydroView chart ©Crown Copyright/HR Wallingford Ltd. All rights reserved. Not to be used for navigation.

3.4 Electrofishing

Electrofishing methods have been developed as an alternative to the mechanical and hydraulic dredging methods and shown to be a highly effective method for harvesting *Ensis* spp. (Murray *et al.*, 2014; Woolmer *et al.*, 2011). These methods exploit the tendency for razor clams to leave their burrows when exposed to an electric field where they can then be collected by a dredge or (typically) divers (for further details see the useful review by Breen *et al.*, 2011). The development of razor clam electrofishing techniques has been motivated by the potential for reduced physical impact on the seabed, reduced bycatch, and a higher quality product free from the physical damage or excessive grit caused by dredging methods (Murray *et al.*, 2014). However, commercial electrofishing is, at present, highly controversial and is currently illegal in European Waters. The optimisation and environmental impact of electrofishing are active areas of research, and various trials have been undertaken in a number of European countries where derogations have been issued. In the case of razor clams in the UK, the main concerns about legalising electrofishing relate to its high efficiency and the potential for excess harvesting (Fox, 2017).

It is known that there has been widespread illegal experimentation with electrofishing of *Ensis* spp. in the UK, particularly in Scotland. However, the first scientific trial in the UK was in South Wales by Woolmer *et al.* (2011). This trial targeted the west of Carmarthen Bay, in a sheltered area thought to be typical *Ensis* spp. habitat (Figure 3.5) which confirmed the presence of *E. siliqua* in the site with bycatch including *P. legumen*. This study demonstrated that *Ensis* spp. could be effectively exposed using relatively simple and low voltage electric gear and observed by divers with no serious impacts on the epifaunal and macrofaunal benthic communities. Since then, there has been one prosecution in South Wales for illegal electrofishing (B. John, pers. comm. 2018). In 2013, a pulsed DC electrofishing rig with collection cages was trialled in Liverpool Bay but failed to find a significant stock of razor clams (Aitken and Knott, 2018) with suggestions that the vessels draft prevented access to shallow beds (J. Wilson, pers. comm. 2018).

4 Predictive habitat mapping of potential razor clam distribution

Predictive habitat mapping, also known as Species Distribution Modelling (SDMs), have become increasingly more common in the marine environment for a variety of species. Although multiple SDM models exist, each with their own advantages and disadvantages, MaxEnt (Phillips *et al.*, 2006; Phillips and Dudik, 2008), is considered by many to provide a reliable estimate of species distributions. MaxEnt estimates species distribution by examining presence only species observations in relation to environmental variables, based on maximum entropy.

4.1 Materials and methods

The species distribution model (SDM) used was MaxEnt (version 3.3.3k). Species presence records and environmental variables are required in order to run the model. Presence records were downloaded from Marine Recorder (JNCC snapshot) and environmental layers were sourced from EMODnet bathymetry (EMODnet 2016), tidal strength predictions from the Atlas of UK Marine Renewable Energy Resources (ABPmer 2008), and substrate type derived from UKSeaMap (JNCC). Nine sediment categories were identified within the UKSeaMap data set and included;

- coarse substrate,
- fine mud,
- mixed sediment,
- mud to muddy sand,
- rock or other hard substrate,
- sand,
- sandy mud to muddy sand,
- seabed,
- unknown.

The Marine Recorder database was queried for all *Ensis* species records as well as records from other razor clam species mentioned in Section 2. All records were plotted in GIS with only those located within the Welsh EEZ used in the analysis. A total of 192 records were exported, 166 were *Ensis* species (Table 4.1). In 92 cases, only ‘*Ensis*’ was recorded, rather than a defined species. This species category was treated separately to the identified species and any interpretation of results for this species category should be treated with a degree of caution as there is a possibility that it includes multiple species within it. The three *Ensis* species and ‘*Ensis*’ were also combined to an ‘*Ensis* spp.’ in order to more fully encapsulate all available records. However, the same cautionary approach in the interpretation should be adhered to as that with ‘*Ensis*’.

Table 4.1. Species records located within the Welsh EEZ for razor clam species. Data extracted from Marine Recorder.

Species	Number
<i>Ensis</i>	92
<i>Ensis ensis</i>	50
<i>Ensis magnus</i>	17
<i>Ensis siliqua</i>	7
All <i>Ensis</i> species	166
<i>Pharus legumen</i>	25
<i>Solen marginatus</i>	1*

* As there was only one record for this species within the Welsh EEZ, it was not possible to run a model prediction for *S. marginatus*.

A total of eight environmental layers were used in the model and included; tide, substrate type, depth and the associated layers of aspect, curvature, hillshade, ruggedness, and slope. All layers were processed to the same extent and spatial resolution before being converted to a .asc file to run in the model. The model was run using the default settings with a random test percentage of 25. Predicted distributions were run for each species, including a combined *Ensis* species. In total, six SDM models were run for each of the species categories listed in Table 4.1. Area Under the Curve (AUC) was used to assess the appropriateness of the model fit for each species. Mapped outputs were converted to GIS floating rasters with all logistic probabilities less than 0.5 removed.

4.2 Results

The six predicted distributions were found to have a good model fit (Figure 4.1) with *E. magnus* and *E. siliqua* considered to have an excellent model fit based on Test AUC values of 0.97 for each species.

The main contributing factor for the model output was found to be depth, followed by tide and sediment (Figure 4.2). Tide was the main contributing factor (55%) for *E. magnus* and was the only prediction which did not have depth (37%) as the main contributor. Sediment was found to have the largest contribution for *E. siliqua* (32%) and was found to be associated with sand with a corresponding logistic output of 0.62. Sand was also found to have the largest logistic output in *P. legumen* (0.31) and the second largest in *E. magnus* (0.62). However, the second most common type of sediment for *E. magnus* was found to be “rock or other hard substrate”. *Ensis ensis* was found to occur most on mixed sediment. Depth occurrence was found to decrease with increasing depth for both *E. magnus* and *E. siliqua* while *E. ensis* and *P. legumen* were found to have density peaks at depths of 8.2 m and 6.2 m, respectively. The density peaks for *Ensis* were found to be at a depth of 3.6 m. A negative relationship was found between species logistic output and tidal strength. All species were found in areas of low tide strength and, at a logistic output of 0.5, the mean peak currents of spring tides from each species distribution was found to vary from 0.38 ms⁻¹ to 0.50 ms⁻¹.

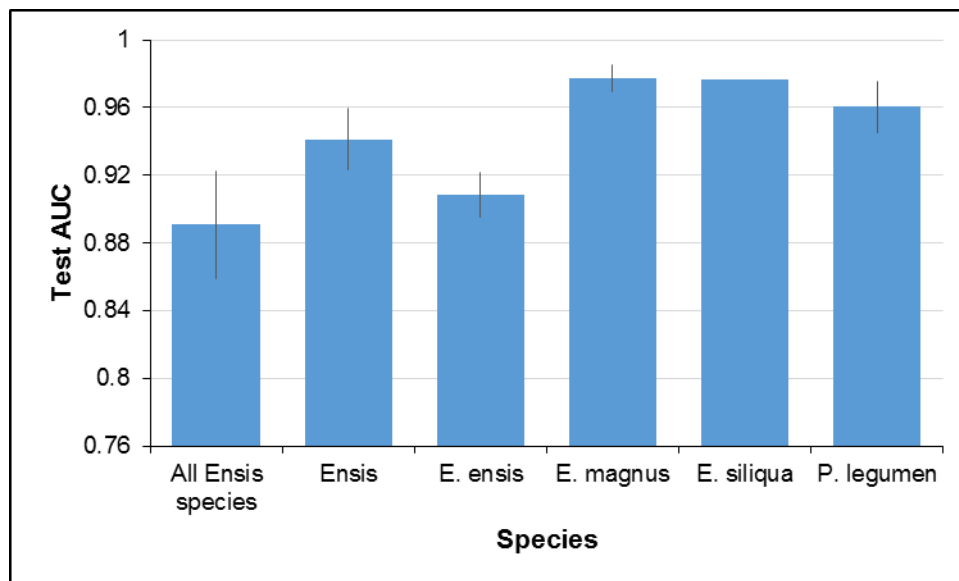


Figure 4.1. Test Area Under the Curve (AUC) values for each species, and species combination, model run. Error bars show standard deviations.

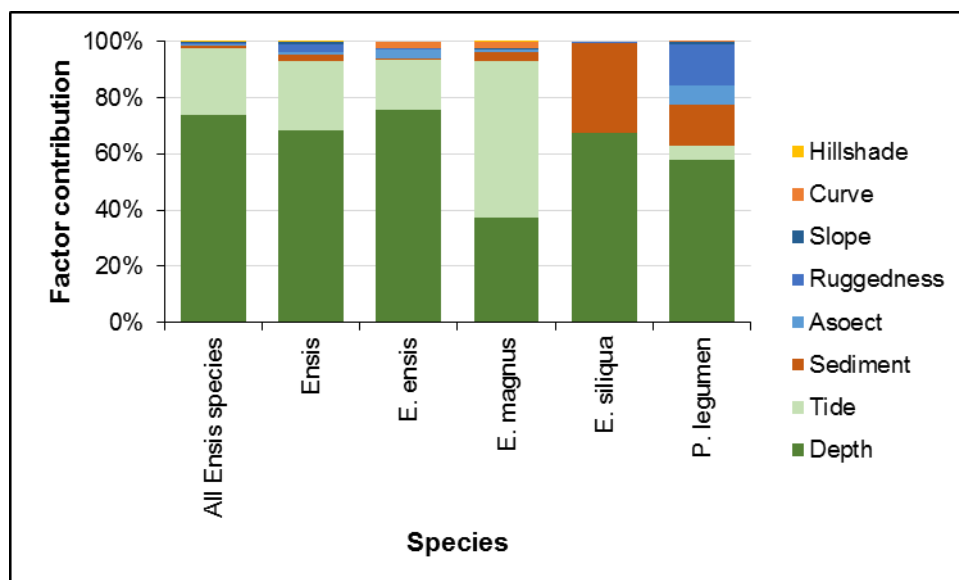


Figure 4.2. Factors contributing to each model output.

Mapped outputs showed similar overall distributions with localised species-specific variations (Figure 4.3 to Figure 4.8).

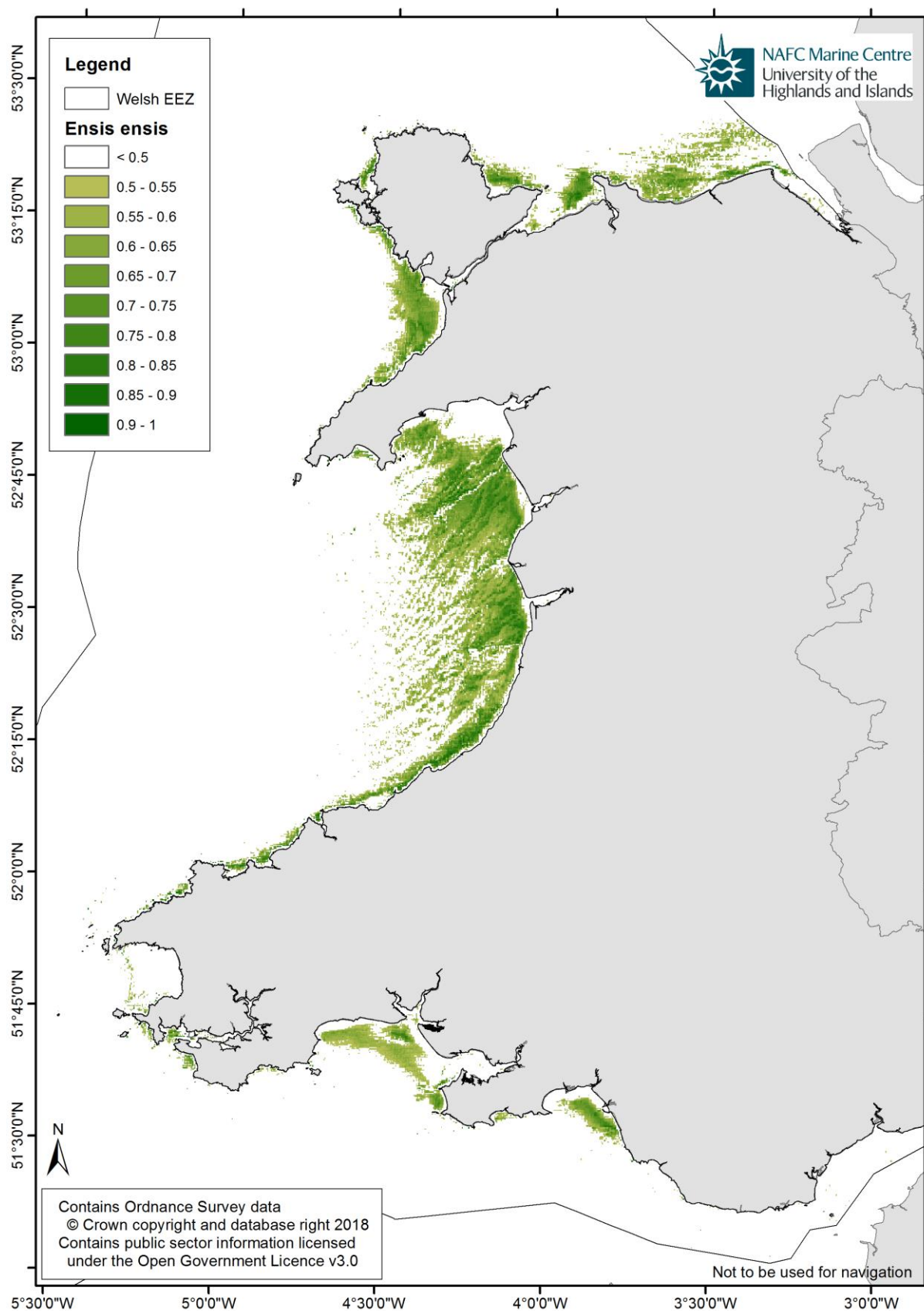


Figure 4.3. Predicted distribution of all *Ensis ensis* records based on logistic outputs (probability of presence) of 0.5 or greater.

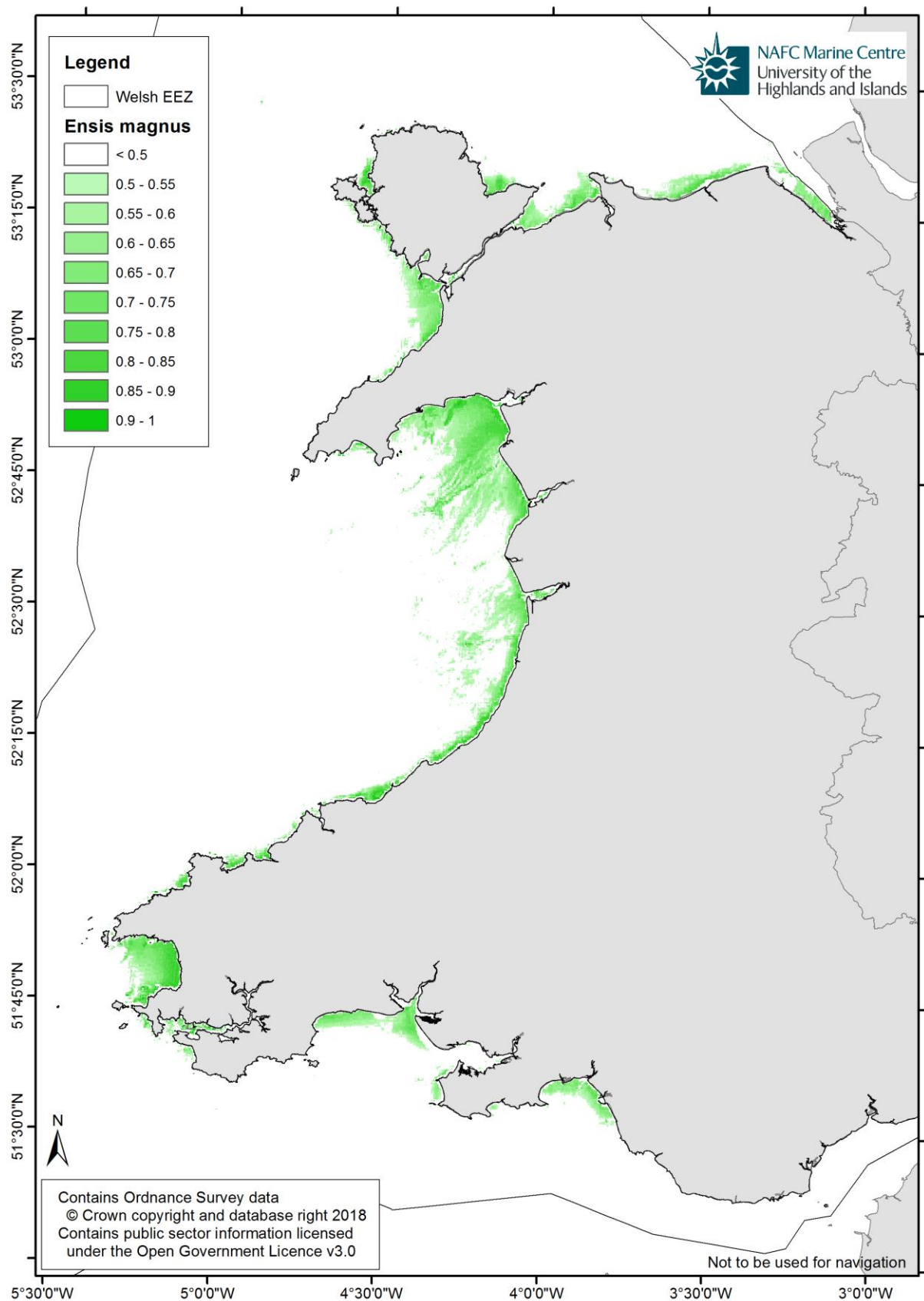


Figure 4.4. Predicted distribution of all *Ensis magnus* records based on logistic outputs (probability of presence) of 0.5 or greater.

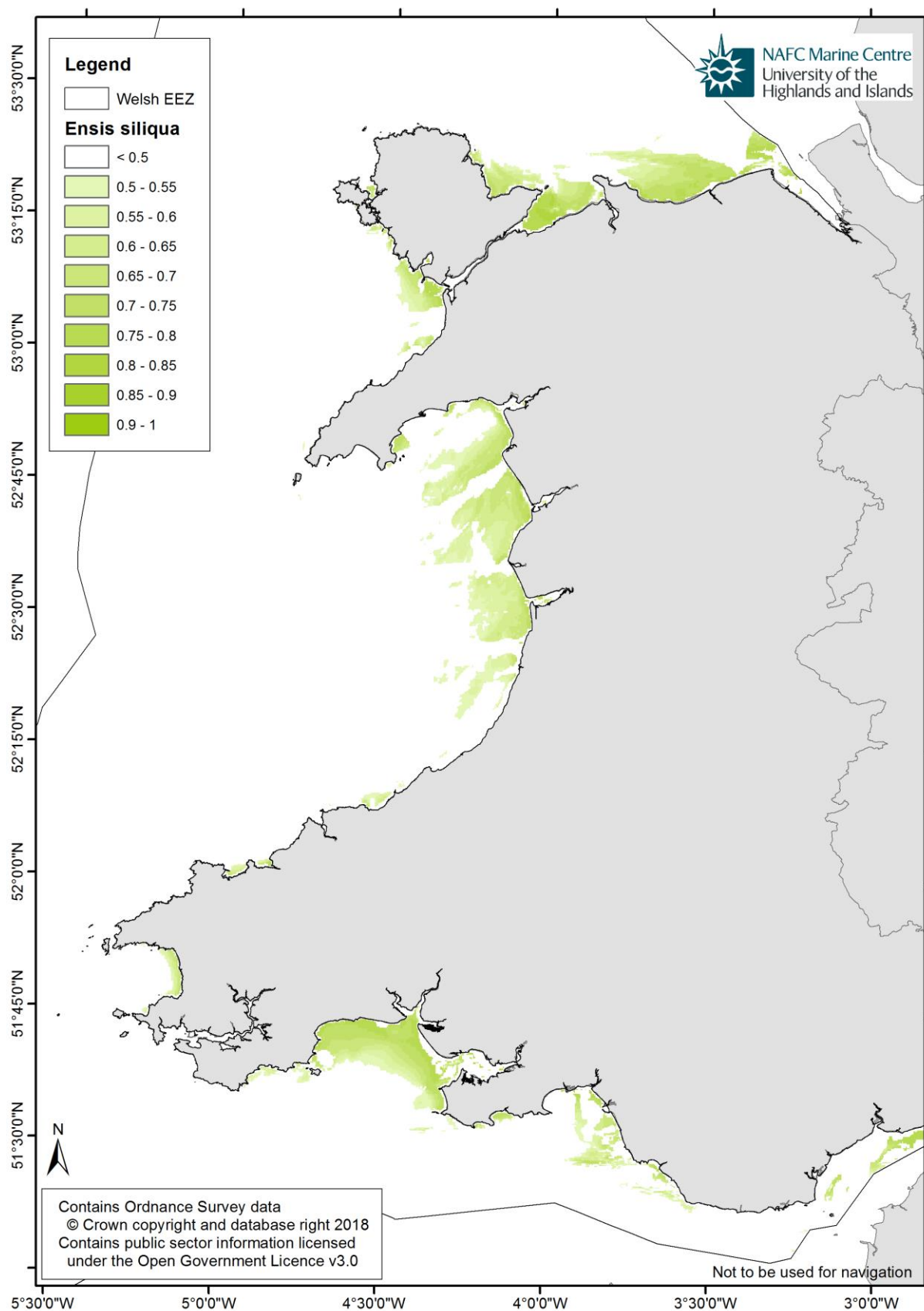


Figure 4.5. Predicted distribution of all *Ensis siliqua* records based on logistic outputs (probability of presence) of 0.5 or greater.

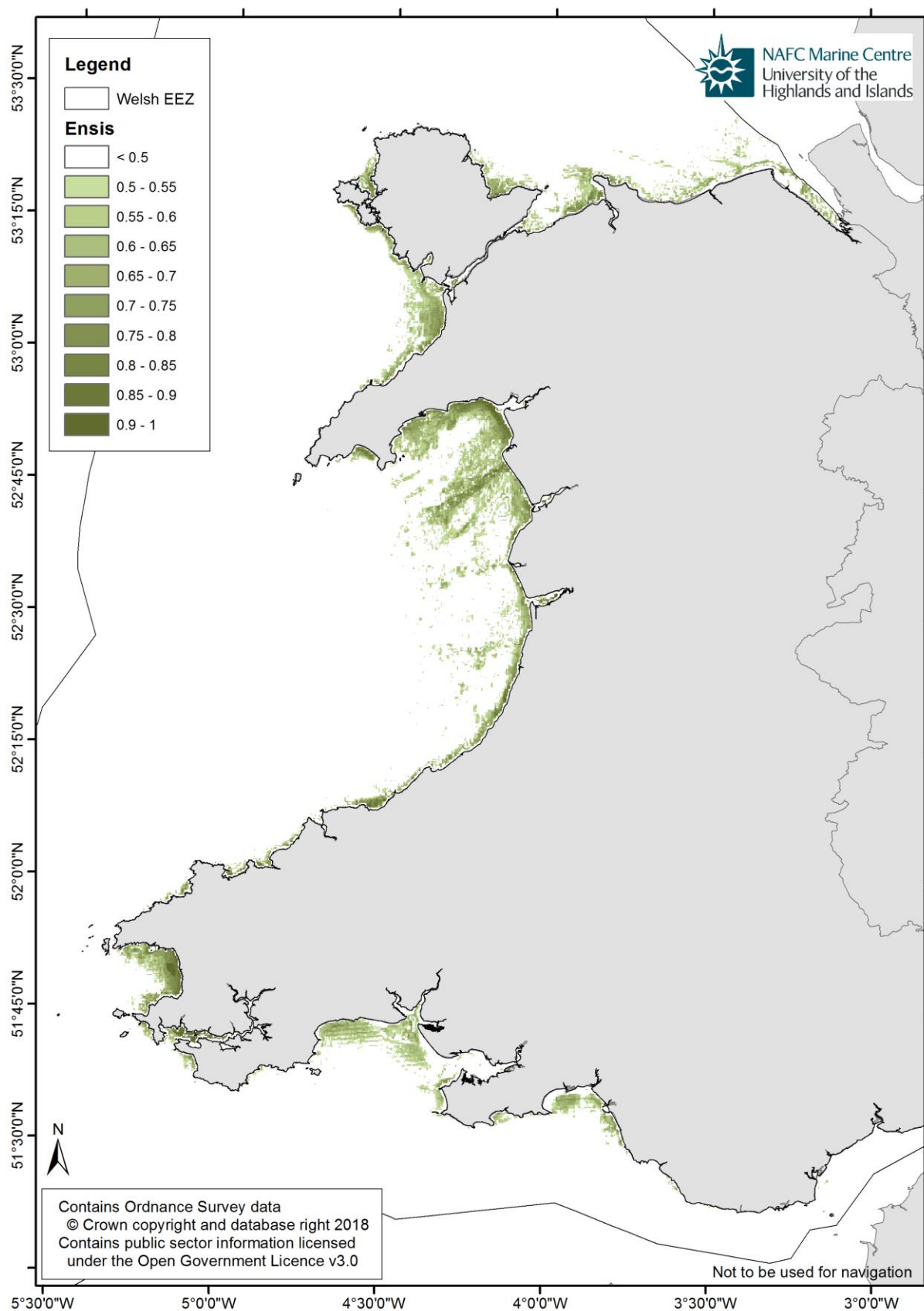


Figure 4.6. Predicted distribution of all “*Ensis*” records based on logistic outputs (probability of presence) of 0.5 or greater.

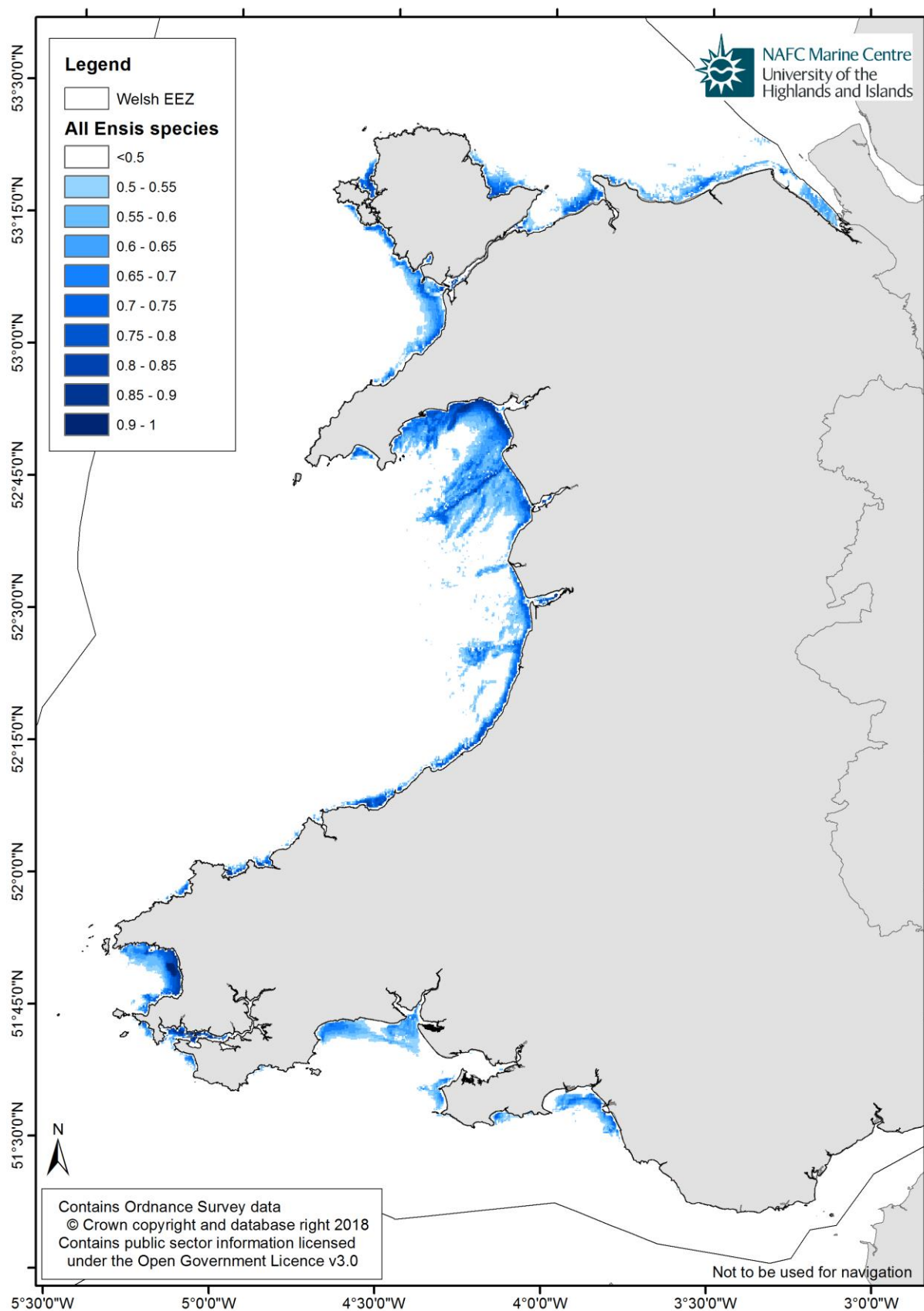


Figure 4.7. Predicted distribution of all *Ensis* species records based on logistic outputs (probability of presence) of 0.5 or greater.

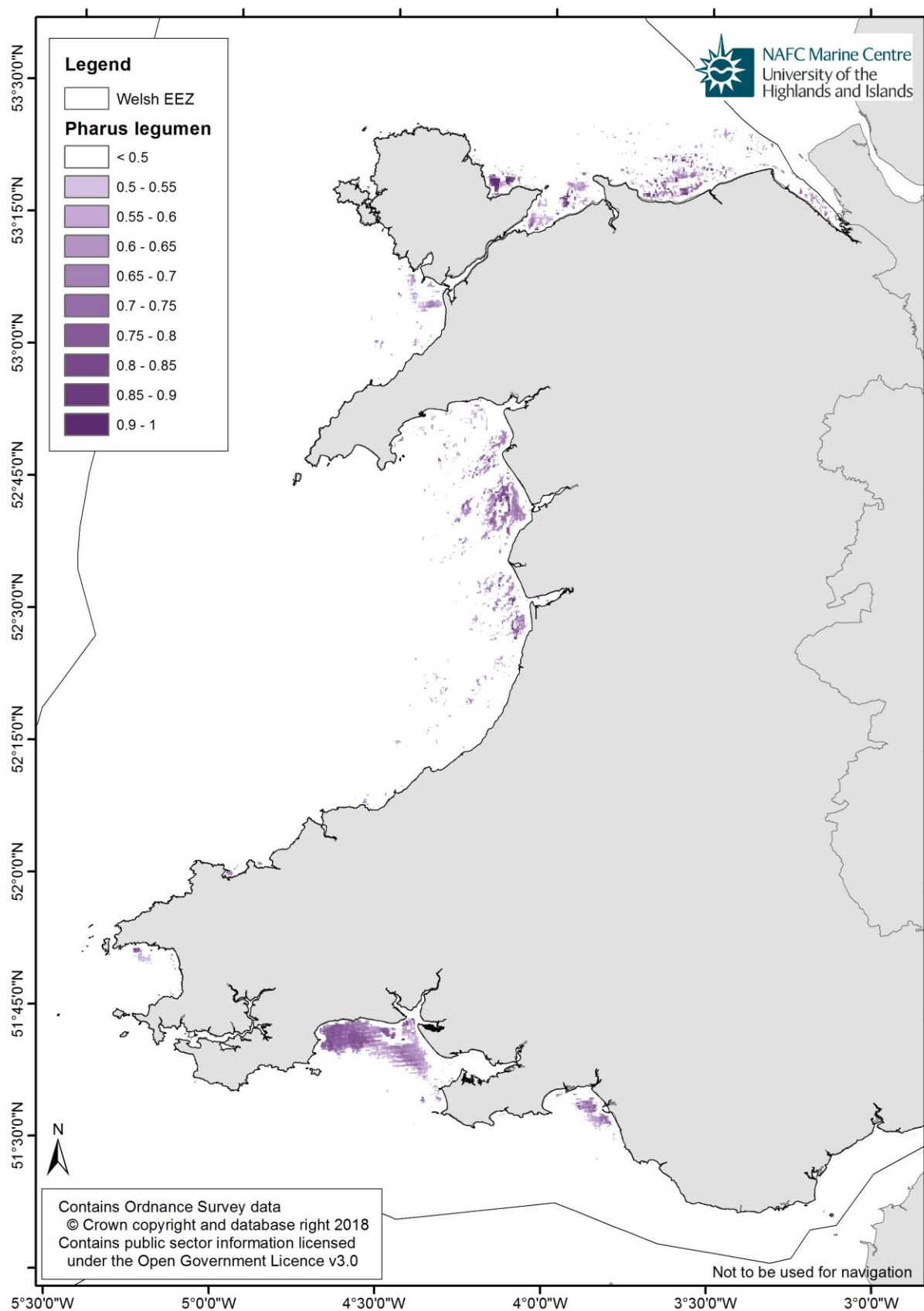


Figure 4.8. Predicted distribution of all *Pharus legumen* records based on logistic outputs (probability of presence) of 0.5 or greater.

4.3 Interpretation and limitations

The predictive habitat maps, produced from the MaxEnt output, provide a good, based on the Test AUC, indication of potential razor clam locations, especially in the subtidal. As with all predictive mapping, the outputs are heavily dependent on the quality of the inputted information. In this instance, the SDM relied on species presence only records and environmental information for bathymetry, sediment type, and tide. Although the environmental layers used in this work were considered to be the best known available data at the time, each data set has its own limitations and it is important to understand these when trying to interpret the results. Both the bathymetry and tidal data sets were appropriate to use at a large geographic scale of Wales but care should be taken when using this information at a more local level due to the original resolution of the data. A major data gap in most marine benthic studies is the lack of high-definition sediment information. The UKSeaMap data has tried to address this issue at a national level but the outputs from this work show that there would still be a requirement for further detail at regional and local levels. Razor clams are burying species and would not be expected to be found on rocks or hard substrates, as was suggested from the SDM predictions for *E. magnus*. This result is either due to a low confidence in the sediment information, inaccuracies in the locations of historic species records (as discussed in Shelmerdine *et al.*, 2014), or a combination of the two. Section 2.1 summarises abiotic factors influencing razor clam distributions including, amongst others, sediment penetrability which is not accounted for in the sediment environmental layer used in this instance.

The predictive species distribution maps (Figure 4.3 to Figure 4.8) were found to corroborate the identified areas of intertidal harvesting (Figure 3.1 to Figure 3.3) but the predictive maps show an extended distribution to the subtidal. The predictive maps should not be treated as definitive razor clam areas but rather an indication for potential surveys to quality control the outputs.

Due to low numbers of historic razor clam records (Table 4.1) it would be appropriate to first consider the SDM relating to all *Ensis* species (Figure 4.7), rather than individual species distributions. Although this predictive map is possibly more conservative than the individual species distributions, it is based on multiple *Ensis* species where the underlying species presence data is greater ($n = 166$) compared with specific species (e.g., *E. siliqua*, $n = 7$). Once more species presence information has been gathered, through additional survey work or potential future stock assessments, it would be appropriate to run the SDMs again to enhance each species predicted distribution. These updated distributions could then be utilised in fine-tuning future surveys.

5 Review of razor clam stock assessment methods

Razor clams pose a unique challenge for survey work and the design of stock assessments due to their unusual behavioural characteristics and their occurrence in both intertidal and subtidal habitats. Therefore, a range of survey methods are likely to be required in order to provide a full understanding of the distribution and nature of stocks. In the case of Wales, there are no directly analogous fisheries with a comprehensive monitoring programs for *Ensis* spp. to draw from. Consequently, work on related species and insights from various trials are described below to review potential stock assessment methods and outline possible limitations to each approach.

5.1 Intertidal methods

Standard intertidal survey methodologies for shellfish have been developed for a range of bivalve fisheries. Such surveys typically depend on the shallow excavation of sediment from within randomly positioned quadrats (e.g., Llewellyn, 2016) which is then sieved to remove macrofauna from the substrate with position recorded by GPS. Shallow shellfish beds can be accessed on foot at low water or by all-terrain or 4×4 vehicles; while small inflatable boats can be used to safely access sandbanks or deeper areas. To cover a large intertidal area a coarse grid of sampling points can first be used, which can then guide more intensive sampling on areas where high densities occur, in order to provide more accurate abundance estimates (Southall and Tully, 2014). However, standard intertidal survey methodologies may clearly not be appropriate for razor clams due to their tendency to burrow to depth when disturbed. Although intertidal collection of *Ensis* spp. for biological analysis is documented (e.g., Henderson and Richardson, 1994), comprehensive intertidal surveys of *Ensis* spp. distribution or abundance are lacking.

5.1.1 *Salting, digging, and show counts*

Previous intertidal investigations of intertidal *Ensis* spp. stocks in Wales have used salting to gather razor clams at low water. Henderson and Richardson (1994) describe how razor clam shows would develop after stamping over the bed which then had table salt applied causing razor clams to emerge within 2 to 10 minutes. That study also described how replicate 0.1 m³ sediment samples were sieved with a 2 mm² mesh size to check for small razor clams, and that small clams could occasionally be collected by digging, unlike large clams that burrowed too quickly. However, no attempt to estimate abundance or density by these methods was given.

Transects and sampling stations could be defined which would provide density estimates using the above methods within quadrats. Salting, digging, or simply counting shows requires no specialised equipment and is consequently highly transferrable and likely to be relatively cheap. In North America, intertidal stock assessment methods for the “Pacific razor clam”, *Siliqua patula* (Dixon, 1789) have included counts of shows along transects, digging of transects, stratified random digs, and screening (Bourne and Quayle, 1970; Ayres and Simons, 1989; Jones *et al.*, 2001). Digging techniques have the advantage that they provide immediate information on the relative number and size composition of razor clam stocks (Ayres and Simons, 1989). However, the efficiency of all these techniques and application to *Ensis* spp. is unclear and is likely to be highly sensitive to the environmental conditions at the time, the size and species composition of the bed, any previous disturbance, and the skill or technique of data collectors. A further limitation of these techniques is that they can only be employed over the intertidal bed at brief occasions during low spring tides.

5.1.2 Hydraulic sampling

In Alaska, USA, Szarzi *et al.* (1995) describe the use of a circular sampling ring with a surface area of 0.5 m² and a mobile water pump with a metal “wand” connected to the outlet hose. The wand was inserted into the substrate within the sampling ring so that the water pump liquefies the substrate to a depth of approximately 1 m causing *S. patula* to rise to the surface where they are collected. The density of razor clams can then be estimated with the assumption that all razor clams are sampled inside the circular area and that none are sampled from outside of it. Sampling was then undertaken using a three-stage randomised design along transects perpendicular to the coastline to provide a density and abundance estimate for the study area. Szarzi *et al.* (1995) found abundance estimates using the above hydraulic sampling method were more accurate than alternative approaches based on catch per unit effort monitoring used in management at the time. In Canada, Jones *et al.* (2001) used similar equipment to survey intertidal *S. patula*, and found that it required three to five minutes per sample with a five person crew. To isolate the sampling area, the sampling ring was forced into the sand to a depth of about 0.5 m before pumping. Razor clams were captured by straining the liquefied mixture with a coarse (5 mm) and fine (< 1 mm) mesh dip net. A very similar method is currently used as the basis of annual stock assessment work in Washington State, USA, and termed the “pumped area method” with large intertidal razor clam beds surveyed by the use of multiple 0.5 m² sample rings at set distances along randomly selected transects (D. Ayres, pers. comm. 2018).

Hydraulic sampling is thought to have the advantage that it provides an unbiased sample of the population with relative ease, and is now the dominant method in which all intertidal pacific razor clam stock assessments are undertaken (D. Ayres, pers. comm. 2018). Compared to digging and screening, which can be laborious and selective for larger clams (Jones *et al.*, 2001), the pumped area method can sample both large adults and juveniles as small as 5 mm (D. Ayres, pers. comm. 2018). However, the disadvantage of this approach is the requirement for specialised pumping gear, potentially long hoses to a water source, and specialised sampling equipment. As with other methods, the time available for sampling is clearly limited by temporary bed exposure at low spring tides.

5.1.3 Core samples

Core samples taken as part of an intertidal benthic survey have been used to assess the distribution of *E. directus* in the Dutch Wadden Sea (Compton *et al.*, 2012). This study used a stratified random survey design at 500 m intervals with additional sampling points added to specific areas. Samples were extracted using 25 cm deep cores using small inflatable boats and by foot. The cores were analysed to provide maps of the sediment composition and the density of *E. directus* and other benthic macrofauna. However, specific biological details on captured razor clams or the effectiveness of this approach for razor clam surveying were not given. Surveying of *E. directus* in the Wadden Sea is also described by Dekker and Beukema (2012) using a variety of hand-operated and ship-based corers in a long term monitoring project of intertidal areas. The use of coring tools which can be operated by hand and with small vessels may provide greater flexibility in the timing and coverage of surveys. However, details on the specifics of the coring tools used and capture efficiency are not given and so the application of these survey methods to other areas and stocks is unclear.

5.1.4 Other methods

Ayres and Simons (1989) describe the use of a mark-recapture method for intertidal *S. patula* populations. In this method, razor clams collected during previous stratified random digs are measured and marked with numbers etched by an abrasive drill before being introduced into a set area of the bed. This area was then left until at least the following tide before further digging, which is repeated until 20% of the marked clams are recovered. The total population of the area is then computed statistically by considering the total number of razor clams collected and the number of marked razor clams recovered. This method has since been superseded by the pumped area method (D. Ayres, pers. comm. 2018).

There is no evidence that any intertidal survey has ever taken place using electrofishing for razor clams. However, intertidal electrofishing gear could potentially be developed which could be towed by an all-terrain vehicle along transects or deployed relatively quickly at set sampling stations. Such an approach would be lacking any precedent, would undoubtedly depend on special derogations, and would require careful consideration for health and safety. However, if the effectiveness of electrofishing for *Ensis* spp. in the intertidal is the same as at sea then there could be clear advantages in efficiency compared to other techniques, allowing coverage over relatively large areas within the limited time available at spring tides.

5.2 Subtidal methods

Most stock assessment work for *Ensis* spp. has been undertaken in the subtidal where commercial harvesting takes place. While spring tides limit intertidal razor clam hand collection and survey methods to occasional periods and limited areas, intertidal harvesting can take place regularly over potentially extensive beds. Although a variety of benthic surveying methods are well established, reliably assessing razor clam populations at depth is a unique challenge without an obvious solution which has led to the trial of a range of methods.

5.2.1 Hydraulic dredging

Most focussed subtidal survey work for razor clams and similar species has been undertaken with hydraulic dredging gear (e.g., McKay, 1992; Bailey *et al.*, 1998; Hutton *et al.*, 2007). The advantage of hydraulic dredge surveys is that this replicates the gear used in commercial fisheries and so provides numerous samples for biological analysis and is also useful in determining the commercial viability of stocks. For example, Palmer (2007) reported commercially viable beds of *E. siliqua* in a survey of the northeast Irish Sea with catches up to 17 kg in a 10 minute tow at 0.2 to 0.4 knots. Some studies have also taken samples opportunistically from established commercial hydraulic dredging fisheries (e.g., Fahy *et al.*, 2001).

The use of hydraulic dredges for razor clam stock assessment in Wales has been investigated by Trundle (2004) in Carmarthen Bay. In that study, 29 tows were undertaken with a 1.5 m dredge width at 0.1 knots for 15 minutes. In the areas of greatest abundance, catches of 30 to 50 kg per tow were reported. The tow length was taken to be 45 metres, allowing an estimate of the dredge area and *Ensis* spp. density to be computed. This produced an estimate of 13 400 tonne fishable biomass within the 10 m contour in Carmarthen Bay. No *Ensis* spp. less than 100 mm length were found in this study, and it was unclear if this was due to the dredge selectivity or abundance of younger razor clams. This highlights a potential disadvantage of fishery-based technology in stock assessment work. Efforts to use a “blinder” in the dredge to retain smaller razor clams were unsuccessful due to the volume of sediment

which blocked the collecting basket and caused the vessel to come fast within a few minutes of deployment. In another study, the capture of small *Ensis* spp. by hydraulic dredge was only recorded when the dredge was clogged (Bailey *et al.*, 1998) so that quantitative estimates of juvenile density could not be made.

Hydraulic dredging is used to survey *Ensis* spp. beds in Ireland to estimate biomass and provide guidance on total allowable catches using three to five minute tows and developed statistical analyses (Marine Institute and Bord Iascaigh Mhara, 2016). In the Netherlands, where there has been a hydraulic dredge fishery for *E. directus* since 1990 and currently six active licenses, razor clam stock biomass and distribution is estimated annually through independent research surveys using a grid of sampling stations stretching the entire Dutch coastline (Aitken and Knott, 2018). A suction trawl is used in shallow parts of the survey; however, most of the survey is undertaken with specialised sampling gear including a modified cockle dredge with 20 cm blade which penetrates 7 cm into the sediment (Hervás *et al.*, 2012). This specialised dredging gear only collect the upper part of the animal requiring width conversion into length and weight (Perdon *et al.*, 2016) and changes to this survey methodology have been planned (Cappell *et al.*, 2018).

The fishing efficiency of hydraulic dredging has been shown to be over 90% in appropriate conditions (Hauton *et al.*, 2007). However, this may depend on careful adjustments and refinements to the gear for particular areas, and much lower efficiencies have been reported (e.g., Bailey *et al.*, 1998). The coverage of any stock assessment by hydraulic dredging would be limited by the depth range of the gear used, which may be as little as 3 to 5.5 m in the case of continuous recovery techniques (MacKay, 1992). Further, the effectiveness of hydraulic dredging techniques is limited by tide and weather. Even moderate waves have been shown to reduce the effectiveness of hydraulic methods and increase breakages for *Ensis* spp. (MacKay, 1992). In strong wind or tides the gear may drift too quickly with reduced penetration depth, and in rough conditions razor clams are thought to burrow deeper which would further decrease dredge efficiency and increase breakages (Muir, 2003). Hydraulic dredging trials in the northeast Irish Sea demonstrated commercially viable stocks but described the biggest hurdle to the future development of a fishery being the requirement of calm conditions for beds exposed to prevailing winds (Palmer, 2010).

5.2.2 Electrofishing

In the absence of legal commercial fisheries using electrofishing, electrofishing studies of razor clams have focussed on gear development or environmental impact rather than stock assessment (e.g., Woolmer 2011; Murray *et al.*, 2014). However, electrofishing methods for *Ensis* spp. have shown to be extremely efficient. Murray *et al.*, (2014) reported that 100% of *E. siliqua* emerged within 37 seconds during tank trials using an AC system with an output voltage of approximately 25 volts and current of approximately 42 amps. This study also reports that during field trials razor clams were the only animals which emerged from the sediment following exposure to the electrical current, and that consequently all other species observed in study quadrats were epifaunal. An exception to the lack of electrofishing stock assessment work for razor clams is the recent work of Fox (2017) off the west coast of Scotland. That study focussed on the development of an electrofishing camera system and is treated in more detail in Section 5.2.3. A significant advantage of electrofishing over other methods is that it is not thought to be size selective (C. Fox, pers. comm. 2018). However,

electrofishing rigs are at prototype levels of development and, like hydraulic dredging, sampling coverage is limited by the conditions the gear can be worked in.

In 2017 the Scottish Government authorised a limited trial electro-fishery for razor clams following a public consultation. Trials are expected to take place in 2018 and continue for a number of fishing seasons by a limited number of fishing vessels issued with derogations for harvesting razor clams by electrofishing in restricted areas. This has been supported by implementation of new legislation prohibiting fishing for razor clams in Scottish waters and of the landing of razor clams in Scotland, aimed at targeting illegal electrofishing outside the trial. The published objectives of this trial include to gather information on razor clam populations and stocks by the trial participants.

5.2.3 Cameras

Trundle (2004) investigated the utility of a towed sled fitted with camera equipment for identifying razor clams and it was found that the conditions in Carmarthen Bay during the summer were excellent with spouts from disturbed razor clams easily visible. An advantage of using camera equipment was the ability to describe surface sediment type as well as conspicuous epifauna and associated biotopes. However, comparison with results from a dredge survey in the same areas showed that biomass estimation did not match and the efficacy of using video for identifying razor clam abundance was questioned (C. Trundle, pers. comm. 2018). An obvious disadvantage of camera footage is the inability to measure samples, and it was suggested that the visible spouts may not only be produced by *Ensis* spp. However, Coates (1999) described the spouting reactions characteristic of *Ensis* spp. as a useful way to provide counts accepting the lack of detailed biological information.

Recent work in Scotland has demonstrated promising results with the use of a combined electrofishing rig with a towed-camera array for stock assessment applications (Fox, 2017). In that study, a commercial fishing vessel was used for tows of between 30 to 60 minutes duration at several sites with cameras mounted 2 m behind the electrofishing rig and supported by divers. Analysis was undertaken on the footage using interactive software to provide length measurement, abundance estimates, distribution information, and behavioural observations. Further development since and trials in the Clyde Sea has demonstrated that this approach can be used without the need for divers (Fox, 2018). Such an approach may be more efficient, cost effective, and potentially would reduce the environmental impact of assessing the status of razor clam beds using traditional dredging methods. One issue identified in that survey was the difficulty in maintaining slow towing speeds in challenging tide and wind conditions, which led to excessive towing speeds of the electrofishing rig and reduced electric field exposure to razor clams.

A combined electrofishing drop-down camera has also been suggested (Fox, 2017). This could be designed around the basis of a quadrat frame of known area with electrodes at the base and a downward looking camera mounted above at a set height and attached to a lifting line with power and video feeds to the vessel. By deploying the frame on the seabed and applying an electrical current, the density, size, and species of emerging razor clams could be efficiently estimated. Although probably limited to areas with low tide, a dedicated system of this design could be used as part of a spatially random sampling design by a wide range of vessels and without the need for divers. However, the disadvantage of such a system compared to towed methods would be need to undertake a very large number of recordings

to assess the same area (C. Fox, pers. comm. 2018). Quadrat frames with high definition cameras attached were previously used by Murray *et al.* (2014) to monitor the recovery *Ensis* spp. following electrofishing trials.

Cameras could potentially be fitted to other platforms such as remotely operated vehicles (ROVs) to conduct visual surveys of razor clam burrows. This could follow a similar approach to diver visual surveys, but with potentially extended sampling times and increased depth coverage. However, the use of such platforms for razor clam stock assessments work has not been trialled.

The effectiveness of any camera systems, and visual methods generally, depend on a clear and unobstructed view of the seabed. Reduced visibility due to the presence of dense seagrass and macro-algae is described by Fox (2017), which could cause razor clam abundance to be underestimated and consequently limit the use of camera systems to specific areas or particular times of year.

5.2.4 Grab and core samples

Samples using a 0.1 m² long armed Van Veen grab and a 0.1 m² Day grab were collected by Woolmer (2011) on a razor clam bed in Carmarthen Bay, using standard sampling and processing protocols. However, there is no description of any razor clam species being captured by the grabs in that study. Trundle (2004) also describes the use of grab samples in Carmarthen Bay, in this case intended for a systematic survey to sample smaller bivalve species including juvenile *Ensis* species. In that study, a Day grab was used which was found to have limited success at capturing *Ensis* spp., potentially due to the pressure shock of deploying the grab propelling shallow burrowing juvenile razor clams out of the sample. Further, no evidence of *Ensis* spp. spat was encountered, so grab samples were considered more useful for classifying other benthos and the biotope (C. Trundle, pers. comm. 2018). However, other grab designs and deployment strategies may be more effective at capturing juvenile *Ensis* spp., if present.

Muir (2003) describes the logistics of benthic sampling gears, such as grabs and corers, as unsuitable for razor clam surveying due to the ability of adult *Ensis* spp. to burrow rapidly to evade capture. Similarly, Coates (1999) noted that standard “biologist type” grabs do not penetrate the sediment deeply enough and that frequently only part of the animal is obtained. However, various larger core sampling equipment designs exist which are capable of penetrating to several meters and could be considered for *Ensis* spp. sampling. Grabs have previously been used to sample soft sediments in Liverpool Bay during a survey to identify a potential razor clam fishery described in Aitken and Knott (2017), and proved capable of capturing *E. siliqua* and a bycatch of other bivalve species including *P. legumen*. Similarly, the distribution of subtidal *E. directus* has been assessed in the Netherlands using a box corer by Witbaard *et al.* (2015), with the captured sediment sieved over a 1 mm screen and repeated samples taken every three to six weeks providing further information on *E. directus* growth, condition, gonadal development, and the overall population development. A Van Veen Box corer was also used during Dutch *E. directus* stock assessments to provide sampling coverage in rocky areas which could not be sampled by dredging methods (Hervás *et al.*, 2012).

5.2.5 Diver surveys

Diver surveys can be used to assess the subtidal abundance of razor clams by a variety of means. In Muir (2003), diver transects were defined across known razor clam beds perpendicularly to the shore and extending from the extreme low water mark seaward. Along each transect, stations were established at measured depths where a diver counted visible razor clams and razor clam shows and spouts within a defined area to estimate the adult razor clam density. This enabled a relatively large area to be effectively sampled with minimal disturbance using highly transferrable gear. Previous studies in Scotland (Bailey *et al.*, 1998) also used diver counts of spouts and shows to survey *Ensis* species. In that study, an exercise was undertaken to confirm that *Ensis* spp. were indeed the only species associated with the observed spouting behaviour and shows. A technique to stimulate spouting behaviour was also described in that study by inserting a blade into the sediment and moving it from side-to-side causing spouts from *Ensis* spp. within a radius of 25 cm of a blade. Coates (1999) also described how divers have been used to effectively count razor clams by their shows and spouting reactions in Carmarthen Bay.

A limitation of diver counting methods is that razor clam shows may not be very distinct compared with some other burrowing species (Muir, 2003). However, some studies suggest that skilled divers are able to correctly identify *Ensis* spp. shows and also identify other burrow forms which were not caused by razor clams (Bailey *et al.*, 1998). In any case, diver visual surveys will not be able to differentiate *Ensis* spp. and may be less effective for juvenile razor clams which are less obvious visually. Another factor found to affect estimates is the wind-driven swell in shallow waters which forces razor clams to burrow deeper into the sediment, reducing their visibility at the surface (Hauton *et al.*, 2011). A further consideration for counting spouting reactions is that multiple plumes in close proximity can be generated by a single individual burrowing at an angle (Bailey *et al.*, 1998) which could lead to the overestimation of *Ensis* spp. density.

In Ireland, the distribution and density of razor clams has been estimated by divers salting quadrats of 0.33 m² (Fahy *et al.*, 2001). In that study, stations were selected at approximately 500 m intervals from the intertidal working seawards with up to five quadrats at each station and increased sampling focussed in areas of higher razor clam densities. A litre of granular salt was poured over the sediment enclosed by the quadrat, and within 10 minutes all razor clams were deemed to have emerged and were collected by the divers for measurement. Other studies have tried diver salting by injecting a saturated salt solution into burrows (Bailey *et al.*, 1998), which was found not to expose the occupant in all cases. Experiments with repeated salting by divers have suggested that not all razor clams in a given area are visible at a particular time (Coates, 1999) and so some correction for visibility may be appropriate for diver visual surveys depending on conditions.

To assess juvenile abundance, Muir (2003) described a diver digging method for counting razor clams which were difficult to observe *in situ*. At set measurement stations, divers exposed small razor clams (with length < 50 mm) by digging with a single gloved hand within a 0.25 m² quadrant and recorded the number of juveniles present. The excavation of 0.5 m² quadrants to a depth of 1 m was found to be excessively time consuming and disturbed all nearby razor clams. Similarly, diver digging has been described as ineffective and dangerous by Coates (1999). In Hauton *et al.* (2007), 0.25 m² quadrats were excavated by divers using

a hand held jet supplied by the deck wash pump of the survey vessel, with clams recovered by hand from the fluidised sediment.

Surveying using diver operated suction air-lift pumps (e.g., Barnett and Hardy, 1967) has been investigated for *Ensis* species. However, Muir (2003) reports that this method was excessively time consuming, required a large number of compressed air cylinders, was unable to retrieve all razor clams which buried deep, and disturbed all razor clams within the immediate vicinity. Thus, diver-operated air-lift samplers were deemed ineffective for razor clam surveys. The use of Venturi lift gear to sample quadrats in Ireland was described by Fahy *et al.* (2001) using a 4 mm bag mesh which was shown to yield a large number of small (<10 mm) razor clams and suggested that these were not efficiently collected by alternative diver hand collection methods. A diver-operated Venturi lift system was also trialled in Scotland to filter the sediment to depths in excess of 0.5 m within a 0.1 m² core through a fine mesh bag (Bailey *et al.*, 1998). However, it was found in that study that individual razor clams could burrow faster than the sediment could be excavated, and that *Ensis* spp. over a wide area were disturbed and would dig deeper, leading to this approach being abandoned.

Divers have also been used in combination with hydraulic dredges (e.g., Hauton *et al.*, 2007) to provide an independent assessment of gear performance and the razor clam stock. In addition, divers have been used in combination with electrofishing rigs (e.g., Woolmer *et al.*, 2011) to conduct visual surveys of the seabed and take observational notes of gear impacts. In all cases, divers are flexible and can provide detailed information but are likely to overlook small razor clams and the use of divers can be time consuming, expensive, and involves numerous additional health and safety considerations.

5.2.6 Other methods

A limited “tag-and-release” program for assessing razor clam movement is described by Muir (2003). In this study, *E. siliqua* were hand-collected by divers, measured, and fitted with tags before being returned to the seabed. Two types of tags were used. At one site individually numbered plastic “T-bar” tags were inserted into the flesh around the siphons. At another site, a 1 m length of fishing line was fixed to the posterior end of the right valve and a small numbered cork threaded onto the line for identification and to assess the relative location of each razor clam without having to expose the animal. Tagging results revealed most *E. siliqua* successfully reburied but that only a small number were subsequently retrieved from the area of release. The cork tags showed that razor clams were still present when their siphons were not visible, and indicated that the lower estimated abundances recorded during winter by diver surveys were related to the visibility of razor clams which were more likely to be buried out of sight at depth in rough weather. Similar tagging work could be considered to establish the visibility and movement of razor clam stocks in support of other stock assessment methodologies.

Raineault *et al.* (2012) investigated the use of bathymetric sonars and side-scan sonars fitted to an autonomous underwater vehicle (AUV) for the purposes of benthic habitat mapping and macroscopic organism identification. The AUV travelled at a constant height of at least 2 m from the seabed during surveying with high positional accuracy (0.1% error). They found that although some benthic organisms were acoustically detectable by this method, razor clams (*E. directus* in that case) were not.

In Québec, Canada, an *E. directus* fishery uses licensed hydraulic dredging vessels. Stock assessment work has been carried out there using information from logbooks and purchase slips to monitor the catch per unit effort and stock distribution with supporting biological data collected by a commercial sampling program (DFO, 2012). Similarly, *E. siliqua* fishery indicators have been monitored for several years in Ireland, where strict management measures are in place, with commercial data and logbooks used to calculate stock biomass indicators and landings per unit effort in support of biomass estimates from survey work (Marine Institute and Bord Iascaigh Mhara, 2015). In Scotland, trials based on a commercial electrofishing beginning in 2018 aim to assess stocks across specified areas in a highly regulated trial fishery controlled by issued derogations.

6 Discussion

6.1 Potential stock assessment methods for use in Welsh waters

There are a wide range of stock assessment methods available each with their own particular strengths and weaknesses, as detailed in Section 5. In order to determine the most appropriate stock assessment methods for Welsh fisheries, the biology of the species must be central to the consideration of methodologies; however, the management aims which are to be addressed by the assessment outputs are also critical. It is important to distinguish within a management and assessment context, between the requirement to regulate intertidal hand gathering, and the desire to develop a well-managed vessel based razor fishery. It may be that separate management and assessment mechanisms are required for each fishery. This is also relevant within the context of a mixed fishery which could be the case for many areas around the Welsh coast (see Figure 3.1 to Figure 3.3 and Figure 4.3 to Figure 4.8).

A further important consideration when considering the cost of stock assessment methodologies is the processing, analysis and reporting of data, and the timescales over which this is required for management. A cost effective sampling programme will be ineffective if the assessment outputs cannot be provided in a timely manner.

The fishing methods which will be utilised to prosecute the fishery should also be considered when designing stock assessments. Fishery dependent information collected from commercial catches, either by observers or through self-sampling programmes, can be very valuable in the stock assessment process. However, an understanding of the quality of the data and any sources of potential bias is required to ensure that the assessment outputs can be appropriately interpreted. The environmental impacts of the proposed assessment methodology may also need to be taken into consideration.

There are a number of challenges in developing appropriate stock assessment methodologies including (but not limited to): patchy and overlapping distribution of habitats; fishery is likely to take bycatch of other razor clam species; high heterogeneity of density within beds; variable recruitment and age structured populations. In addition there is a lack of existing fisheries data with which to establish a baseline or to determine the potential virgin status of the stocks. The following paragraphs discuss the potential benefits and drawbacks of using only fisheries data, and of selected intertidal and subtidal assessment methods.

6.1.1 *Fishery derived data*

The recording and analysis of fisheries data can be utilised to inform stock assessment and management, with catch rates used as a proxy for stock status. In this way a reduction in catch rates could indicate a decline in stocks. It is important to recognise that external factors can influence catch rates particularly in subtidal fisheries which can be affected by a wide range of factors (e.g., gear efficiency and settings, weather conditions, fishers behaviour). Fisheries data is used in razor clam fisheries in Canada, supported by biological data collection from commercial catch sampling, and also in Ireland, alongside strict management measures and again to support a wider stock assessment programme. The use of only fisheries derived data for the assessment and management of *Ensis* spp. fisheries is a reactive approach and would rely on quick feedback and analysis of data, it would also be appropriate to apply this within a strict framework of management measures as carried out in Ireland. A lack of provision of population estimates would not permit the proactive setting of fishery regulation such as quota based on a calculation of biomass.

While the use of fisheries data alone might be considered cost effective due to the lack of a targeted survey programme, it would not be recommended as a stand-alone assessment method. Szarzi *et al.* (1995) noted that, for an intertidal fishery, estimating density from sampling data was more accurate than measuring abundance using catch per unit effort, as it did not change enough. Fisheries derived data can, however, make an important contribution to the stock assessment process, and should be utilised alongside an appropriate survey programme. This is particularly relevant and important for target stocks with discrete distributions such as *Ensis* species.

6.1.2 Intertidal methods

Intertidal assessments are most suitable for fisheries which are prosecuted from land, and for stocks which have a distribution mainly within the intertidal. In this respect intertidal sampling methods would be suitable for the assessment of hand gathered fisheries. Difficulties in using intertidal methods are that they are not able to cover the full depth distribution of *E. siliqua* or *E. magnus* and would not be suitable for *E. ensis*, which generally has a subtidal distribution. This is a relevant consideration should both intertidal gathering and subtidal fishing be occurring within the same location.

Intertidal methods would be appropriate as part of a suite of tools to survey a fishery area which extended from the intertidal to the subtidal. They would allow sampling in areas where vessel or diver operated sampling might be impractical, and they can provide useful information on any potential age or species segregation within beds. The integration of several methodologies within an assessment process would need to be fully considered and explored within the design phase to ensure that the data produced was compatible and robust.

Care needs to be taken in the interpretation of intertidal surveys, given that initial settlement is likely in the intertidal zone, with smaller individuals likely to be found further up the beach where there is less tide (Henderson and Richardson, 1994; Hernández-Otero *et al.*, 2014c). Beach sampling of small razor clams at the end of the summer could provide an indication of the strength of a particular year class. It would be important to monitor the year class as it nears the minimum landing size and therefore recruitment to the fishery. An understanding of survivability would enable effective predictions of a strong year class entering the fishery in future years. The implementation of a transect based sampling protocol would be desirable to create a size and age profile of the intertidal area. This type of approach may better allow for spatial differences in the population structure to be identified, along with any temporal changes in these differences (potentially linked to recruitment), than stratified random sampling.

With regards to sampling protocol, it may be that different methods would be appropriate for different size classes, such as the approach described by Henderson and Richardson (1994). This is a low-tech approach using digging and sieving techniques to target different sizes of individuals. This approach has the benefit of being cost effective in that it does not require specialist equipment or vessel time, however, it can be labour intensive and this could impact on the number of stations which could be sampled within the limited time at low spring tides. The results of this type of survey can also be affected by the skill and experience of the sampler, therefore suitable training of samplers, and monitoring of data quality would need to be built into any intertidal assessment protocol. Consideration of the different methods of data collection may be required in the interpretation of the data produced.

Hydraulic sampling in the intertidal, such as that used by Szarzi *et al.* (1995) for *Siliqua patula*, is an efficient and accurate methodology, which can sample relatively large areas and a wide size range of individuals, with less risk of sampling bias towards larger individuals. This “pumped area method” is likely to be less cost effective than more traditional sampling mechanisms, as it requires specialist equipment and up to five people to operate the equipment efficiently (Jones *et al.* 2001). The practicalities of utilising such equipment on the foreshore would also need to be investigated prior to including this method in any survey design.

6.1.3 Subtidal methods

A range of appropriate subtidal methodologies are available for consideration, with hydraulic dredging, electrofishing, and diver surveys the most effective. Each of these methods have been used to successfully assess razor clam stocks, however, each has its drawbacks. Hydraulic dredging is widely used, however, dredge efficiency can be significantly affected by sea state and it may not be a suitable survey method within areas where dredging is prohibited or is not desirable (e.g., marine protected areas). Of the different dredge options available, a designed survey dredge may be appropriate in order to target and retain undersized individuals, and to maintain consistency in results. Electrofishing is an extremely efficient survey technique, which targets a wide size range of razor clams. This method has historically relied on divers following the gear, with associated health and safety considerations. A recent development in this methodology combining electrofishing with cameras, as reported by Fox *et al.* (2017), is an attractive option because of the high selectivity and low environmental impact of the gear. This sampling set up, which costs around £2 000 per vessel (C. Fox, pers. comm. 2018), could also be placed on commercial vessels (subject to this being an approved fishing gear for commercial purposes) to provide additional data. This type of approach can, however, be limited by tidal speeds which may restrict sampling opportunities.

Both dredging and electrofishing have the potential to cover much greater areas than a diver survey and would have the ability to provide species level identification, size data, and to include small individuals which may be missed by even the most experienced dive surveyor. For this reason, although dive surveys would be more cost effective due to lower vessel and equipment costs, they are not recommended here.

The approach taken in the Marine Stewardship Council accredited Dutch Razor fishery for *E. directus* (Hervás *et al.*, 2012; Cappell *et al.*, 2018), is clearly a comprehensive and suitable approach for assessing razor stocks which ensures that the fishery can be managed at a sustainable level. The independent research surveys utilise three different gear types in a grid survey with sampling stratification based on the previous year’s population density results. The outputs of these assessments permit the allocation of quota to vessels based on the estimated stock biomass.

This scale of work may not be cost effective for Welsh fishery stock assessment, however, a mixed gear sampling approach may be appropriate. Hydraulic dredging is a proven and well-studied methodology which could be utilised alongside electrofishing with a camera system. In that way the hydraulic dredges could be used in areas where tides or currents might limit the use of an electrofishing rig, while the latter could be utilised in areas where there was a requirement to protect the seabed. As electrofishing with a camera set up is a new

assessment technique, the performance and efficiency of the gear is less well studied. The combination of both techniques might be a way to quantify the effectiveness of electrofishing and the balance of methods used in future surveys could be adjusted as necessary to meet management requirements and to effect cost efficiencies.

6.2 Data gaps and requirements

Significant data gaps have already been identified by Aitken and Knott (2018) and include data on the target species, non-target species (including those suitable for commercial bycatch), and impacts of fishing activity on habitats.

6.2.1 Fisheries data

A critical factor will be the collection of adequate fisheries data from both hand gathered and vessel based fisheries. Appropriately collected fisheries dependent data can contribute significantly to the stock assessment process. Examples of relevant data, along with possible methods of collection, are shown in Table 6.1.

Table 6.1. Relevant data types and their possible method of collection.

Data Source	Data Type	Method of Collection
Intertidal	Effort (e.g., person hours)	Logsheet
	Location	Logsheet
	Area Covered	Logsheet
	Catch (weight/numbers)	Logsheet
Subtidal		
Vessel	Type	Application form/fishers survey
	Length	Application form/fishers survey
	Power	Application form/fishers survey
Gear	Type	Application form/fishers survey
	Quantity	Application form/fishers survey
Fishing activity	Location	Logsheet/VMS
	Duration (e.g., time spent towing)	Logsheet
	Gear (type and quantity fished on day)	Logsheet
Catch	Landings	Logsheet
	Live returns (including reason for return)	Logsheet/observers at sea
	Bycatch (ETP* species/habitat interactions)	Logsheet/verbal returns/observers at sea
	Length Frequency	Observers (sea and/or shore)/fisher self-sampling

*Endangered, Threatened or Protected

6.2.2 Biological data

Initial additional sampling effort or targeted research may be required to produce biological data to inform stock assessment methodology. For example, by providing sufficient

background knowledge about the timing of recruitment events and the size distribution of individuals on the shore, the implementation of the sampling programme can be timed effectively and the data collected can be incorporated effectively into assessment advice. For example, low recruitment could be reported erroneously if the timing of recruitment is not known and used to inform sampling protocols.

Key life history data gaps which would need to be addressed through appropriate research projects would include:

- Identification of size at maturity for species of commercial interest in order to develop appropriate minimum landing sizes (MLS).
- Identification of the timing of spawning, and recruitment events. For recruitment an understanding of when and where individuals recruit to the population and to the fishery (on reaching the MLS) would be important given the age segregation in beds.
- Investigation of differential growth rates between the sexes should also be considered, as this can result in increased harvesting rates in faster growing individuals which can skew the sex ratio of exploited populations over time.
- Quantification of mortality rates. Understanding natural mortality rates is key to understanding population dynamics and it will also be important to determine discarding practices and the associated mortality rates so that they can be considered within the assessment process.

This is not an exhaustive list, as the research required to support assessment will depend, to a considerable extent, on the management tools and mechanisms to be implemented. For example the setting of quotas for the following would require a biomass estimate for the population and may require information on what the potential unfished or virgin biomass was. Should a modelling approach which provides stock predictions relating to various harvest strategies be required, a different range of data may be required, for example on the age structure of the population.

A variety of methods have been employed to determine the age of razor clams. In some cases, bivalves can be aged relatively simply by the analysis of surface growth lines which has been attempted for *Ensis* spp. (e.g., Fahy and Gaffney, 2001; Palmer, 2004). However, these lines can be poorly defined and of non-annual origin (Breen *et al.*, 2011) with finer growth increments related to spring-neap cycles and abrupt clefts related to external disturbances (Henderson and Richardson, 1994). Consequently, more accurate age estimation techniques have been developed based on the analysis of internal growth bands by microscopically inspecting the shell sections (e.g., Muir, 2003) or acetate peel replicas (e.g., Henderson and Richardson, 1994). For quality control, different age determination techniques can be applied to the separated right and left valves (e.g., Hernández-Otero *et al.*, 2004a).

6.2.3 *Spatial and temporal considerations*

It can be seen from the MSC Accredited Dutch razor fishery, which utilises an extrapolation of stratified survey samples up to the scale of the fishing ground being surveyed, that spatial data is very important to the stock assessment process. In order to calculate a biomass for the fishery in that geographical location, spatial information on the extent of the fishery is critical. The spatial footprint of the fishery, as defined through inshore VMS reporting, can be utilised alongside relevant sediment data to provide an estimate of a fishery area.

High quality sediment surveys would make understanding the stock distribution and potential fishing areas much easier and would be useful in the stock assessment process. This was highlighted in the SDMs where species were predicted to occur on rock and hard substrate (see Section 4). In order to gain a better understanding of their subtidal distribution, higher resolution information (species occurrences and sediment types in particular) would have to be sourced, especially for smaller, more localised, geographic scales.

For analytical stock assessments such as Virtual Population Analysis (VPA), which is used in the assessment of scallop stocks, a time series of data is important in the effective running of the model, and the effective length of this time series can be linked to the lifespan of a cohort within the population. It is therefore important when reviewing potential assessment methodologies that the length of time over which data is collected can provide a robust assessment.

6.3 Management

As indicated, the proposed management strategy for a fishery and potential tools to be utilised will have a bearing on the data required, either for stock assessment or through the inclusion of targeted research to fill data gaps. It is important that the management mechanisms, objectives, and resourcing are fully considered as part of an integrated stock assessment programme before selecting the preferred methodologies. A review of management processes and tools used in other fisheries is detailed in Aitken and Knot (2018).

Shellfish can vary in their life history characteristics over relatively small spatial scales (e.g., Alfaro, 2006; Shelmerdine *et al.*, 2007; Broitman *et.al.*, 2008), it is therefore recommended that research into the size at maturity is carried out on the populations of *Ensis* spp. of commercial interest in order to determine if the existing MLS is appropriate or if it requires change, or multiple MLS for the different target species. Information on the size at maturity and size distributions can also be utilised to implement technical management measures such as gear specifications. In the Rosslare – Cahore fishery in Ireland for example, vessels are limited to one dredge not exceeding 1.22 m width and with bar spacing at no less than 10 mm (The Marine Institute and Bord Iascaigh Mhara, 2014), and the Dutch North Sea fishery operates a maximum dredge blade width of 1.25 m with minimum bar spacing of 11 mm (Hervás *et al.* 2012).

When considering a mix of shallow subtidal and intertidal harvesting the age distribution of individuals relative to the shore is important. If younger/smaller individuals are found higher up the shoreline (Henderson and Richardson, 1994; Hernández-Otero *et al.*, 2014c), spatial management measures could be utilised to protect areas of juvenile or undersized individuals, these could include closures of areas to intertidal harvesting, or segregating subtidal and intertidal fisheries. The latter would ensure that where populations extended from the intertidal into the subtidal the whole population would not be subject to exploitation. Further spatial management measures could include restrictions relating to water depth which would provide refuges for populations in shallow subtidal areas.

If survey work indicates the presence of beds of *Ensis* spp. with limited age/size classes, a rotational harvesting approach may work. Here exploitation of a bed would be permitted for a specified period of time, or until density levels reached a limit reference point (a lower

threshold which would require monitoring activity). The bed would then be closed, again this could be for a specified period of time (linked to a number of reproductive cycles), or could be related to a specific density of harvestable individuals on the bed (which would take into account the potentially sporadic recruitment and allow time for individuals to reach the minimum landing size).

Due to patchy distribution and low densities not suitable to support a fishery over much of the *Ensis* spp. range, effort is likely to be concentrated on a few areas of suitable habitat where the density is highest until catches become uneconomic there. Due to the intermittent recruitment and slow growing nature of *Ensis* spp. it could be several years before commercial stocks recover in an area. In such cases, it has been estimated that recovery could take seven or more years (Bailey *et al.*, 1998). Bailey *et al.* (1998) proposed rotational resting of grounds in the Western Isles, Scotland, to give time for the replacement of commercially sized *Ensis* species. In Ireland, Fahy (2006) also suggests management controls such as closed areas and fallow periods alongside rigorous log book schemes to guard against 'boom-and-bust' exploitation.

For this type of management approach to be effective the stock assessment methodologies utilised would need to have sufficient resolution to provide information on changes in stock levels as the fishery was carried out, and to observe recovery of closed areas. Care would need to be taken in the identification of the target species as beds where there were mixed species may have different recruitment and growth rates. Any fisheries management plan should take this into consideration as harvesting may favour some species over others (e.g., the short lived invasive species, *E. directus*).

7 Recommendations

Intertidal:

- The most cost effective sampling method is a combination of sieving/digging.
- Appropriate training of samplers is required to reduce any bias in results.
- The practicalities of a hydraulic sampling approach should be investigated similar to that used in Pacific razor clam fisheries as it has the potential to produce higher quality data than other intertidal sampling methods.
- Additional sampling effort/research would be beneficial to support assessment survey design (e.g., timing of recruitment, distribution of age classes, survivability).

Subtidal:

- A combination of hydraulic dredging using a designed survey dredge and camera linked electrofishing would be the most effective mechanism for subtidal surveying. The extent to which each method is utilised would depend on the management objectives (including environmental objectives) in the area to be surveyed and the potential methods of fishing to be licenced (i.e., it may be prudent to utilise survey methods comparable with the commercial fishery).
- Where dredges are to be used, survey specific dredges should be designed to ensure retention of as wide a size range of individuals as possible.
- For electrofishing, should this method be approved for commercial purposes it may be possible to supplement independent research surveys with sampling on commercial vessels.
- For any vessel based assessment methods it would be important to carry out a quantification of sampling efficiency prior to any survey work or stock assessment.

General:

- Targeted research is required to determine appropriate minimum landing sizes (MLS) for relevant species (including commercial bycatch).
- Effective mechanisms for the recording and reporting of fisheries data, linked to fisheries management aims and objectives, should be implemented.
- Vessels should submit daily catch and effort logsheets which permit recording of discards.
- All vessels should be fitted with suitable VMS systems set at a ping rate which will allow the effective identification of fishing activity for both stock assessment and enforcement purposes.
- A biological sampling programme for commercial catches should be implemented to provide data for inclusion in assessment and trends analysis.
- Although not at present significant, *E. directus* should be monitored to assess any spread in distribution or growth in abundance which may affect other *Ensis* spp. or lead to *E. directus* becoming a fishable resource itself.

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