BioInvasions Records (2024) Volume 13, Issue 1: 57–68

Rapid Communication

First record of non-native *Yoldia limatula* (Say, 1831) in the United Kingdom: evidence of a newly established population (Bivalvia: Protobranchia)

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Citation: Barry PJ, Dyson J, Engelhard GH (2024) First record of non-native *Yoldia limatula* (Say, 1831) in the United Kingdom: evidence of a newly established population (Bivalvia: Protobranchia). *BioInvasions Records* 13(1): 57–68, https://doi.org/10.3391/bir.2024.13.1.06

Received: 31 May 2023
Accepted: 8 August 2023
Published: 29 November 2023

Handling editor: Ben Hoffmann
Thematic editor: April Blakeslee

Abstract

This paper reports the first recorded presence of a non-native protobranch bivalve, *Yoldia limatula* (American file clam), in the United Kingdom. In November 2020, it was found to be present in already high numbers (257 individuals recorded) in subtidal sediments in the estuarine zone of the Tees River, Northeast England. This record is far outside the species' native range of North America. The species has recently also been found on the continental margin of Northwest Europe. It is likely to have been introduced into the UK *via* marine traffic, with larval displacement through ballast water exchange thought the most likely route of entry. The bioturbating activities of the species in its native range are discussed, which might have significant ecosystem implications if the species were to become fully established in UK waters. An identification guide to separate this species from similar species of protobranch bivalves in the UK is included.

Key words: *Yoldia*, non-indigenous species, protobranch bivalve, Tees Estuary, bioturbator

Introduction

In recent years there has been a marked increase in the number of non-indigenous marine bivalves discovered in the United Kingdom (UK), many transported *via* pathways linked to human activities (Roy et al. 2018). The Marine Bivalve Shells of the British Isles website (Oliver et al. 2016) currently lists 31 non-indigenous species (NIS) that have been found in the British Isles, out of a total of almost 400 listed species. Some of these are thought to have been washed ashore attached to marine debris (Holmes et al. 2015), some having escaped from aquaculture (Guy and Roberts 2010) and others having arrived *via* unknown or unproven pathways. A small number have established breeding populations in the UK, mostly in or nearby large ports; examples are the Asian date mussel *Arcuatula senhousia* (W.H. Benson, 1842) (Barfield et al. 2018); the Asian Semele, *Theora lubrica* Gould, 1861 (Worsfold et al. 2020); and the American jackknife clam *Ensis leei* M. Huber, 2015, which has become particularly abundant in large swathes of UK waters where they can establish very dense populations and disrupt community functioning (Gollasch et al. 2015). Ports are often NIS hotspots, as organisms with suitable life-histories can exploit ship-borne transport and spread by vessel traffic (Seebens et al. 2016; Fernández-Rodríguez et al. 2022). With so many introductions concentrated in ports (Kakkonen et al. 2019; Pezy et al. 2021), regular monitoring is needed to fulfil the requirements of national and regional conventions and legislation (Lehtiniemi et al. 2015). Regular monitoring programmes in high-risk areas [e.g. HELCOM monitoring programme in Baltic (Backer et al. 2010) and DFO in Canadian (DFO Fisheries and Oceans Canada 2013) ports] can be supplemented by citizen sciences (Lehtiniemi et al. 2020) or partnerships with industry (Ma et al. 2016), but can also be augmented by incorporating the results of Environmental Impact Assessments (EIAs) particularly in those high-risk ports (e.g., Worsfold et al. 2020).

The Tees Estuary (54.63°N; 1.15°W) is a narrow tidal estuary in Yorkshire in the northeast of England, UK (Figure 1) which opens into the North Sea, and since 2019 has been designated a Site of Special Scientific Interest (Teesmouth and Cleveland Coast SSSI) for the presence of populations of wading birds and harbour seals (Natural England 2019). The southern bank of the river has historically been developed into the commercial port known as Teesport, which is one of the busiest ports in the UK (Tidbury et al. 2016). A recent EIA conducted prior to development of the south quayside (Page et al. 2021) resulted in the discovery of the American file clam *Yoldia limatula* (Say, 1831) at numerous locations in the subtidal sediments of the estuary during the subtidal macrofauna survey.

This record represents the first confirmed observations of *Y. limatula* in the United Kingdom. In North America, this species' range extends from the Gulf of St. Lawrence to North Carolina on the Atlantic coast (Johnson 1934) and on the Pacific coast from the Arctic Ocean to San Diego, California (Dall 1921) in sheltered or semi-enclosed water bodies (Bender and Davis 1984). *Yoldia limatula* has recently been found in continental Europe in the Netherlands (de Kisangani and Kerckhof 2020; J. Craeymeersch *pers. comm.*), Belgium and France (Dauvin et al. 2022) but in low numbers. To date, this species represents the only protobranch bivalve to be considered a NIS (Dauvin et al. 2022). While other genera from the family Yoldiidae are native to the UK, most are restricted to deep water. Therefore, this record represents the first confirmed species of *Yoldia* in the UK. The aim of this paper is to describe the individuals found in the Tees Estuary, to discuss the likely pathway of introduction, and to draw attention to the bioturbating activities and possible ecosystem effects were the species to become widely established.

Materials and methods

Sample collection

As part of the EIA process for the licensing of a new quay in Teesside, a targeted benthic survey was conducted to provide a current baseline of the

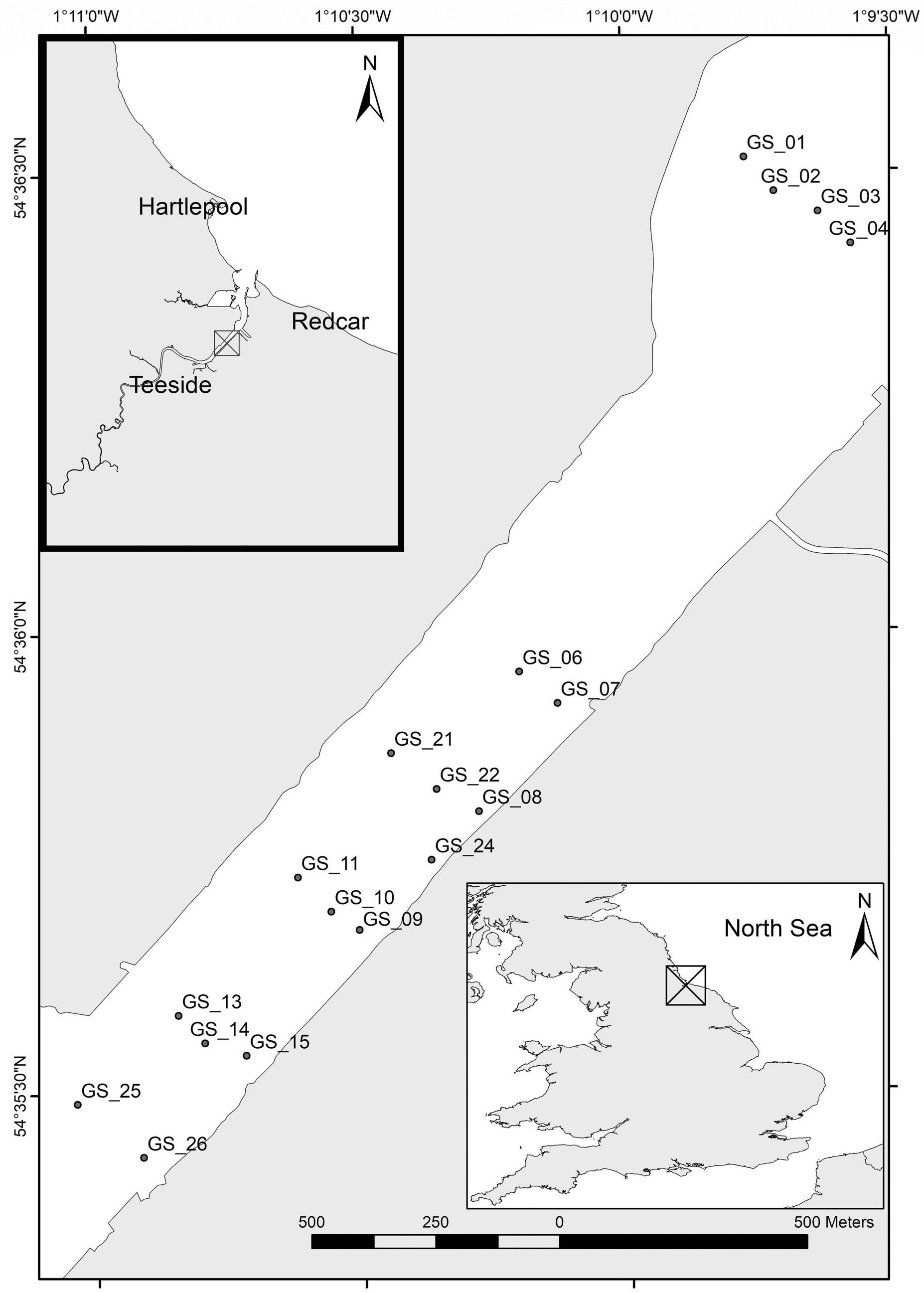

Figure 1. Map of the survey site within the Tees Estuary and sampling locations where *Yoldia limatula* was detected.

benthic invertebrate species and assemblages of the area (Page et al. 2021). Nineteen benthic grab samples were sampled from subtidal sediments within the estuary between 12th and 19th of November 2020 (Figure 1). The stations were located within the central channel of the Tees Estuary, across a depth range of 3.4 to 10.3 metres (Supplementary material Table S1).

At each sampling station, benthic grab samples were obtained using a 0.1 m^2 Day grab operated from a survey vessel. One macrofaunal and one Particle Size Analysis (PSA) sample were taken at each station. The sediments for macrofaunal assessment were washed over a 0.5 mm mesh sieve onboard and fixed in 10% buffered formal saline solution.

Table 1. Size and estimated age classes of *Yoldia limatula* found in the Tees Estuary, November 2020, where age was estimated based on age-length relationships in Lewis et al. (1982).

Size (mm)	Estimated age (year)	Number
> 38.7	> 4	1
33.8–35.2	3	2
26.7–28.0	2	1
13.8–17.7	1	2
3.0–10.5	< 1	11
< 3.0	Juvenile	240

Macrofaunal analysis

All macrofauna species were identified to the lowest practicable taxonomic level, in line with the Northeast Atlantic Marine Biological Analytical Quality Control scheme Taxonomic Discrimination Protocol (Worsfold et al. 2010). Identification of *Yoldia limatula* was made following the description in Drew (1899). Five randomly selected individuals from among a growth series (2–38.7 mm) were selected from stations GS_03 and GS_24 for detailed morphological examination. All collected shells (257 individuals) were measured along the long axis of the shell using digital vernier calipers and sorted into size classes.

PSA analysis

Sediment samples for PSA were analysed using a 1.0 mm mesh sieve followed by laser diffraction analysis of finer material following the NMBAQC guidance (Mason 2022). Sieve and laser data were merged and inputted into the computer program GRADISTAT, used for the analysis of grain size statistics (Blott 2010), which provided sediment descriptions based on the Wentworth (1922) scale and British Geological Survey modified Folk classification (Long 2006).

Results

In all but one of the sampling stations visited during the benthic survey in the Tees Estuary (18 out of 19) the American file clam *Yoldia limatula* were detected. These stations were distributed over most of the inner harbour channel, up to 3 km apart (Figure 1, Table 2). In total, 257 individuals of various life stages were detected: 17 adult clams, and 240 juveniles (see Table S1). All individuals were collected as live specimens.

The benthic habitat of those 18 stations was dominated by annelids (> 95% of all individuals recorded) with a high number of oligochaetes and cirratulids such as *Chaetozone gibber*, *Tharyx* sp. and *Chaetozone vivipara* (Page et al. 2021). The overall habitat was defined under the JNCC Marine Habitat Classification (Connor et al. 2004) as: *Melinna palmata* with *Magelona* spp. and *Thyasira* spp. in infralittoral sandy mud (SS.SMu.ISaMu. MelMagThy) (Connor et al. 2004) [(A5.334 under the EUNIS classification)],

Table 2. Comparison of morphological features of *Yoldia limatula* with similar looking protobranch species recorded in UK waters, and the Arctic species *Yoldia hyperborea*.

Adult specimens	*Yoldia limatula*	*Yoldia hyperborea*	*Nuculana pernula*	*Nuculana minuta*
Shell outline	Elongate elliptical, posterior subrostrate	Elongate elliptical, posterior subrostrate	Elongate elliptical, posterior rostrate	Elongate elliptical, posterior rostrate
Sculpture	Smooth, with fine commarginal lines	Smooth, with fine commarginal lines	Fine raised commarginal ridges	Prominent raised commarginal ridges
Position of umbo	Slightly anterior to the midline	Behind the midline	Anterior to the midline	Anterior to the midline
Rostrum	Subrostrate	Subrostrate	Elongate	Elongate, pronounced
Posterodorsal margin	Weakly convex, compressed area demarcated by shallow furrow extending to end of the rostrum	Weakly convex, shallow furrow extending across half the length	Weakly convex, demarcated by a straight raised ridge the length of the rostrum	Weakly concave, demarcated by a curved raised ridge the length of the rostrum
Shell length	40–50 mm	40–50 mm	Up to 30 mm	Up to 20 mm
Depth range	6–490 m	5–677 m	9–900 m	9–183 m
Geographic range	North America, North Sea	Subarctic	Northern UK, Faroes, Norway	British coasts, mainly northern, excluding the western English Channel and Bristol Channel

Information on size and distribution was compiled from records in Ockelmann (1954), Marine Species Identification Portal (de Kluijver et al. 2022) and the Marine Bivalve Shells of the British Isles website (Oliver et al. 2016).

typical of an organically enriched estuarine environment (Page et al. 2021). Sediments were classified as either mud, sandy mud, or gravelly mud with percentages of up to 62.2% sand and up to 86.2% fines (Table S1).

Main features of Yoldia limatula

***Yoldia limatula* (Say, 1831)**

Material examined: 1 large individual from Stn. GS_24 (Figure 2); 4 small individuals from Stn. GS_03 (Figures 3, 4).

Description of adult (Figure 2)

Shell thin, solid; equivalve; subequilateral, beaks just in front of midline; compressed; elongate elliptical, posterior subrostrate; anterodorsal margin convex, frequently with high shoulder; anterior broadly rounded; posterodorsal margin slightly convex, sloping with pronounced inflection midway; margins compressed and delimited by shallow furrow to end of rostrum; rostrum broad, pointed; ventral margin broad, gently curved; sculpture consisting of very fine commarginal lines; periostracum thin, glossy, olive-green to greenish brown; inner margin smooth; ligament internal, on triangular resilifer below the beaks; hinge taxodont, with up to 26 teeth in anterior and 23 in posterior. Central teeth thin, erect, distal teeth laterally expanded.

Description of juveniles (Figure 3)

Shell thin, solid; equivalve; slightly subequilateral; beaks opisthogyrate, just behind the midline; moderately inflated; elliptical, posterior subrostrate; anterodorsal margin evenly convex; anterior broadly rounded; posterodorsal margin straight or convex; rostrum truncate; ventral margin broad, gently curved; sculpture of very fine commarginal lines; periostracum thin, transparent, glossy.

Figure 2. Adult *Yoldia limatula* sampled at station GS_24. Length: 34.9 mm. Left: exterior view of right valve (with damaged ventral margin) (top) and interior view of left valve (below). Right: exterior view of left valve (top) and soft parts of animal illustrated (below). Photograph by P. Barry.

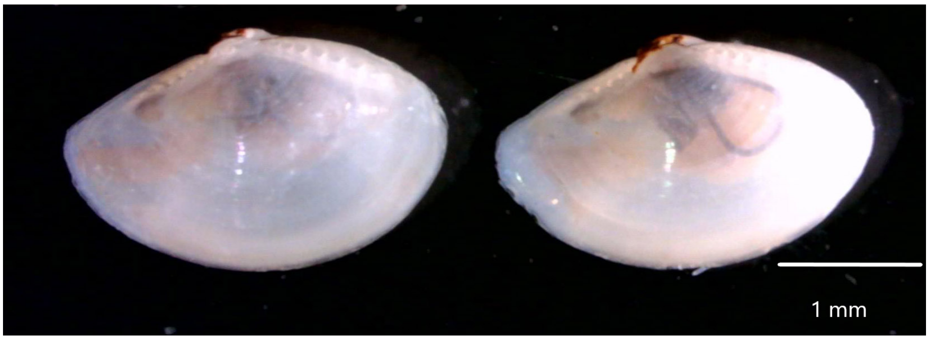

Figure 3. Juvenile *Yoldia limatula*: view of right valves sampled at station GS_03. Length of both individuals: 2.6 mm. Photograph by P. Barry.

Remarks: the single gut loop is visible through the shell on younger shells but is obscured in older shells with thicker valves and cannot be used as a diagnostic feature.

Estimated ages of individuals

Using the age-length relationship reported for *Yoldia limatula* (Lewis et al. 1982), age classes were inferred from shell length measurements of individuals over 3 mm, from the Tees Estuary (Table 1). Since Lewis et al. (1982) used discontinuous size classes (see Table 1), only recorded individuals

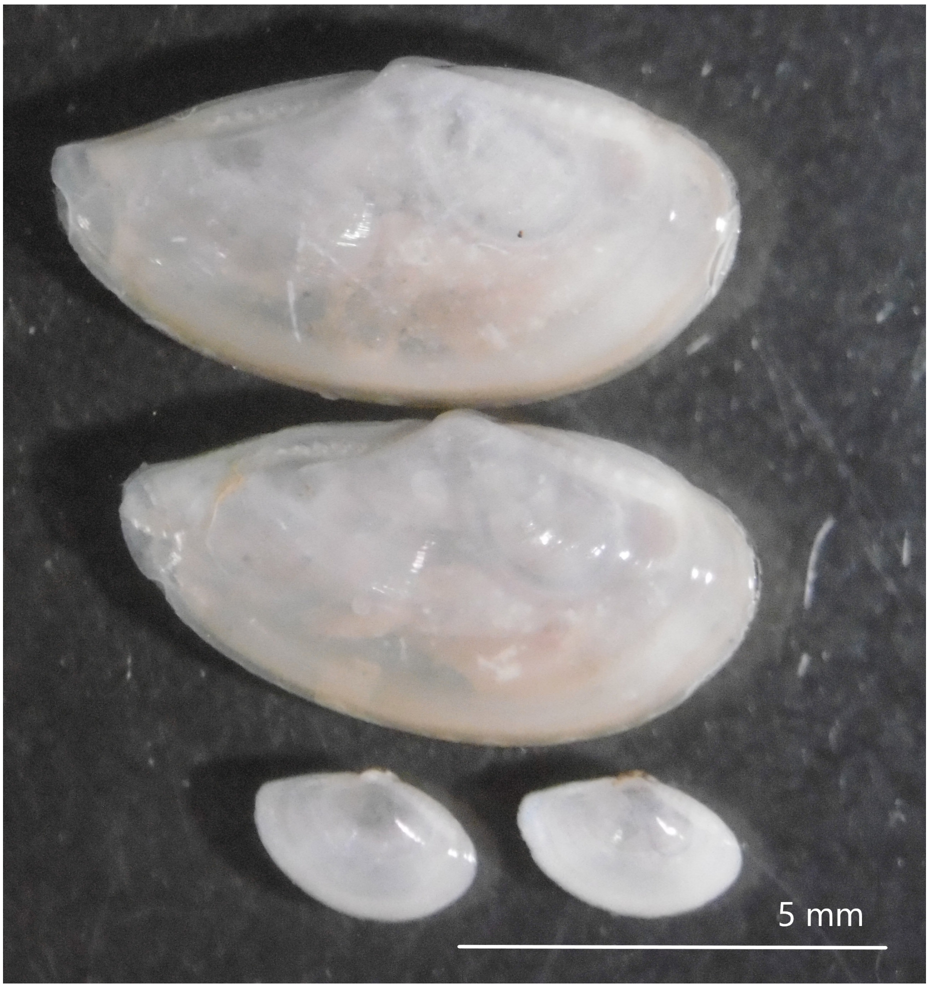

Figure 4. Growth series of immature (< 1 year old) *Yoldia limatula* from station GS_03 showing the right valve of each, with the single gut loop visible. Top specimen length: 8.0 mm; middle specimen length: 7.6 mm; bottom two individuals both 2.6 mm. Photograph by P. Barry.

within the ranges given for each year were included. Specimens below 3 mm were classed as "Juvenile". We acknowledge there might be differences in growth rates between our samples and the Canadian specimens studied by Lewis et al. (1982), owing to differences in seasonal temperature and variations in diet, hence these figures are intended as a proxy for probable ages of the individuals only.

Discussion

This paper documents the first occurrence, and possibly a viable population, of the bivalve *Yoldia limatula* in the UK. No less than 257 individuals were found across 18 locations sampled by benthic grab, within the shipping zone of the Teesside port. The suggestion this might be a viable population of this non-indigenous species is based on the individuals spanning a wide age distribution, with adults and many juveniles, at different locations throughout a 3 km stretch of the Tees Estuary.

The most recent macrofaunal survey within the estuary was in 2019 (Page et al. 2021). The resulting survey report contained no direct mention of *Y. limatula*, but some bivalves were tentatively identified as "*Yoldia* cf. *hyperborea*" (along with individuals of another non-indigenous bivalve, *Theora lubrica*). It is possible that these were immature individuals of *Yoldia limatula* since identification is more difficult when dealing with underdeveloped individuals (Figure 3). While similar in outline, *Y. hyperborea* (A. Gould, 1841) has a distribution in Arctic seas, far north of the British Isles, under far cooler climatic conditions (Ockelmann 1954). A guide to separating these from *Y. limatula* and other native protobranch bivalve species is included in Table 2.

Since these initial, potential records of *Y. limatula* in 2019, the species has so far only sporadically been recorded elsewhere in Europe: three individuals in Le Havre, northern France; three along the Belgian coast; and 19 in the south-western Netherlands of which 18 were in the Voordelta and one in the Western Scheldt. Using age-length keys inferred from Lewis et al. (1982) the continental European *Y. limatula* were considered adults of at least 4 years (Belgian individuals) or 1–2 years of age (Le Havre individuals); ranging 4.5–4.7 cm and 0.75–2.51 cm in length respectively (Dauvin et al. 2022). The age range of the Tees Estuary individuals (Table 1) is representative of a recruiting population, likely to have been present in the Tees for up to 4 years before sampling took place in 2020.

The EUNIS habitat classification of the Tees Estuary (i.e., A5.334) matched that reported for Le Havre Harbour, where three live individuals were found (Dauvin et al. 2022). The composition of fine sediment was much higher (95.6–96.2% silt) in the Le Havre samples compared to that of the Tees Estuary samples (20.5–86.2%), and while detailed sediment analyses were not available from the Dutch or Belgian samples (Driessen et al. 2020; de Kisangani and Kerckhof 2020) they were reported from silty-sandy areas. This matches the sediment profile of their native range in North America: Maurer et al. (1974) recorded *Y. limatula* as abundant in shallow, stenohaline environments with "high silt-clay" content. Drew (1899) regarded them as a shallow water bivalve, and to date the records from Europe have all been found in less than 20 metres water depth. Thus, this deposit feeder may be restricted to euryhaline, muddy/silty sands commonly found in estuaries.

Dauvin et al. (2022) proposed that the continental European populations could be the result of multiple introductions via ballast water, directly from North America, as was suggested for another American bivalve, *Mulinia lateralis* (Say, 1822) that has been found in high numbers off the Dutch coast (Craeymeersch et al. 2019). Port areas are often stressed environments that are readily colonised by alien species arriving via global traffic (Occhipinti-Ambrogi and Savini 2003; Ferrario et al. 2017). For example, *Y. limatula* from Le Havre is just one of 75 NIS recorded in that harbour (Pezy et al. 2021). There is heavy exchange of marine traffic between North Sea ports, and Teesport has been included in the highest category of shipping intensity in the UK and identified as "high risk" for NIS introductions via international shipping (Tidbury et al. 2016). With such a large volume of traffic, an exchange of ballast water carrying bivalve larvae is likely (Keller et al. 2011). *Yoldia limatula* can reproduce multiple times in their lifetime (Lewis et al. 1982) with larvae observed to remain active in the plankton for up to 100 hours (under laboratory conditions) (Drew 1899); this raises the possibility that viable *Y. limatula* larvae could have been successfully transported in ballast water between a number of North Sea ports.

Early detection of NIS is key to their effective management (Reaser et al. 2020) so surveillance monitoring for this species in similar estuarine ports is recommended. While populations currently appear to be localised, control and even eradication might still be possible before this NIS has had opportunity to develop and spread (Guy and Roberts 2010). Management actions within the Tees should be expedited, particularly as a viable population has apparently become established within a Site of Special Scientific Interest and could start to influence sediment stability.

Numerous studies on *Y. limatula* in eastern North America (Sanders 1960; Rhoads 1963; Rhoads and Young 1970) suggest the species is a major bioturbator, highly effective at reworking the top layers of sediment. For example, Davis (1993) observed the species had a substantial effect on sediment-water relationships by breaking up the cohesive structure of the sediment, increasing sediment-water content and increasing resuspension of particulate matter. Populations have been observed to modify the character of the substratum by transferring deeper sediments from 3–4 cm depth and expelling these, so decreasing stability and making sediments more susceptible to erosion (Rhoads 1963; Rhoads and Young 1970; Davis 1993). With some individuals able to rework up to eight times their body weight per hour (Bender and Davis 1984), this bivalve is a significant contributor to seabed bioturbation. In view of this, it is possible that if *Y. limatula* were to increase its population densities within the Tees Estuary, there could be indirect impacts on the structural and functional characteristics of the benthic habitat there, which could have implications for the designatory features of this SSSI. If this NIS, here shown to have established itself for at least 4 years in an SSSI, were to establish itself beyond the Tees Estuary, there might be similar implications for bioturbation and sediment re-working in wider UK waters or beyond, and there could be knock-on effects on sensitive benthic species and habitats.

Identification in comparison to other protobranch species recorded in UK waters

Yoldia limatula belongs to the ancient group of protobranch bivalves (Subclass Protobranchia). Members of this group are characterised by a shell with a taxodont hinge (with numerous small teeth and sockets), with an internal ligament separating the two series of teeth; the animal has primitive gills with small feather-like structures situated posteriorly. Other protobranch bivalves with a similar appearance that could potentially be confused with *Y. limatula* are included in Table 2. Of these, *Yoldia hyperborea* has yet to be recorded in the UK but is included here given that a previous macrofauna survey (Page et al. 2021) reported "*Y.* cf. *hyperborea.*" The native shallow water species *Nuculana minuta* (O.F. Müller, 1776) has an overlapping geographic and bathymetric range but can be differentiated from *Y. limatula* by the clearly raised, fine concentric sculpture, and a more attenuated posterior rostrum. The second *Nuculana* species in the UK, *Nuculana pernula* (O.F. Müller, 1779) has the same attenuated posterior which separates it from *Y. limatula* but also the shell has much coarser raised concentric ribs which should immediately differentiate it from *Y. limatula*. Similar, smooth-sculptured genera of the closely related family Nuculanidae include *Yoldiella*, *Portlandia* and *Ledella* but these are much smaller and generally restricted to offshore waters of greater than 200 metres depth. Thus, *Y. limatula* is unlikely to be mistaken for other shallow coastal species, although this distinction only applies to fully grown individuals.

Acknowledgements

PB and GHE would like to thank the internal reviewers at the Centre for Environment Fisheries and Aquaculture Science (Cefas), particularly Stefan Bolam for assistance with an early draft. We would like to thank Paul McIlwaine (Cefas) for creating the map in Figure 1. PB was funded through the GIA 07 (DEFRA) project. GHE was supported by Innovate UK through the Horizon Europe Guarantee Scheme [project B-USEFUL]. JD would like to thank the survey team at Fugro GB Marine LTD for collecting the samples and Matthew Parsons for drawing our attention to an unusual bivalve in the samples. JD would also like to thank Jeremy Shottin and Andy Addleton (Fugro) for their assistance and support.

Funding declaration

Funding was provided by DEFRA project GIA 07 to support PB writing of the manuscript. Funding was provided by the Horizon Europe Guarantee Scheme [project B-USEFUL] to support GHE.

Authors' contribution

PE and JD for conceptualisation, writing and editing; GHE for writing, editing and reviewing.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Sampling locations with physical characteristics and abundance of *Yoldia limatula* across the 19 sampling stations in the Tees Estuary, November 2020 (Page et al. 2021).

This material is available as part of online article from:
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