MarLIN
Marine Information Network
Information on the species and habitats around the coasts and sea of the British Isles

Capitella capitata and *Thyasira* spp. in organically-enriched offshore circalittoral mud and sandy mud

MarLIN – Marine Life Information Network
Marine Evidence–based Sensitivity Assessment (MarESA) Review

Dr Heidi Tillin & Eliane De-Bastos

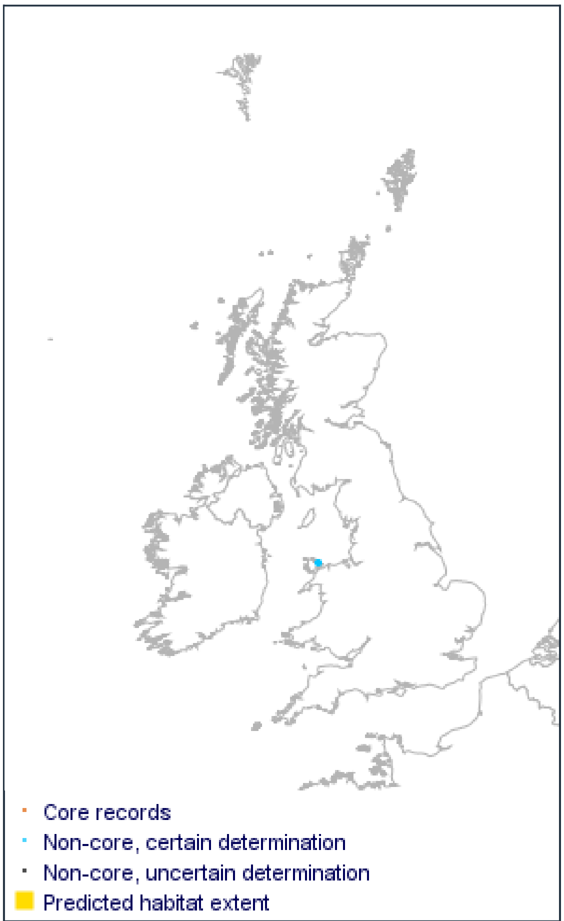
2016-06-30

A report from:
The Marine Life Information Network, Marine Biological Association of the United Kingdom.

Please note. This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [https://www.marlin.ac.uk/habitats/detail/1114]. All terms and the MarESA methodology are outlined on the website (https://www.marlin.ac.uk)

This review can be cited as:
Tillin, H.M. & De-Bastos, E. 2016. [Capitella capitata] and [Thyasira] spp. in organically-enriched offshore circalittoral mud and sandy mud. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. DOI https://dx.doi.org/10.17031/marlinhab.1114.1

(page left blank)



17-09-2018
Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Eliane De-Bastos **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A5.374	*Capitella capitata* and *Thyasira* spp. in organically-enriched offshore circalittoral mud and sandy mud
JNCC 2015	SS.SMu.OMu.CapThy	*Capitella capitata* and *Thyasira* spp. in organically-enriched offshore circalittoral mud and sandy mud
JNCC 2004	SS.SMu.OMu.CapThy	*Capitella capitata* and *Thyasira spp.* in organically-enriched offshore circalittoral mud and sandy mud
1997 Biotope		

Description

In circalittoral and deep offshore mud and sandy mud adjacent to oil or gas platforms, organic enrichment from drill cuttings leads to the development of communities dominated by *Capitella capitata*, an opportunist polychaete especially associated with organically enriched and polluted sediments as described for SS.SMu.ISaMu.Cap (Warren, 1977; Pearson & Rosenberg, 1978). The bivalves *Thyasira flexuosa* or *Thyasira sarsi* may also be found in moderate numbers at some sites. Other taxa may be present in low numbers in areas of less severe enrichment including *Pholoe inornata*, *Lagis koreni*, *Hermania scabra* (syn. *Philine scabra*), *Phyllodoce groenlandica* (syn. *Anaitides groenlandica*), *Mediomastus fragilis* and *Paramphinome jeffreysii.* (Information from Connor *et al.*, 2004; JNCC, 2015).

Depth range

-

Additional information

-

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

The biotope is defined by the presence of large numbers of the polychaete *Capitella capitata* (agg.), supported by organic enrichment from drill cuttings occurring in circalittoral and deep offshore mud and sandy mud adjacent to oil and gas platforms (Connor *et al.*, 2004). *Thyasira* spp. bivalves may also occur in moderate numbers at some sites.

Capitella capitata and *Thyasira* spp. are considered the key characterizing species of the biotopes, and are therefore the focus of the sensitivity assessments. Other taxa present contribute to species richness and diversity but are not considered important characterizing, defining or structuring species and are not considered within the assessment.

Resilience and recovery rates of habitat

Capitella capitata is a classic opportunist species possessing life history traits of rapid development, many reproductions per year, high recruitment and high death rates (Grassle & Grassle, 1974; McCall, 1977). Experimental studies using defaunated sediments have shown that on small scales *Capitella* can recolonize to background densities within 12 days (Grassle & Grassle, 1974; McCall, 1977). In Burry Inlet, Wales, tractor towed cockle harvesting led to a reduction in density of some species but *Capitella capitata* had almost trebled its abundance within the 56 days in a clean sandy area (Ferns *et al.*, 2000).

In favorable conditions, maturity can be reached in <3 months and growth rate is estimated to be 30 mm per year. Adult potential dispersal is up to 1 km. The species complex displays reproductive variability and planktonic larvae are able to colonize newly disturbed patches but after settlement the species can produce benthic larvae brooded within the adult tube to rapidly increase the population before displacement by more competitive species (Gray, 1979). Bolam & Fernandes (2002) and Shull (1997) noted that *Capitella capitata* can colonize azoic sediments rapidly in relatively high numbers. Shull (1997) also demonstrated that this occurs by larval settlement, bedload transport and by burrowing. Thus, when conditions are suitable, the time for the community to reach maturity is likely to be less than six months.

Little information was available for *Thyasira flexuosa*. The larval development of the congener *Thyasira equalis* is lecithotrophic and the pelagic stage is very short or suppressed (Tillin & Tyler-Walters, 2014). This agrees with the reproduction of other *Thyasira* sp., and in some cases (e.g. *Thyasira gouldi*) no pelagic stage occurs at all (Thorson, 1946, 1950). This means that larval dispersal is limited. Sparks-McConkey & Watling (2001) found that a population of *Thyasira flexuosa* in Penobscot Bay, Maine recovered rapidly (within 3.5 months) following trawler disturbance that resulted in a decrease in the population. Benthic reproduction allows recolonization of nearby disturbed sediment and leads to rapid recovery where a large proportion of the population remains to repopulate the habitat.

Resilience assessment. *Capitella capitata* dominated biotopes are likely to reach maturity very rapidly because the species of the complex are short lived, reaching maturity within about four months and reproducing throughout the year. However, other species within the biotope may colonize more slowly. For example, *Thyasira* spp. have fragile shells that are vulnerable to damage, are thought to be slow growing, with benthic reproduction and sporadic recruitment. So where the majority of the population remain (resistance is High, Medium or Low), and/or recruitment by adult mobility is possible, resilience is likely to be **High**. However, where recovery through juvenile recruitment is required, this may be low in places where complete extinction of *Thyasira* spp. occurred. Although polychaetes tend to have high recovery rates and *Capitella capitata* is likely to recolonize the habitat quickly, the low energy environments where the biotope occurs are likely to slow the time for most species and particularly the characterizing species *Thyasira* to re-establish biomass and age-structured populations. Therefore, where impacts remove a significant proportion of the population (resistance is None), recovery is likely to be **Medium** (2-10 years).

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	Medium Q: High A: Medium C: Medium	High Q: High A: Low C: High	Low Q: High A: Low C: Medium

Capitella capitata is a cosmopolitan species in coastal marine and estuarine soft sediment systems. Grassle & Grassle (1976) used electrophoretic enzyme analysis to determine that the global population is actually made up of several genetically distinct (and apparently genetically isolated) sibling species whose distributions overlap such that local *Capitella capitata* populations actually consist of a number of co-occurring sibling species. Within the complex, tolerances may vary and local acclimation is possible. *Capitella capitata* has also been recorded in extreme environments around hydrothermal vents (Gamenick & Giere, 1997), which suggests that the species complex would be relatively tolerant to an increase in temperature.

Experimental evaluation of the effects of combinations of varying salinities and temperature on *Capitella capitata* were carried out by Redman (1985) and Warren (1977). Redman (1985) found that length of life decreased as follows: 59 weeks at mid-temperature and salinity (15°C, 25 ppt); 43 weeks at high temperature and high salinity (18°C, 30 ppt); 33 weeks at lower temperature and high salinity (12°C, 30 ppt); 17 weeks at high temperature and low salinity (18°C, 20 ppt). Redman (1985) also found that net reproduction (Ro: the mean number of offspring produced per female at the end of the cohort) decreased as follows: 41.75 control; 36.69 under high salinity, high temperature; 2.19 high temperature, low salinity; 2.16 low temperature, high salinity. Therefore, a combination of changes in temperature and salinity may decrease the viability of the population. Warren (1977) used individual worms collected from Warren Point (south west England) to test response to high and low temperatures. Worms were acclimated to 10°C for 10 days and subsequently heated in a water bath to experienced a rise in temperature of 1°C per 5 min. When the temperature had reached 28°C worms were removed at 0.5°C intervals and returned to a constant temperature of 10°C. The percentage mortality after 24 h was calculated. Larvae were removed from the maternal tube and tested using the same method. The experiments indicated that temperatures above 30°C were most critical; the upper lethal temperature was 31.5°C for adult worms and a little higher for the larvae.

Thyasira flexuosa does not occur in the southernmost part of the North Sea but is distributed from Norway to the Azores, and extends into the Mediterranean (Tillin & Tyler-Walters, 2014). However, *Thyasira* populations in the British Isles are restricted to areas where the bottom waters remain cool all year round (Jackson, 2007). Wilson (1981) investigated temperature tolerances of six bivalve species from Dublin Bay. The author concluded that species variations in tolerance to increased temperature varied seasonally and with distribution along tidal height. Lethal temperatures for all six bivalve species in the study varied greatly and were, in most cases, well above 20°C. The maximum sea surface temperatures around the British Isles rarely exceed 20°C

(Hiscock, 1998).

Sensitivity assessment. Typical surface water temperatures around the UK coast vary seasonally from 4-19°C (Huthnance, 2010). The biotope, based on the characterizing species, is considered likely to tolerate a 2°C increase in temperature for a year. The experimental studies by Redman (1985) suggest that changes in temperature may reduce the life-span of *Capitella capitata*, however, this effect is not considered to alter the character of the biotope as the short life cycle of this species should lead to rapid replenishment of the population. The experiments by Warren (1977) suggest that both the chronic and acute increases in temperature would not exceed the thermal tolerance of *Capitella capitata*. However, *Thyasira* spp. may suffer some mortality as a result of an acute increase in temperature so resistance is therefore assessed as **Medium** (loss <25%). Resilience is likely to be **High,** so the biotope is considered to have **Low** sensitivity to an increase in temperature at the pressure benchmark level.

Temperature decrease (local)	Medium Q: Low A: NR C: NR	High Q: High A: Low C: High	Low Q: Low A: NR C: NR

Capitella capitata is a cosmopolitan species in coastal marine and estuarine soft sediment systems. Grassle & Grassle (1976) used electrophoretic enzyme analysis to determine that the global population is actually made up of several genetically distinct (and apparently genetically isolated) sibling species whose distributions overlap such that local *Capitella capitata* populations actually consist of a number of co-occurring sibling species. Within the complex, tolerances may vary and local acclimation is possible. Wu *et al*. (1988) collected animals at seawater temperatures of -2°C that harboured mature oocytes indicating reproductive activity even under low temperatures.

Warren (1977) used individual worms collected from Warren Point (south west England) to test response to high and low temperatures. Worms were acclimated to 10°C for 10 days prior to testing. The worms were cooled in a water bath to experience a decrease in temperature of 1°C per 5 min. When the final temperature was reached, worms were removed at 0.5°C intervals and returned to a constant temperature of 10°C. The percentage mortality after 24 h was calculated. Each experiment was repeated once. Larval *Capitella capitata* were removed from the maternal tube and tested using the same method. Both adults and larvae were tolerant of low temperatures, 50% of the adults and 65% of the larvae surviving at -1°C.

Thyasira flexuosa does not occur in the southernmost part of the North Sea but is distributed from Norway to the Azores, and extends into the Mediterranean (Tillin & Tyler-Walters, 2014). However, *Thyasira* populations in the British Isles are restricted to areas where the bottom waters remain cool all year round (Jackson, 2007). Short-term acute periods of extreme cold and icing conditions are likely to cause stress and some mortality in bivalve populations (Dame, 1996). However, no specific information on temperature tolerances of *Thyasira* spp. Was found.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary, seasonally from 4-19°C (Huthnance, 2010). The biotope, based on the characterizing species, is considered to tolerate a 2°C decrease in temperature for a year. The experiments by Warren (1977) suggest that both the chronic and acute decreases in temperature would not exceed the thermal tolerance of *Capitella capitata*. However, characterizing species *Thyasira* spp. May suffer some mortality as a result of an acute decrease in temperature so resistance is therefore assessed as **Medium** (<25% loss), but with low confidence. Resilience is likely to be **High,** so the biotopes are considered to have **Low** sensitivity to a decrease in temperature at the pressure benchmark level.

Salinity increase (local)	Low Q: Low A: NR C: NR	High Q: High A: Low C: High	Low Q: Low A: NR C: NR

The biotopes occur in full salinity (30-35 ppt) (Connor *et al.*, 2004) and it is highly unlikely that they would experience conditions of hypersalinity and no evidence was found to assess an increase in salinity above full.

Sensitivity assessment. No direct evidence was found to assess the effects of changes in salinity and OBIS data (OBIS, 2014) was used as the basis of the assessment. The minimum and maximum range of salinities for the characterizing species are 10.0-39.1 psu for *Capitella capitata* and 31.8-39.1 psu for *Thyasira flexuosa*. This data suggests that the key components of the biotopes communities would not be resistant of an increase in salinity to >40 psu, resulting in mortality of the characterizing species. Resistance is therefore assessed as **Low** (loss of 25-75%) but with low confidence. Once normal conditions are resumed, resilience is probably **High,** so that sensitivity is therefore assessed as **Low**.

Salinity decrease (local)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Warren (1977) used individual worms collected from Warren Point (south-west England) to test response to reduced salinity. Individual *Capitella capitata* were acclimated to 33 ‰ for 1 week prior to exposure to salinities of 1.5 ‰, 5.5 ‰, 18 ‰ and 33 ‰. Larvae removed from the maternal tube were also tested in groups of 10. The results of tolerance tests showed that adult *Capitella capitata* acclimated at 33 ‰ were intolerant of reduced salinities below 20 ‰, all exposed adults died within 4 days when exposed at 18 ‰ and within 1 day at 9 ‰. The larvae were more tolerant, living for 10 days at 15.5 ‰ with little apparent ill effect.

Thyasira spp. inhabit waters of reduced salinity with 25-30 psu being optimal. However, adults exposed to lower than optimal salinities produced non-viable or slow developing eggs (Jackson, 2007). There is insufficient information regarding the effects of salinity on adults.

Sensitivity assessment. The biotope is found within fully marine subtidal locations (Connor *et al.*, 2004). However, there are records of *Capitella capitata* dominated biotopes (e.g. SS.SMu.ISaMu.Cap and SS.SMu.SMuVS.CapTubi) occurring in variable (18-35 ppt) and low salinity (<18 ppt) (Connor *et al.*, 2004). Furthermore, the evidence presented suggests that the characterizing species are likely to resist a decrease in salinity at the pressure benchmark level from full (30-35 ppt) to variable (18-35 ppt). The biotopes are, therefore, considered to have **High** resistance to this pressure and **High** resilience (by default), so the biotopes are considered to be **Not Sensitive** to a decrease in salinity at the pressure benchmark level.

Water flow (tidal current) changes (local)	Medium Q: High A: High C: High	High Q: High A: Low C: High	Low Q: High A: Low C: High

Increases and decreases in water velocity may lead to increased erosion or deposition, respectively. The associated pressures alteration to sediment type and siltation are assessed separately. Experimental increases in near-bed current velocity were achieved over intertidal sandflats by placing flumes on the sediment to accelerate water flows (Zuhlke & Reise, 1994). The increased flow led to the erosion of up to 4 cm depth of surface sediments. No significant effect was observed on the abundance of *Capitella capitata* and numbers of *Tubificoides* *benedii* and *Tubificoides pseudogaster* were unaffected, as they probably avoided suspension by burrowing deeper into sediments. This was demonstrated by the decreased abundance of oligochaetes in the 0-1 cm depth layer and increased abundance of oligochaetes deeper in sediments (Zuhlke & Reise, 1994).

As the characterizing *Capitella capitata* can live relatively deeply buried and in depositional environments with low water flows (based on habitat preferences) and low oxygenation, they are considered to be not sensitive to decreases in water flow.

Sensitivity assessment. The hydrographic regime, including flow rates, is an important structuring factor in sedimentary habitats. The low energy environments where this biotope occurs are therefore likely to be important in supporting the development of the mud or sandy mud substrata which characterizes the biotope. Where increased or decreased water flows altered the sediment type, this could lead to sediment reclassification and thus change is assessed in the sedimentary change assessment. As muds tend to be cohesive and the surface tends to be smooth reducing turbulent flow, an increase at the pressure benchmark may not lead to increased erosion. The biotopes resistance is assessed as **Medium** as a precautionary assessment, resilience is assessed as **High** (following restoration of usual conditions) and sensitivity is assessed as **Low**.

Emergence regime changes	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not Relevant to subtidal biotopes.

Wave exposure changes (local)	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: NR C: NR

Potentially the most damaging effect of increased wave action would be the erosion of the fine sediment substratum as this could eventually lead to loss of the habitat that characterizes the biotopes. Decreased exposure will probably lead to increased siltation and reduced grain size (muddy sediment). Changes in wave exposure may therefore influence the supply of particulate matter for tube building and feeding activities of the characterizing species. Food supplies may also be reduced affecting growth and fecundity of the species.

Thyasira gouldi lives in rather wave sheltered areas at the heads of sea lochs (Jackson, 2007). Increases in wave exposure may disrupt the sediment in which they live, cause continual displacement and physical damage to the shells which are thin and fragile. Disturbance of sediment by waves may reduce oligochaete abundance (Giere, 1977) and oligochaetes may be absent from very wave exposed shores (Giere & Pfannkuche, 1982).

Sensitivity assessment. The biotope occurs offshore where wave exposure is likely to be negligible (Connor *et al*., 2004), as the effects of wave action are attenuated with depth, the factor is only likely to affect the biotopes where it occurs at depths of less than 60 m in a strong swell or force 8 gale (Hiscock, 1983). An increase or decrease in wave height at the pressure benchmark (3-5% of significant wave height) is, therefore, considered unlikely to be significant. Resistance and resilience are therefore assessed as **High**, and the biotope is considered to be **Not Sensitive** at the benchmark level but with low confidence.

Chemical Pressures

	Resistance	Resilience	Sensitivity
Transition elements & organo-metal contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Experimental studies with various species suggest that polychaete worms are quite tolerant to heavy metals (Bryan, 1984). High numbers of *Capitella capitata* have been recorded in areas containing high metal concentrations (Petrich & Reish, 1979; Ward & Young, 1982; Olsgard, 1999), although abundance of *Capitella capitata* in Norway has also been noted to have a significant negative correlation between sediment content of Cu and abundance of the species, with an obvious reduction in abundance at approximately 900 ppm Cu (Olsgard, 1999). Some impacts on population size and reproduction of *Capitella capitata* as a result of metal pollution, both in the field and the laboratory, have been observed.

Tests of copper toxicity have been carried out on the characterizing species *Capitella capitata*. Laboratory tests carried out in water may not reflect sediment conditions where, again, copper toxicity and exposure is determined by a number of parameters including the degree to which it is adsorbed on to particles selected as food for deposit feeders. A 2-year microcosm experiment was undertaken to investigate the impact of copper on the benthic fauna of the lower Tyne Estuary (UK) by Hall & Frid (1995). During a 1-year simulated contamination period, 1 mg/l copper was supplied at 2-weekly 30% water changes, at the end of which the sediment concentrations of copper in contaminated microcosms reached 411 g/g. Toxicity effects reduced populations of the four dominant taxa, including *Capitella capitata*. When copper dosage was ceased and clean water supplied, sediment copper concentrations fell by 50% in less than 4 days, but faunal recovery took up to 1 year, with the pattern varying between taxa. Since the copper leach rate was so rapid, it is concluded that after remediation, contaminated sediments show rapid improvements in chemical concentrations, but faunal recovery may be delayed with experiments in microcosms showing faunal recovery taking up to a year.

Rygg (1985) classified *Capitella capitata* as a highly tolerant species, common at the most copper polluted stations (copper >200 mg/kg) in Norwegian fjords.

Hydrocarbon & PAH contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed** but evidence is presented where available.

Suchanek (1993) reviewed the effects of oil spills on marine invertebrates and concluded that, in general, on soft sediment habitats, infaunal polychaetes, bivalves and amphipods were particularly affected. However, high numbers of *Capitella capitata* have been recorded in hydrocarbon contaminated sediments (Ward & Young, 1982; Olsgard, 1999; Petrich & Reish, 1979) and colonization of areas defaunated by high hydrocarbon levels may be rapid (Le Moal, 1980). After a major spill of fuel oil in West Virginia, *Capitella* increased dramatically alongside large increases in *Polydora ligni* and *Prionospio* sp. (Sanders *et al*., 1972 cited in Gray, 1979). Experimental studies adding oil to sediments have found that *Capitella capitata* increased in abundance initially, although it was rarely found in samples prior to the experiment (Hyland *et al*., 1985). *Capitella capitata* is able to withstand relatively high hydrocarbon concentrations and may even take advantage of any available space, caused by mortality of other species and it should be noted that this biotope occurs in organically enriched areas around oil and gas platforms.

Synthetic compound contamination	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

Méndez (2006) showed that the effects of exposing the deposit feeding polychaete *Capitella* to sediment spiked with environmentally relevant concentrations of teflubenzuron (a chemical used to control infestations of sea lice) caused mortality in one species of *Capitella* and reduced the egestion rate of another.

Neverthelethis pressure is **Not assessed**.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No Evidence.

Introduction of other substances	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

This pressure is **Not assessed**.

De-oxygenation	Medium Q: High A: High C: High	High Q: High A: High C: High	Low Q: High A: High C: High

Capitella capitata exhibits a relatively high tolerance for sediment hypoxia, hydrogen sulphide concentration, and other sediment conditions avoided by many infauna (Henriksson, 1969). Forbes & Lopez (1990) experimentally demonstrated that reduced oxygen concentrations (pO_2 = 20 mm Hg or less) led to decreased *Capitella capitata* growth rates and cessation of burrowing and feeding activity even when an abundance of food was provided. The authors hypothesized that animals rely solely on anaerobic metabolism once this threshold is crossed. Mangum & Van Winkle (1973) similarly observed that *Capitella capitata* oxygen uptake ceased when pO_2 fell to between 0-34 mm Hg. The fact that experimental worms lost body mass under these conditions supports the contention that full aerobic metabolism cannot be sustained at very low ambient oxygen conditions despite a very high affinity of *Capitella capitata* hemoglobin for oxygen.

López-Jamar *et al.* (1987) stated that *Thyasira flexuosa* is adapted to living in reduced sediments and also is found in organically enriched sediments. However, Dando & Spiro (1993) found that numbers of the congeners *Thyasira equalis* and *Thyasira sarsi* decreased rapidly following the deoxygenation of bottom water in the deep basin of the Gullmar fjord in 1979-80. Rosenberg *et al.* (1991) exposed benthic species from the NE Atlantic to oxygen concentrations of around 1 mg/l for several weeks, including species of small bivalves. After 11 days in hypoxic conditions, bivalve individuals were still alive, although individuals showed increased stretching of syphon out of the sediment. In a meta-analysis study of hypoxia, median sub-lethal oxygen concentrations reported in experimental assessments, although no specific data was reported for all the characterizing species of these biotopes, the thresholds of hypoxia for different benthic groups was LC50 1.42 mg/l for bivalves, and sub-lethal (SLC50) of 1.20 mg/l for annelids (Vaquer-Sunyer & Duarte, 2008).

Sensitivity assessment. Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg/l and probable adverse effects below 2 mg/l. Different species in the biotope will have varying responses to deoxygenation. Based on the evidence presented, the characterizing species are likely to only be affected by severe deoxygenation episodes. However, some mortality of *Thyasira* spp. might occur in near anoxic (0% oxygen) conditions. Resistance to deoxygenation is, therefore, assessed as **Medium.** Resilience of the biotope is likely to be **High** and the biotope is, therefore, considered to have **Low** sensitivity to exposure to dissolved oxygen concentration of less than or equal to 2 mg/l for 1 week.

Nutrient enrichment	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The benchmark is set at compliance with WFD criteria for good status, based on nitrogen concentration (UKTAG, 2014).

Sensitivity assessment. Not Sensitive at the pressure benchmark that assumes compliance with good status as defined by the WFD.

Organic enrichment	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Benthic responses to organic enrichment have been described by Pearson & Rosenberg (1978) and Gray (1981). In general, moderate enrichment increases food supply and increases productivity and abundance. Dense *Capitella capitata* populations are frequently located in areas with greatly elevated organic content such as areas of sewage disposal and below fish farms and mussel long lines, even though eutrophic sediments are often anoxic and highly sulfidic (Gray, 1979; Tenore, 1977; Warren, 1977; Tenore & Chesney, 1985; Bridges *et al.*, 1994; Haskoning, 2006; Callier *et al.*, 2007).

Benthic fauna underneath floating salmon farm cages in a Scottish sea loch showed marked changes in species number, diversity, faunal abundance and biomass in the region of the fish farm (Brown *et al.*, 1987). Four 'zones' of effect were identified: in zone 1 directly beneath and up to the edge of the cages there was an azoic zone; in zone 2, from the edge of the cages out to 8 m, the sediments were highly enriched and dominated by *Capitella capitella.* Kutti *et al.* (2008) studied organic enrichment of sediments below a fish farm in a fjord system (Norway), during periods of high organic loading production was mostly by *Capitella capitata*.

Thyasira spp. are characteristic of organically enriched offshore sediments with *Capitella capitata* (Connor *et al.*, 2004) and have been identified as a 'progressive' species, i.e. one that shows increased abundance under slight organic enrichment (Leppakoski, 1975 cited in Gray, 1979). Borja *et al.* (2000) and Gittenberger & Van Loon (2011) assigned *Thyasira flexuosa* to their Ecological Group III - 'Species tolerant to excess organic matter enrichment; these species may occur under normal conditions, but their populations are stimulated by organic enrichment (slight unbalance situations)'.

Sensitivity assessment. The evidence indicates that increased organic matter levels favour *Capitella capitata and Thyasira* spp. and resistance is therefore considered to be **High**, resilience **High** (by default) and the biotope is assessed as **Not Sensitive. I**t should be noted that this biotope occurs in organically enriched areas around oil and gas platforms and that a reduction in organic enrichment may reduce habitat suitability for the characterizing species, leading to biotope loss.

Physical Pressures

	Resistance	Resilience	Sensitivity
Physical loss (to land or freshwater habitat)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

All marine habitats and benthic species are considered to have a resistance of **None** to this pressure and to be unable to recover from a permanent loss of habitat (resilience is **Very Low**). Sensitivity within the direct spatial footprint of this pressure is therefore **High**. Although no specific evidence is described, confidence in this assessment is High due to the incontrovertible nature of this pressure.

Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

The biotope is characterized by the sedimentary habitat (Connor *et al*., 2004),a change to an artificial or rock substratum would alter the character of the biotope leading to reclassification and the loss of the sedimentary community including the characterizing *Capitella capitata*, other polychaetes and oligochaetes and *Thyasira* spp. that live buried within the sediment.

Sensitivity assessment. Based on the loss of the biotopes, resistance is assessed as **None**, recovery is assessed as **Very Low** (as the change at the pressure benchmark is permanent), and sensitivity is assessed as **High**.

Physical change (to another sediment type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High

Capitella capitata can survive in a range of habitats including fine sands and areas with boulders, a change in sediment type was not judged to completely reduce habitat suitability for this species. An increase of sediment coarseness to sand would not exclude this species, based on published habitat preferences, but may have population level effects as habitat suitability may be reduced. Recovery would depend on the return of previous habitat conditions.

The characterizing species *Thyasira* spp. have a range of sediment preferences including mud, muddy sand, sandy mud (Jackson, 2007).

Sensitivity assessment. A change in sediment type to mixed or coarser particles could lead to changes in the density of *Capitella capitata*, other burrowing polychaetes and oligochaetes depending on species specific responses. However, the loss of the muddy sediment that characterizes this habitat would change the character of the biotopes, the characterizing species, with potentially an increase in bivalves or crustaceans and is likely to lead to reclassification. Based on a change in character, the biotopes are considered to have a resistance of **None** to this pressure, and resilience is assessed as **Very Low** (as a change at the pressure benchmark is permanent), and biotopes sensitivity is assessed as **High**.

Habitat structure changes - removal of substratum (extraction)	None Q: High A: High C: High	High Q: High A: Low C: High	Medium Q: High A: Low C: High

Sedimentary communities are likely to be highly intolerant of substratum removal, which will lead to partial or complete defaunation, exposing underlying sediment which may be anoxic and/or of a different character or bedrock and lead to changes in the topography of the area (Dernie *et al.*, 2003). Any remaining species, given their new position at the sediment/water interface, may be exposed to conditions to which they are not suited. Removal of 30 cm of surface sediment will remove the polychaete and oligochaete community and other important species present in the biotopes. Recovery of the biological assemblage may take place before the original topography is restored, if the exposed, underlying sediments are similar to those that were removed. Hydrodynamics and sedimentology (mobility and supply) influence the recovery of soft sediment habitats (Van Hoey *et al.*, 2008).

Sensitivity assessment. Extraction of 30 cm of sediment will remove the characterizing biological component of the biotope. Resistance is assessed as **None** and biotopes resilience is assessed as **High**. Biotope sensitivity is therefore **Medium**.

Abrasion/disturbance of the surface of the substratum or seabed	Medium Q: High A: Medium C: Medium	High Q: High A: Medium C: High	Low Q: High A: Medium C: Medium

Capitella capitata is a soft bodied, relatively fragile species inhabitaing mucus tubes close to the sediment surface. Abrasion and compaction of the surficial layer may damage individuals. *Capitella capitata* and *Pygospio elegans* have been categorized through literature and expert reviews as AMBI fisheries Group IV- 'A second-order opportunistic species, which are sensitive to fisheries in which the bottom is disturbed. Their populations recover relatively quickly however and benefit from the disturbance, causing their population sizes to increase significantly in areas with intense fisheries' (Gittenberger & Van Loon, 2011). Chandrasekara & Frid (1996) found that in intertidal muds, along a pathway heavily used for five summer months (ca 50 individuals a day), some species including *Capitella capitata* and *Scoloplos armiger* reduced in abundance. Bonsdorff & Pearson (1997) found that sediment disturbance forced *Capitella capitata* deeper into the sediment, although the species was able to burrow back through the sediment to the surface again.

Thyasira spp. are small bivalves, the shells are thin and fragile and abrasion is likely to lead to damage and mortality within the population depending on the force (Jackson, 2007). Sparks-McConkey & Watling (2001) found that trawler disturbance resulted in a decline of *Thyasira flexuosa* in Penobscot Bay, Maine. However, the population recovered after 3.5 months.

Sensitivity assessment. Abrasion may damage or kill a proportion of the population of the characterizing *Capitella capitata, Thyasira* spp. and associated species. Biotope resistance is assessed as **Medium** and resilience as **High**, so sensitivity is assessed as **Low**.

Penetration or disturbance of the substratum subsurface	Low Q: High A: High C: Low	High Q: High A: Medium C: High	Low Q: High A: Medium C: Low

Rabaut *et al*. (2008) found that beam trawling on intertidal *Lanice conchilega* reefs reduced the abundance of *Capitella capitata*. Ferns *et al*. (2000), however, found that tractor-towed cockle harvesting had little effect on *Capitella capitata*, but species that are present at the surface were more badly affected. The tractor dredging removed 83% of *Pygospio elegans* (initial density 1850/m^2). These results are supported by work by Moore (1991) and Rostron (1995) who also found that cockle dredging can result in reduced densities of some polychaete species, including *Pygospio elegans*.

Bergman & Van Santbrink (2000) estimated the direct mortality of benthic macrofauna caused by the single pass of commercial beam and otter trawls. The results showed that a single pass of a 4 m or 12 m beam trawl or an otter trawl, in shallow sandy areas and deep silty sand areas (with 3-10% silt) in the North Sea caused a mortality of 20-65% of bivalves and 5-40% of gastropods, starfish, small-medium sized crustaceans and annelid worms. The delicate shells of *Thyasira* spp. are vulnerable to physical damage (e.g. by otter boards), but small size relative to meshes of commercial trawls may ensure survival of at least a moderate proportion of disturbed individuals which pass through (Rees & Dare, 1993).

Sensitivity assessment. *Capitella capitata* and other characterizing species of the biotopes are present in the surface layers of sediment and may be damaged, displaced or killed by penetration and disturbance of the sediment. Resistance is assessed as **Low** and resilience as **High**, so sensitivity is assessed as **Low**.

Changes in suspended solids (water clarity)	Medium Q: Low A: NR C: NR	High Q: High A: Low C: High	Low Q: Low A: Low C: Low

An increase in suspended solids with high organic content may benefit deposit feeders, such as characterizing *Capitella capitata* if these are deposited. Deposit feeders and tube builders rely on deposition of suspended sediment. A decrease in suspended sediment will reduce this supply and therefore may compromise growth and reproduction.

Sensitivity assessment. The biological assemblage characterizing the biotope is infaunal and consists of sub-surface deposit feeders. Increased suspended solids are unlikely to have an impact and resistance is assessed as **High** and resilience as **High**, so the biotope is considered to be **Not Sensitive**. A reduction in suspended solids may reduce deposition and supply of organic matter, resistance to a decrease is therefore assessed as **Medium**, as a shift between deposition and erosion could result in the net loss of surficial sediments. A reduction in organic matter as suspended solids could also reduce production within the biotope. Resistance is assessed as **High,** as over a year the impact may be relatively small, following restoration of usual conditions. Biotope sensitivity is therefore assessed as **Low**.

Smothering and siltation rate changes (light)	Low Q: High A: Medium C: Medium	High Q: High A: Low C: High	Low Q: High A: Low C: Medium

Capitella capitata has been categorized through expert and literature review, as AMBI sedimentation Group IV – 'A second-order opportunistic species, insensitive to higher amounts of sedimentation. Although they are sensitive to strong fluctuations in sedimentation, their populations recover relatively quickly and even benefit. This causes their population sizes to increase significantly in areas after a strong fluctuation in sedimentation' (Gittenberger & Van Loon, 2011). The effects of siltation will depend on the amount and rate that particles are added. *Capitella capitata* is sedentary and adults are judged unlikely to have any mechanism to escape from large inputs. A deep covering of sediment will prevent feeding. Where inputs are at low rates and similar to background sediments then adults may be able to extend tubes to reach the surface to feed.

Powilleit *et al.* (2009) studied responses to smothering for three bivalves; *Arctica islandica*, *Limecola balthica* and *Mya arenaria*. These successfully burrowed to the surface of a 32-41 cm deposited sediment layer of till or sand/till mixture and restored contact with the overlying water. These high escape potentials could partly be explained by the heterogeneous texture of the till and sand/till mixture with 'voids'. In comparison to a thick coverage, thin covering layers (i.e. 15-16 cm and 20 cm) increased the chance of the organisms to reach the sediment surface after burial. This suggests that characterizing bivalve species such as *Thyasira* spp. are likely to be able to burrow through similar overburdens, although sudden smothering with 5 cm of sediment would temporarily halt feeding and respiration, compromising growth and reproduction owing to energetic expenditure. Furthermore, *Thyasira flexuosa* have highly extensible feet (Dando & Southward, 1986) allowing them to construct channels within the sediment and to burrow to 8 cm depth.

Sensitivity assessment. Biotope resistance to siltation, based on *Capitella capitata* is judged to be **Low** with regard to the rapid addition of silts to a depth of <5 cm. Resilience is assessed as **High** as recovery is predicted to be rapid. Sensitivity is therefore assessed as **Low**. At lower levels of siltation, sensitivity will be likely to be lower.

Smothering and siltation rate changes (heavy)	Low Q: Low A: NR C: NR	High Q: High A: Low C: High	Low Q: Low A: Low C: Low

The pressure benchmark (30 cm deposit) represents a significant burial event and the deposit may remain for some time in low energy environments. *Capitella capitata* populations are likely to be significantly impacted. Some impacts on other oligochaetes may occur and it is considered unlikely that signficiant numbers of the population could reposition, based on (Bolam, 2011). Placement of the deposit will, therefore, result in a defaunated habitat until the deposit is recolonized.

Sensitivity assessment. Beyond re-establishing burrow openings or moving up through the sediment, there is evidence of synergistic effects on burrowing activity of marine benthos and mortality with changes in time of burial, sediment depth, sediment type and temperature (Maurer *et al.*, 1986). Bivalve and polychaete species have been reported to migrate through depositions of sediment greater than the benchmark (30 cm of fine material added to the seabed in a single discrete event) (Bijkerk, 1988; Powilleit *et al.*, 2009; Maurer *et al.*, 1982). However, it is not clear whether the characterizing species are likely to be able to migrate through a maximum thickness of fine sediment because muds tend to be more cohesive and compacted than sand. Some mortality of the characterizing species is likely to occur. Resistance is therefore assessed as **Low** (25-75% loss) and resilience as **High** and the biotopes are considered to have **Low** sensitivity to a 'heavy' deposition of up to 30 cm of fine material in a single discrete event.

Litter	Not Assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR	Not assessed (NA) Q: NR A: NR C: NR

Not assessed.

Electromagnetic changes	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No Evidence is available on which to assess this pressure.

Underwater noise changes	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not Relevant.

Introduction of light or shading	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

As the characterizing biological assemblage occurs within the sediment and can be deeply buried (to 10 cm or more), an increase in light or shading is considered **Not Relevant**. Furthermore, the biotopes are sublittoral (Connor *et al*., 2004), not characterized by the presence of primary producers and are, therefore, not directly dependent on sunlight.

Barrier to species movement	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not Relevant to biotopes restricted to open waters.

Death or injury by collision	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Not Relevant to seabed habitats. NB. Collision by grounding vessels is addressed under 'surface abrasion'.

Visual disturbance	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

The characterizing species of the biotopes live infaunally, so are likely to have poor or no visual perception and unlikely to be affected by visual disturbance. Visual disturbance is therefore considered **Not Relevant**.

Biological Pressures

	Resistance	Resilience	Sensitivity

Genetic modification & translocation of indigenous species	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

Key characterizing species within the biotopes are not cultivated or translocated. This pressure is therefore considered **Not Relevant.**

Introduction or spread of invasive non-indigenous species	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Invasion by the slipper limpet *Crepidula fornicata* may lead to shallower examples of this biotope to revert to SS.SMx.SMxVS.CreMed suggesting high intolerance as the original biotope would be lost. It should be noted that experimental relaying of mussels on intertidal fine sand sediments increased fine sediment proportions and led to colonization by *Capitella capitata* (Ragnarsson & Rafaelli, 1999), so that sediment modification by bivalves may not render habitats unsuitable for *Capitella capitata.*

Sensitivity assessment. Reclassification of the biotope following invasion would result in the loss of the biotope. However, *Crepidula* is typically found around the low water mark and the shallow sublittoral to 60 m (Rayment, 2007), so the depth at which this biotope occurs is likely to offer some protection against invasion. Resistance is therefore assessed as **High**, and resilience as **High** (by default) and the biotope is considered **Not Sensitive** to the introduction of INIS.

Introduction of microbial pathogens	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: NR C: NR

Marine oligochaetes host numerous protozoan parasites without apparent pathogenic effects even at high infestation levels (Giere & Pfannkuche, 1982 and references therein). Furthermore, more than 20 viruses have been described for marine bivalves (Sinderman, 1990). Bacterial diseases are more significant in the larval stages and protozoans are the most common cause of epizootic outbreaks that may result in mass mortalities of bivalve populations. Parasitic worms, trematodes, cestodes and nematodes can reduce growth and fecundity within bivalves and may in some instances cause death (Dame, 1996). A viral infection of the mutualist bacterium living on the gills of *Thyasira gouldi* was suggested as the reason for a major decline in the Loch Etive population (Jackson, 2007), but no information specifically concerning the effects of microbial pathogens and parasites on the viability of the characterizing species was found.

Sensitivity assessment. Based on the lack of evidence for mass mortalities in the biotopes from microbial pathogens, resistance is assessed as **High** and resilience as **High** (by default), so that the biotope is assessed as **Not Sensitive**.

Removal of target species	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR

No characterizing species within the biotopes are targeted by commercial or recreational fishers or harvesters. This pressure is therefore considered **Not Relevant**.

	Resistance	Resilience	Sensitivity
Removal of non-target species	Low Q: Low A: NR C: NR	High Q: High A: Low C: High	Low Q: Low A: Low C: Low

Direct, physical impacts are assessed through the abrasion and penetration of the seabed pressures, while this pressure considers the ecological or biological effects of by-catch. Species in this biotope, including the characterizing species, may be damaged or directly removed by static or mobile gears that are targeting other species (see abrasion and penetration pressures).

Sensitivity assessment. Removal of the characterizing species would result in the biotopes being lost or reclassified. Therefore, the biotope is considered to have a resistance of **Low** to this pressure and to have **High** resilience, resulting in the sensitivity being judged as **Low**.

Bibliography

Bagheri, E. & McLusky, D., 1982. Population dynamics of oligochaetes and small polychaetes in the polluted forth estury ecosystem. *Netherlands Journal of Sea Research*, **16**, 55-66.

Bagheri, E.A. & McLusky, D.S., 1984. The oxygen consumption of *Tubificoides benedeni* (Udekem) in relation to temperature and its application to production biology. *Journal of Experimental Marine Biology and Ecology*, **78**, 187-197.

Bamber, R.N. & Spencer, J.F. 1984. The benthos of a coastal power station thermal discharge canal. *Journal of the Marine Biological Association of the United Kingdom*, **64**, 603-623.

Barnes, R.S.K., 1994. *The brackish-water fauna of northwestern Europe.* Cambridge: Cambridge University Press.

Bergman, M.J.N. & Van Santbrink, J.W., 2000b. Fishing mortality of populations of megafauna in sandy sediments. In *The effects of fishing on non-target species and habitats* (ed. M.J. Kaiser & S.J de Groot), 49-68. Oxford: Blackwell Science.

Bijkerk, R., 1988. Ontsnappen of begraven blijven: de effecten op bodemdieren van een verhoogde sedimentatie als gevolg van baggerwerkzaamheden: literatuuronderzoek: RDD, Aquatic ecosystems.

Birtwell, I.K. & Arthur, D.R., 1980. The ecology of tubificids in the Thames Estuary with particular reference to *Tubifex costatus* (Claparède). In *Proceedings of the first international symposium on aquatic oligochaete biology, Sydney, British Colombia, Canada, May 1-4, 1979. Aquatic oligochaete biology* (ed. R.O. Brinkhurst & D.G. Cook), pp. 331-382. New York: Plenum Press

Bolam, S.G., 2011. Burial survival of benthic macrofauna following deposition of simulated dredged material. *Environmental Monitoring and Assessment*, **181** (1-4), 13-27.

Bolam, S.G. & Fernandes, T.F., 2002. Dense aggregations of tube-building polychaetes: response to small-scale disturbances. *Journal of Experimental Marine Biology and Ecology*, **269**, 197-222.

Bonsdorff, E. & Pearson, T.H., 1997. The relative impact of physical disturbance and predation by *Crangon crangon* on population density in *Capitella capitella*: An experimental study. *Ophelia*, **46**, 1-10.

Borja, A., Franco, J. & Perez, V., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Marine Pollution Bulletin*, **40** (12), 1100-1114.

Bouchet, V.M. & Sauriau, P.-G., 2008. Influence of oyster culture practices and environmental conditions on the ecological status of intertidal mudflats in the Pertuis Charentais (SW France): A multi-index approach. *Marine Pollution Bulletin*, **56** (11), 1898-1912.

Bridges, T.S., 1996. Effects of organic additions to sediment, and maternal age and size, on patterns of offspring investment and performance in two opportunistic deposit-feeding polychaetes. *Marine Biology*, **125**, 345-357.

Bridges, T.S., Levin, L.A., Cabrera, D. & Plaia, G., 1994. Effects of sediment amended with sewage, algae, or hydrocarbons on growth and reproduction in two opportunistic polychaetes. *Journal of Experimental Marine Biology and Ecology*, **177** (1), 99-119.

Brown, J., Gowen, R. & McLusky, D., 1987. The effect of salmon farming on the benthos of a Scottish sea loch. *Journal of Experimental Marine Biology and Ecology*, **109** (1), 39-51.

Bryan, G.W., 1984. Pollution due to heavy metals and their compounds. In *Marine Ecology: A Comprehensive, Integrated Treatise on Life in the Oceans and Coastal Waters*, vol. 5. *Ocean Management*, part 3, (ed. O. Kinne), pp.1289-1431. New York: John Wiley & Sons.

Callier, M. D., McKindsey, C.W. & Desrosiers, G., 2007. Multi-scale spatial variations in benthic sediment geochemistry and macrofaunal communities under a suspended mussel culture. *Marine Ecology Progress Series*, **348,** 103-115.

Cardell, M.J., Sarda, R. & Romero, J., 1999. Spatial changes in sublittoral soft-bottom polychaete assemblages due to river inputs and sewage discharges. *Acta Oecologica*, **20**, 343-351.

Chandrasekara, W.U. & Frid, C.L.J., 1996. Effects of human trampling on tidal flat infauna. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6**, 299-311.

Cole, S., Codling, I.D., Parr, W., Zabel, T., 1999. Guidelines for managing water quality impacts within UK European marine sites [On-line]. *UK Marine SACs Project*. [Cited 26/01/16]. Available from: http://www.ukmarinesac.org.uk/pdfs/water_quality.pdf

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B., 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. ISBN 1 861 07561 8. In JNCC (2015), *The Marine Habitat Classification for Britain and Ireland Version 15.03.* [2019-07-24]. Joint Nature Conservation Committee, Peterborough. Available from https://mhc.jncc.gov.uk/

Cuomo, M.C., 1985. Sulphide as a larval settlement cue for *Capitella* sp. I. *Biogeochemistry*, **1**, 169-181.

Dahlgren, T.G., Åkesson, B., Schander, C., Halanych, K.M. & Sundberg, P., 2001. Molecular phylogeny of the model annelid *Ophryotrocha*. *The Biological Bulletin*, **201**(2), 193-203.

Dame, R.F.D., 1996. *Ecology of Marine Bivalves: an Ecosystem Approach.* New York: CRC Press Inc. [Marine Science Series.]

Dando, P.R. & Southward, A.J., 1986. Chemoautotrophy in bivalve molluscs of the Genus *Thyasira*. *Journal of the Marine Biological Association of the United Kingdom*, **60**, 915-929.

Dando, P.R. & Spiro, B., 1993. Varying nutritional dependence of the thyasirid bivalves *Thyasira sarsi* and *Thyasira equalis* on chemoautotrophic symbiotic bacteria, demonstrated by isotope ratios of tissue carbon and shell carbonate. *Marine Ecology Progress Series*, **92**, 151-158.

Dernie, K.M., Kaiser, M.J., Richardson, E.A. & Warwick, R.M., 2003. Recovery of soft sediment communities and habitats following physical disturbance. *Journal of Experimental Marine Biology and Ecology*, **285-286**, 415-434.

Deslous-Paoli, J.-M., Lannou, A.-M., Geairon, P., Bougrier, S., Raillard, O. & Héral, M., 1992. Effects of the feeding behavior of *Crassostrea gigas* (Bivalve Molluscs) on biosedimentation of natural particulate matter. *Hydrobiologia*, **231** (2), 85-91.

Eagle, R.A. & Rees, E.I.S., 1973. Indicator species - a case for caution. *Marine Pollution Bulletin*, **4**, 25.

EMU, 1992. An experimental study on the impact of clam dredging on soft sediment macro invertebrates. English Nature Research Reports. No 13.

Ferns, P.N., Rostron, D.M. & Siman, H.Y., 2000. Effects of mechanical cockle harvesting on intertidal communities. *Journal of Applied Ecology*, **37**, 464-474.

Flach, E.C., 1991. Disturbance of benthic infauna by sediment-reworking activities of the lugworm *Arenicola marina*. *Netherlands Journal of Sea Research*, **30**, 81-89.

Forbes, T.L. & Lopez, G.R., 1990. The effect of food concentration, body size, and environmental oxygen tension on the growth of the deposit-feeding polychaete, *Capitella* species 1. Limnology and Oceanography, **35** (7), 1535-1544.

Gamenick, I. & Giere, O., 1997. Ecophysiological studies on the *Capitella capitata* complex: respiration and sulfide exposure. *Bulletin of Marine Science*, **60**, 613.

Giere, O., 1977. An ecophysiological approach to the microdistribution of meiobenthic Oligochaeta. I. *Phallodrilus monospermathecus* (Knöllner)(Tubificidae) from a subtropical beach at Bermuda. *Biology of benthic organisms.* Pergamon Press New York, 285-296.

Giere, O., 2006. Ecology and biology of marine oligochaeta–an inventory rather than another review. *Hydrobiologia*, **564** (1), 103-116.

Giere, O. & Pfannkuche, O., 1982. Biology and ecology of marine Oligochaeta, a review. *Oceanography and Marine Biology*, **20**, 173-309.

Giere, O., Preusse, J. & Dubilier, N. 1999. *Tubificoides benedii* (Tubificidae, Oligochaeta) - a pioneer in hypoxic and sulfide environments. An overview of adaptive pathways. *Hydrobiologia*, **406**, 235-241.

Gittenberger, A. & Van Loon, W.M.G.M., 2011. Common Marine Macrozoobenthos Species in the Netherlands, their Characterisitics and Sensitivities to Environmental Pressures. GiMaRIS report no 2011.08. DOI: 10.13140/RG.2.1.3135.7521

Goulletquer, P. & Heral, M., 1997. Marine molluscan production trends in France: from fisheries to aquaculture. *NOAA Tech. Rep. NMFS*, **129**.

Grassle, J.F. & Grassle, J.P., 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. *Journal of Marine Research*, **32**, 253-284.

Grassle, J.F. & Grassle, J.P., 1976. Sibling species in the marine pollution indicator (*Capitella*) (Polychaeta). *Science*, **192**, 567-569.

Grassle, J.F. & Grassle, J.P., 1978. Life histories and genetic variation in marine invertebrates. In *Marine organisms: genetics, ecology and evolution* (ed. B. Battaglia & J.A. Beardmore), pp. 347-364. New York: Plenum Press.

Gray, J.S., 1971. The effects of pollution on sand meiofauna communities. *Thalassia Jugoslovica*, **7**, 76-86.

Gray, J.S., 1979. Pollution-induced changes in populations. *Philosophical Transactions of the Royal Society of London*, Series B, **286**, 545-561.

Gray, J.S., 1981. *The ecology of marine sediments. An introduction to the structure and function of benthic communities.* Cambridge: Cambridge University Press.

Hall, J.A. & Frid, C.L.J., 1995. Response of estuarine benthic macrofauna in copper-contaminated sediments to remediation of sediment quality. *Marine Pollution Bulletin*, **30**, 694-700.

Haskoning UK Ltd. 2006. Investigation into the impact of marine fish farm deposition on maerl beds. *Scottish Natural Heritage Commissioned Report No.* 213 (ROAME No. AHLA10020348).

Henriksson, R., 1969. Influence of pollution on the bottom fauna of the Sound (Öresund). *Oikos*, **20** (2), 507-523.

Hiscock, K., ed. 1998. *Marine Nature Conservation Review. Benthic marine ecosystems of Great Britain and the north-east Atlantic.* Peterborough, Joint Nature Conservation Committee.

Holte, B. & Oug, E., 1996. Soft-bottom macrofauna and responses to organic enrichment in the subarctic waters of Tromsoe, northern Norway. *Journal of Sea Research*, **36**, 227-237.

Hunter, J., & Arthur, D.R., 1978. Some aspects of the ecology of *Peloscolex benedeni* Udekem (Oligochaeta: Tubificidae) in the Thames estuary. *Estuarine and Coastal Marine Science*, **6**, 197-208.

Huthnance, J., 2010. Ocean Processes Feeder Report. London, *DEFRA on behalf of the United Kingdom Marine Monitoring and Assessment Strategy (UKMMAS) Community*.

Hyland, J.L., Hoffman, E.J. & Phelps, D.K., 1985. Differential responses of two nearshore infaunal assemblages to experimental petroleum additions. *Journal of Marine Research*, **43** (2), 365-394.

Jackson, A. 2007. *Thyasira gouldi* Northern hatchet shell. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/species/detail/1149

JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from https://mhc.jncc.gov.uk/

JNCC, 2015. The Marine Habitat Classification for Britain and Ireland Version 15.03. (20/05/2015). Available from https://mhc.jncc.gov.uk/

Karakassis, I., Tsapakis, M., Hatziyanni, E., Papadopoulou, K. & Plaiti, W., 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. *ICES Journal of Marine Science*, **57**, 1462-1471.

Kutti, T., Ervik, A. & Høisæter, T., 2008. Effects of organic effluents from a salmon farm on a fjord system. III. Linking deposition rates of organic matter and benthic productivity. *Aquaculture*, **282** (1), 47-53.

Le Moal, Y., 1980. Ecological survey of an intertidal settlement living on a soft substrata in the Aber Benoit and Aber Wrac'h estuaries, after the *Amoco Cadiz* oil spill. Universite de Bretagne Occidentale, Brest (France), 25pp.

Leppäkoski, E. & Lindström, L., 1978. Recovery of benthic macrofauna from chronic pollution in the sea area off a refinery plant, southwest Finland. *Journal of the Fisheries Board of Canada*, **35** (5), 766-775.

Leppäkoski, E., 1975. Assessment of degree of pollution on the basis of macrozoobenthos in marine and brackish water environments. *Acta Academiae Åboensis*, Series B, **35**, 1-90.

Linke, O., 1939. Die Biota des Jadebusenwatts. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **1**, 201-348.

López-Jamar, E., González, J. & Mejuto, J., 1987. Ecology, growth and production of *Thyasira flexuosa* (Bivalvia, Lucinacea) from Ría de la Coruña, North-west Spain. *Ophelia*, **27**, 111-126.

Méndez, N., 2006. Effects of teflubenzuron on sediment processing by members of the *Capitella* species-complex. *Environmental Pollution*, **139** (1), 118-124.

Méndez, N., 2006. Effects of teflubenzuron on sediment processing by members of the *Capitella* species-complex. *Environmental pollution*, **139** (1), 118-124.

Mangum, C. & Van Winkle, W., 1973. Responses of aquatic invertebrates to declining oxygen conditions. *American Zoologist*, **13** (2), 529-541.

Maurer, D., Keck, R.T., Tinsman, J.C. & Leathem, W.A., 1982. Vertical migration and mortality of benthos in dredged material: Part III—polychaeta. *Marine Environmental Research*, **6** (1), 49-68.

Maurer, D., Keck, R.T., Tinsman, J.C., Leatham, W.A., Wethe, C., Lord, C. & Church, T.M., 1986. Vertical migration and mortality of marine benthos in dredged material: a synthesis. *Internationale Revue der Gesamten Hydrobiologie*, **71**, 49-63.

McCall, P.L., 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. *Journal of Marine Research*, **35**, 221-266.

McLusky, D.S., Teare, M. & Phizachlea, P., 1980. Effects of domestic and industrial pollution on distribution and abundance of aquatic oligochaetes in the Forth estuary. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **33**, 384-392.

Mendez, N., Romero, J. & Flos, J., 1997. Population dynamics and production of the polychaete *Capitella capitata* in the littoral zone of Barcelona (Spain, NW Mediterranean). *Journal of Experimental Marine Biology and Ecology*, **218**, 263-284.

Mitchell, I.M., 2006. In situ biodeposition rates of Pacific oysters (*Crassostrea gigas*) on a marine farm in Southern Tasmania (Australia). *Aquaculture*, **257** (1), 194-203.

Moore, J., 1991. Studies on the Impact of Hydraulic Cockle Dredging on Intertidal Sediment Flat Communities. *A report to the Nature Conservancy Council from the Field Studies Council Research Centre, Pembroke, Wales*, FSC/RC/4/91.

Nugues, M., Kaiser, M., Spencer, B. & Edwards, D., 1996. Benthic community changes associated with intertidal oyster cultivation. *Aquaculture Research*, **27** (12), 913-924.

OBIS 2014. Data from the Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. [online]. Available from: http://www.iobis.org

Olsgard, F., 1999. Effects of copper contamination on recolonisation of subtidal marine soft sediments - an experimental field study. *Marine Pollution Bulletin*, **38**, 448-462.

Parr, W., Clarke, S.J., Van Dijk, P., Morgan, N., 1998. Turbidity in English and Welsh tidal waters. Report No. CO 4301/1 to English Nature.

Pearson, T.H. & Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: an Annual Review*, **16**, 229-311.

Peterson, C.H., 1977. Competitive organisation of the soft bottom macrobenthic communities of southern California lagoons. *Marine Biology*, **43**, 343-359.

Petrich, S.M. & Reish, D.J., 1979. Effects of aluminium and nickel on survival and reproduction in polychaetous annelids. *Bulletin of Environmental Contamination and Toxicology*, **23**, 698-702.

Planas, M. & Mora, J., 1989. Epigenetical changes in *Capitella* (Polychaeta, Capitellidae) in the Ensenada de Lourizan (NW Spain). *Vie et Milieu*, **39**, 159-163.

Powilleit, M., Graf, G., Kleine, J., Riethmuller, R., Stockmann, K., Wetzel, M.A. & Koop, J.H.E., 2009. Experiments on the survival of six brackish macro-invertebrates from the Baltic Sea after dredged spoil coverage and its implications for the field. *Journal of Marine Systems*, **75** (3-4), 441-451.

Qian, P.Y. & Chia, F.S., 1994. In situ measurement of recruitment, mortality, growth, and fecundity of *Capitella* sp. (Annelida: Polychaeta). *Marine Ecology Progress Series*, **111**, 53-62.

Rabaut, M., Braeckman, U., Hendrickx, F., Vincx, M. & Degraer, S., 2008. Experimental beam-trawling in Lanice conchilega reefs: Impact on the associated fauna. *Fisheries Research*, **90** (1), 209-216.

Ragnarsson, S.Á. & Raffaelli, D., 1999. Effects of the mussel Mytilus edulis L. on the invertebrate fauna of sediments. *Journal of Experimental Marine Biology and Ecology*, **241** (1), 31-43.

Rayment W.J., 2007. *Crepidula fornicata*. Slipper limpet. [online]. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [On-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <http://www.marlin.ac.uk>

Redman, C.M., 1985. Effect of temperature and salinity on the life history of *Capitella capitata* (type I). *Dissertation Abstracts*, **46**, 91.

Rees, H.L. & Dare, P.J., 1993. Sources of mortality and associated life-cycle traits of selected benthic species: a review. *MAFF Fisheries Research Data Report, no. 33.*, Lowestoft: MAFF Directorate of Fisheries Research.

Rosenberg, R., 1972. Benthic faunal recovery in a Swedish fjord following the closure of a sulphite pulp mill. *Oikos*, **23**, 92-108.

Rosenberg, R., Hellman, B. & Johansson, B., 1991. Hypoxic tolerance of marine benthic fauna. *Marine Ecology Progress Series*, **79**, 127-131.

Rostron, D., 1995. The effects of mechanised cockle harvesting on the invertebrate fauna of Llanrhidian sands. In *Burry Inlet and Loughor Estuary Symposium*, pp. 111-117.

Rygg, B., 1985. Effect of sediment copper on benthic fauna. *Marine Ecology Progress Series*, **25**, 83-89.

Shull, D.H., 1997. Mechanisms of infaunal polychaete dispersal and colonisation in an intertidal sandflat. *Journal of Marine Research*, **55**, 153-179.

Silva, A.C.F., Tavares, P., Shapouri, M., Stigter, T.Y., Monteiro, J.P., Machado, M., Cancela da Fonseca, L. & Ribeiro, L., 2012. Estuarine biodiversity as an indicator of groundwater discharge. *Estuarine Coastal and Shelf Science*, **97**, 38-43.

Sinderman, C.J., 1990. *Principle diseases of marine fish and shellfish, 2nd edition, Volume 2. Diseases of marine shellfish*. Academic Press, 521 pp.

Soemodinoto, A., Oey, B.L. & Ibkar-Kramadibrata, H., 1995. Effect of salinity decline on macrozoobenthos community of Cibeurum River estuary, Java, Indonesia. *Indian Journal of Marine Sciences*, **24**, 62-67.

Sornin, J.-M., Feuillet, M., Heral, M. & Deslous-Paoli, J.-M., 1983. Effet des biodépôts de l'huître *Crassostrea gigas* (Thunberg) sur l'accumulation de matières organiques dans les parcs du bassin de Marennes-Oléron. *Journal of Molluscan Studies*, **49** (supp12A), 185-197.

Sparks-McConkey, P.J. & Watling, L., 2001. Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. *Hydrobiologia*, **456**, 73-85.

Suchanek, T.H., 1993. Oil impacts on marine invertebrate populations and communities. *American Zoologist*, **33**, 510-523.

Tait, R.V. & Dipper, R.A., 1998. *Elements of Marine Ecology*. Reed Elsevier.

Tenore, K.R., 1977. Growth of *Capitella capitata* cultured on various levels of detritus derived from different sources. *Limnology and Oceanography*, **22** (5), 936-941.

Tenore, K.R. & Chesney, E.J., 1985. The effects of interaction of rate of food supply and population density on the bioenergetics of the opportunistic polychaete, *Capitella capitata* (type 1). *Limnology and Oceanography*, **30** (6), 1188-1195.

Thom, R.M. & Chew, K.K., 1979. The response of subtidal infaunal communities to a change in wastewater discharge. In: *Urban Stormwater and Combined Sewers Overflow Impact on Receiving Water Bodies*, Orlando, Florida, November 26-28, pp. 174-191.

Thorson, G., 1946. Reproduction and larval development of Danish marine bottom invertebrates, with special reference to the planktonic larvae in the Sound (Øresund). *Meddelelser fra Kommissionen for Danmarks Fiskeri- Og Havundersögelser, Serie: Plankton*, **4**, 1-523.

Thorson, G., 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biological Reviews*, **25**, 1-45.

Tillin, H. & Tyler-Walters, H., 2014. Assessing the sensitivity of subtidal sedimentary habitats to pressures associated with marine activities. Phase 2 Report – Literature review and sensitivity assessments for ecological groups for circalittoral and offshore Level 5 biotopes. *JNCC Report* No. 512B, 260 pp. Available from: www.marlin.ac.uk/publications

UKTAG, 2014. UK Technical Advisory Group on the Water Framework Directive [online]. Available from: http://www.wfduk.org

Van den Broek, W., 1978. Dietary habits of fish populations in the Lower Medway Estuary. *Journal of Fish Biology*, **13** (5), 645-654.

Van Hoey, G., Guilini, K., Rabaut, M., Vincx, M. & Degraer, S., 2008. Ecological implications of the presence of the tube-building polychaete *Lanice conchilega* on soft-bottom benthic ecosystems. *Marine Biology*, **154** (6), 1009-1019.

Vaquer-Sunyer, R. & Duarte, C.M., 2008. Thresholds of hypoxia for marine biodiversity. *Proceedings of the National Academy of Sciences*, **105** (40), 15452-15457.

Ward, T.J. & Young, P.C., 1982. Effects of sediment trace metals and particle size on the community structure of epibenthic seagrass fauna near a lead smelter, South Australia. *Marine Ecology Progress Series*, **9**, 136-146.

Ward, T.J., & Young, P.C., 1983. The depauperation of epifauna on *Pinna bicolor* near of lead smelter, Spencer Gulf, South Australia *Environmental Pollution (Series A)*, **30**, 293-308.

Warren, L.M., 1976. A population study of the polychaete *Capitella capitata* at Plymouth. *Marine Biology*, **38**, 209-216.

Warren, L.M., 1977. The ecology of *Capitella capitata* in British waters. *Journal of the Marine Biological Association of the United Kingdom*, **57**, 151-159.

Whomersley, P., Huxham, M., Bolam, S., Schratzberger, M., Augley, J. & Ridland, D., 2010. Response of intertidal macrofauna to multiple disturbance types and intensities – an experimental approach. *Marine Environmental Research*, **69** (5), 297-308.

Wilson, J.G., 1981. Temperature tolerance of circatidal bivalves in relation to their distribution. *Journal of Thermal Biology*, **6**, 279-286.

Wu, B., Qian, P. & Zhang, S., 1988. Morphology, reproduction, ecology and isoenzyme electrophoresis of *Capitella* complex in Qingdao. *Acta Oceanologica Sinica*, **7** (3), 442-458.

Zuhlke, R. & Reise, K., 1994. Response of macrofauna to drifting tidal sediments. *Helgolander Meeresuntersuchungen*, **48** (2-3), 277-289.