Polychaete / bivalve dominated muddy sand shores

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

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2006-02-07

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

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This review can be cited as:
Tyler-Walters, H. & Marshall, C., 2006. Polychaete / bivalve dominated muddy sand shores. 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.21.1

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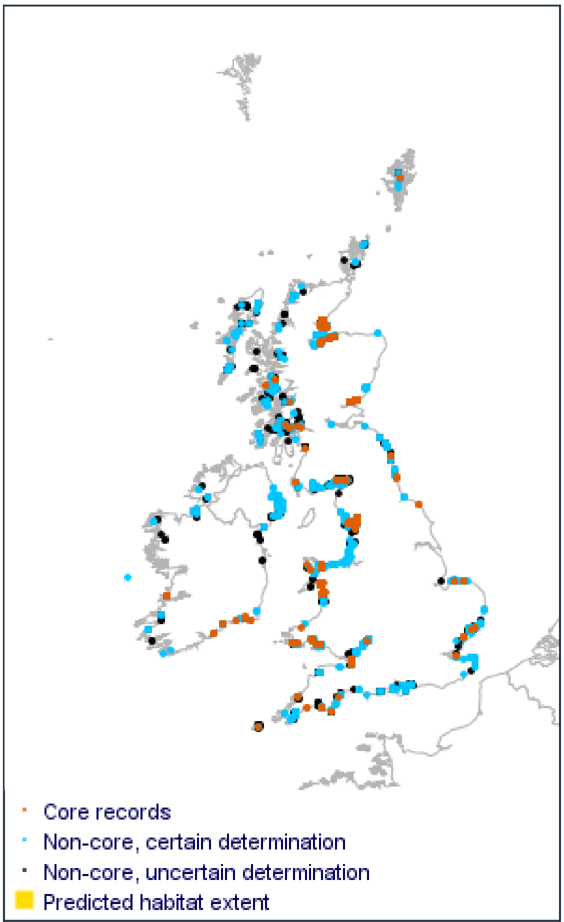
View across a cockle strand (biotope LMS.Pcer).
Photographer: Joint Nature Conservation Committee



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

Researched by Dr Harvey Tyler-Walters & Charlotte Marshall **Refereed by** Mike Kendall

Summary

UK and Ireland classification

EUNIS 2008	A2.24	Polychaete/bivalve-dominated muddy sand shores
JNCC 2015	LS.LSa.MuSa	Polychaete / bivalve dominated muddy sand shores
JNCC 2004	LS.LSa.MuSa	Polychaete / bivalve dominated muddy sand shores
1997 Biotope	LS.LMS.MS	Muddy sand shores

Description

Shores of muddy sand, typically consisting of particles less than 4 mm in diameter, where the mud fraction (less than 0.063 mm diameter particles) makes up between 10 and 30% of the sediment. Typically, the sand fraction is medium (particle diameter 0.25-1 mm) or fine (particle diameter 0.063-0.25 mm) sand. Muddy sand usually forms gently sloping flats that remain water-saturated throughout the tidal cycle. They support communities predominantly of polychaetes and bivalves, including the lugworm *Arenicola marina*, the cockle *Cerastoderma edule* and the Baltic tellin *Limecola balthica*. (Information taken from the Marine Biotope Classification for Britain and Ireland, Version

97.06: Connor *et al.*, 1997a, b).

Depth range

Strandline, Upper shore, Mid shore, Lower shore

Additional information

-

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Habitat review

Ecology

Ecological and functional relationships

Intertidal sand and mudflats are invaluable in supporting predator communities (Elliot *et al.*, 1998). Large mobile epibenthic predators such as bottom-feeding fish, crabs and birds are important predators in marine soft-bottom communities and they are important regulators of species abundance (Ambrose, 1984). Exclosures set up on sandy and muddy flats in the Wadden Sea revealed that the removal of predation by shore crabs, shrimps, gobies, flatfish and birds led to a marked increase in the species diversity and the abundance of infaunal species (Reise, 1978).

- The following ecological relationships are likely.
- Mobile epifauna including crabs (e.g. *Carcinus maenas*) and shrimps (e.g. *Crangon crangon*) take small bivalves, polychaetes and crustacea. *Carcinus maenas* and *Crangon crangon* significantly reduce populations of *Corophium volutator* in estuaries, and *Crangon crangon* is a significant predator of small plaice during and immediately after the fish larval settlement.
- The flatfish *Solea solea* (sole), *Limanda limanda* (dab), *Platichythys flesus* (flounder) and *Pleuronectes platessa* (plaice) feed on polychaetes and their tails (e.g. *Arenicola* and *Nereis*), young bivalves and their siphons (e.g. *Macoma* and *Angulus*) and tidally active crustacea such as *Bathyporeia* and *Eurydice* spp.. Gobies (e.g. *Pomatoschistus* spp.) prey heavily on *Corophium volutator* (Elliot *et al.*, 1998). Within estuaries numerous demersal fish may be opportunistic predators (Costa & Elliot, 1991; Elliot *et al.*, 1998).
- Wildfowl feed on a variety of species, originally thought to be determined by depth of prey and bill size or shape. Recently however, waders are thought to be opportunistic feeders (McLusky, 1989). *Arenicola marina* reportedly provided 94% of the energy in the diet of the bar-tailed godwit (*Limosa lapponica*) at Lindisfarne on the north east coast of England (Baird *et al.*, 1985). The bar-tailed godwit also feeds on large *Hediste diversicolor* (studied as *Nereis diversicolor*), which provided the main food source for this species on a reclaimed mudflat in the Tees (Evans *et al.*, 1998). In the same area, Evans *et al.*, (1998) reported that *Hediste diversicolor* was also an important component in the diet of the curlew (*Numenius arquata*) and grey plover (*Pluvialis squatarola*).
- Shelducks (*Tadorna tadorna*) were found to feed primarily on small oligochaetes, however, copepods, *Hydrobia* sp. and *Macoma* sp. also form part of their diet (Evans *et al.*, 1979). Eider ducks take *Mytilus edulis* in shallow water. Black-tailed godwit feeds mainly on *Scrobicularia plana* and small amounts of *Nereis* sp. and *Hydrobia* sp. (Elliot *et al.*, 1998).
- Where high densities of *Hydrobia ulvae* exist, the pearl bubble *Retusa obtusa* may also be found since *Hydrobia ulvae* represents an important part of its diet.
- Many infauna are also important predators within marine soft-bottom communities. Polychaete worms are dominant infaunal predators that actively pursue prey and are generally opportunistic, although they have prey size preferences (Elliot *et al.*, 1998). *Nephtys* sp. are usually considered to be carnivorous. However, Warwick *et al.* (1979) found that faecal pellets produced by *Nephtys* (collected fresh from the field) contained almost exclusively algal cells. They concluded that *Nephtys* was a broad-spectrum omnivore and that plant material contributed about 90% of its annual production. At the sandier end of the mud-sand continuum, the speckled sea louse *Eurydice pulchra* is a highly predatory carnivore feeding on other infaunal invertebrates.
- *Nephtys* sp. and *Eurydice pulchra* may also scavenge dead organic material. Note that the

presence of various *Nephtys* sp. will vary along the mud-sand continuum with species such as *Nephtys hombergii* characteristic of muddier sediment while species including *Nephtys cirrosa* are more likely to be found in clean sand (Kendall, pers. comm.).
- *Hediste diversicolor* is one of the most common intertidal estuarine polychaetes and is found in muddy habitats including sandy mud and muddy sand. It displays a variety of feeding methods and can be considered as a suspension feeder, deposit feeder, omnivore and scavenger (see *MarLIN* review). Tubificoid polychaetes (e.g. *Tubificoides benedii*) and spionid polychaetes (e.g. *Pygospio elegans*) are also abundant in muddier sands and all are important in the diets of wading birds (Kendall, pers. comm.).
- Deposit feeding and filter feeding represent the two fundamental feeding methods among the fauna of mud and sand (Eltringham, 1971). Deposit feeders might include *Corophium volutator* and *Arenicola marina*, the former of which is also a filter / suspension feeder. *Arenicola marina* is a burrower and bioturbator, the activity of which can adversely effect *Corophium volutator* and the juveniles of various other species (see *MarLIN* review). *Arenicola marina* feeds on detritus and bacteria in the sediment.
- Suspension feeders may include *Limecola balthica* and *Cerastoderma edule*, the former of which is also a deposit feeder, feeding on detritus and deposited plankton.
- Meiofauna such as harpacticoid copepods are probably important consumers of microphytobenthos in this biotope and both larger epibenthic and shallow burrowing forms are common in fine sediments.

Seasonal and longer term change

The presence of algal mats of *Ulva* sp. are likely in the summer months, and microphytobenthos colouration of the sediment surface will be more noticeable to summer. Fish species, e.g. juvenile plaice, move offshore in autumn and winter avoiding low temperature and storm induced turbulence. Storms have significant effects on the distribution and survival of infauna as well as the success of recruitment by newly settled spat or larvae (see Hall, 1994 for review). For example:

- storm events can change sediment distribution and composition significantly e.g. the removal of the top 20 cm of sand has been reported (Dolphin *et al.*, 1995);
- storms may cause dramatic changes in distribution of macro-infauna by washing out dominant species, opening the sediment to recolonization by adults and/or available spat/larvae (Eagle, 1975; Rees *et al.*, 1977; Hall, 1994);
- storms are likely to have larger effects in shallow waters and wave induced disturbance is likely to contribute to gradients in faunal composition (Hall, 1994), e.g. Emerson & Grant (1991) demonstrated that bedload sediment transport due to storms, currents and tides had a significant effect on population density and recruitment in *Mya arenaria, and*
- storms may also cause onshore strandings and, hence, mass mortalities of infaunal organisms e.g. Rees *et al.* (1977) reported stranding of several intertidal and sub-tidal species due to the storms of 1975-76 in Red Wharf Bay, Anglesey.

The percentage and composition of wildfowl varies with season. Several species overwinter in UK intertidal areas, and others pass through on migration routes. Feeding times vary with season, location, tide and species. However, most shorebirds forage at low tide or on rising tides. In cold periods shore birds require additional energy for thermoregulation and greater foraging is required since prey are scarcer at the same time (Davidson & Rothwell, 1993).

Habitat structure and complexity

Biodiversity is influenced by the stability of the habitat and the sediment type, partly because the complexity of the habitat will determine the number of available niches (Elliot *et al.*, 1998). For example, muddy sand will have a higher proportion of finer particles and a greater organic content, and therefore microbial population, than cleaner sand. The productivity of muddy sands relates (in part) to the small size of clay mineral particles and the massive surface area that they provide for microbial growth (Kendall, pers. comm.).

The productivity of tidal flats is dependant on the tidal range and shore slope. Gray (1981) reported the highest abundance and biomass of in-fauna occurring at the mid-tidal level, although mid tide level was more productive because there was little true low shore. Edwards *et al.* (1992) found that the muddy sand / gravel lower shore of the Gann Flat contained the highest number of species. In sandier places, the shore slope continues to the sublittoral (Kendall, pers. comm.). Towards the lower shore, current speeds increase near channels whereas higher on the shore, emergence and desiccation increase.

Additional complexity may result from the presence of rocks (pebbles, cobbles, boulders), that provide substrata for rocky shore species and macrophytes, and shell fragments that alter the porosity and available niches within the sediment.

Physical habitat complexity:

- Fine and silty sands reflect low energy conditions and are characterized by small median particle size, shallow slope, high water content due to low porosity (pore space is occupied by small silt particles packed between sand grains), and low permeability.
- Muddy sands retain water at low tide as a result of their shallow gradient and the capillary action of closely packed particles (Gray, 1981). Muddy sands tends to be more freely draining than mud alone due to their increased average particle size (Jones *et al.*, 2000).
- Muddy sands have a high organic content resulting from settlement of organic detritus and growth of heterotrophic autotrophic micro-organisms. They also have a high microbial population and high sediment stability due to cohesion. The clay mineral particles provide a massive surface area for microbial growth (Kendall, pers. comm.). Allochthonous organic material is derived from anthropogenic activity (e.g. sewerage) and natural sources (e.g. plankton, detritus). Autochthonous organic material is formed by benthic microalgae (microphytobenthos e.g. diatoms and euglenoids) and heterotrophic micro-organism production. Although the surface is well oxygenated, poor oxygenation lower down in the muds results in low degradation rates and the accumulation of organic material.
- High levels of organic material support large microbial populations. The high oxygen demand of their activity, combined with the fact that much of the sediment is poorly oxygenated, means that much of the organic material undergoes anaerobic degradation releasing hydrogen sulphide, methane and ammonia, together with dissolved organic materials, which can be used by aerobic surface bacteria. Anaerobic degradation produces reducing conditions forming a 'black' layer, the depth of which depends on the depth to which oxygen can permeate (Elliot *et al.*, 1998). Chemoautotrophs are present in the reducing layer and at depth (Libes, 1992).
- Microbial activity stabilizes organic flux in estuaries, reducing seasonal variation in productivity, cycling nutrients and making the primary production available to animal consumption (McLusky, 1989; Elliot *et al.*, 1998).

Ecological complexity:
The food web within muddy sandy shores is reasonably well understood. Some key features that contribute to its complexity are presented below.

- The biomass of microbes may be of the same order of magnitude as the biomass of infauna (Elliot *et al*., 1998).
- The mucilaginous secretions of microphytobenthos and bacteria may stabilize the sediment. Microphytobenthos often appears as a subtle brown or greenish shading on the sediment surface. In shallow waters the biomass of microphytobenthos may exceed that of the pelagic phytoplankton (MacIntyre *et al*., 1996).
- The macrophyte community is invariably poorer than on rocky shores. However, fucoids can often be found on more complex LMS.MS shores with e.g. pebbles and rocks (Kendall, pers. comm.). Mats of *Ulva* sp. may also be found.
- In addition to increased macrophyte diversity on shores with coarser particles, barnacles, anemones and winkles may also be found (Kendall, pers. comm.).
- Muddy sands (LMS.MS) may have a lower diversity and biomass than mudflats but exhibit a higher diversity than sandflats. The infauna of mudflats often shows low species diversity but high biomass (depending on silt content). Sandflats, however, are free draining (subjected to desiccation) and less stable.
- Muddy sands support communities of amphipods, polychaetes, and molluscs (Elliot *et al*., 1998; Connor *et al*., 1997a).
- The heart urchin *Echinocardium cordatum* occurs in muddy and clean sand but grows more slowly in muddy sand (Buchanan, 1966).
- Several tidal migrants occur e.g. mysids, amphipods, decapods and epi-benthic fish.
- *Liocarcinus depurator*, *Carcinus maenas*, *Atelecyclus rotundatus* and *Macropodia* spp. are mobile species associated with silty sands.
- Many infauna are limited to the upper oxygenated layer, for example *Abra* sp., *Phoronis* sp. (horseshoe worms) and *Venus* sp. (Pearson & Eleftheriou, 1981). However, others penetrate deeper in irrigated burrows (such as the terebellid polychaete *Pectinaria belagica* and the capitellid worms *Notomastus* sp.) or extend their burrows upwards into the oxygenated layer (such as *Lucinoma*) (Pearson & Eleftheriou, 1981). In contrast, species such as the oligochaete *Tubificoides benedii* have a high capacity to tolerate anoxic conditions.
- Tidal elevation affects the distribution of fish, e.g. in summer, plaice populations are largest at the waters edge to a depth of 1-3 m and may migrate with the tide, with larger fish inhabiting greater depths (Gibson, 1973, cited in Elliot *et al*., 1998). The young of several fish migrate into the intertidal with the tide to feed (Elliot *et al*., 1998).
- Reduced salinity in estuaries will affect the communities present, e.g. with decreasing salinity (further into an estuary or in riverine inflow) *Nereis diversicolor* replaces *Nephtys* spp.
- The zonation of wildfowl on the shore is very dependent on the profile of the shore and if the shore is flat with creeks and channels, not much pattern is evident (Kendall, pers. comm.). Mohamed (1998) found that the density of waders on the shores of islands in Bahrain was largest in sites with a large dry intertidal area and a very gentle slope. The distribution of birds up the shore is also influenced by tidal level, with some birds feeding at the waters edge and other further up or down.

Factors affecting complexity:
Physical forces are the dominant factors structuring the substratum in intertidal mud and sand flats, however, the effects of the interaction of the organisms inhabiting the substratum may

modify it secondarily.

- Decreasing wave exposure is associated with finer sediments that, in turn, support more small-bodied surface dwelling species such as the small epibenthic crustacean *Bathyporeia* spp., which lives on the sediment surface and burrows quickly as the tide falls. Many sedentary polychaete species prefer stable sediments. *Arenicola marina* prefers more stable habitats because it cannot produce the large amounts of mucus that would be needed to stabilize its burrow in more fluid mobile sediment. It can be found on moderately exposed shores where it can burrow down to 40 cm to avoid the physically disturbing effects of wave action. *Capitella capitata*, in contrast, is more tolerant of mobile sediments. The sand digger shrimp *Bathyporeia sarsi* is found in both stable and unstable sites.
- Deposit feeders dominate over suspension feeders in areas with high percentages of silt.
- Competitive interactions can play a significant role in determining the temporal and spatial abundance of macrobenthos in muddy sand communities (Peterson, 1977). Organisms may compete for, for example, space and / or food and competitive exclusion may occur. Experimental manipulation revealed that the total abundance of three tube-building polychaetes negatively affected the abundance of a burrowing polychaete (Woodin, 1974). Within particular trophic guilds (feeding types), competition may result in resource partitioning, e.g. *Hydrobia* sp. and *Corophium* sp. ingest different size particles (Fenchel, 1972).
- The substratum characteristics may be modified by organisms. Spionid tubes and microphytobenthic mats, for example, may stabilize the sediment surface whereas excessive reworking of the sediment (bioturbation) by mobile infauna (e.g. *Limecola balthica) may destabilize the sediment. Biosedimentation may increase supply of sediment from the water column, e.g. through the activity of suspension feeders such as Cerastoderma edule. Bioturbation by burrowing infauna such as Arenicola marina rework sediment bringing material and nutrients to the surface while allowing oxygenated water to reach deeper sediment (Elliot et al., 1998; see Hall, 1994 for review).*

Productivity

Allochthonous organic material is derived from anthropogenic activity (e.g. sewerage) and natural sources (e.g. plankton, detritus). Autochthonous organic material is formed by benthic microalgae (microphytobenthos e.g. diatoms and euglenoids) and heterotrophic micro-organism production. Organic material is degraded by micro-organisms and the nutrients recycled. The high surface area of fine particles provides a surface for microflora. Microphytobenthos, water-column phytoplankton and deep sediment chemoautotrophs provide primary productivity to sediments although opportunistic algal mats of *Ulva* sp. may develop. However, photosynthesis is light limited in turbid conditions. Most macrofauna productivity is secondary, derived from detritus and organic material. Intertidal mudflats in estuarine systems may have a higher productivity than subtidal sediments although coastal sandflats have very poor productivity (McLachlan, 1996, cited in Elliot *et al.*, 1998).

Recruitment processes

Some macrofauna in LMS.MS breed several times in their life history (iteroparous) such as *Arenicola marina* and *Nephtys hombergii* while others, such as *Hediste diversicolor*, are semelparous. Some species are planktonic spawners producing large numbers of gametes (depending on food availability) with fertilization in the water column. In these species, dispersal potential is high, although in sheltered bays the larvae may be entrapped, and recruitment is linked to the hydrographic regime with regards to dispersal. Small scale eddy's (e.g. over obstacles and inconsistencies in the surface of the substratum) may result in concentration of larvae or propagules. High densities of adults, suspension feeders and surface deposit feeders together with epibenthic predators and physical disturbance result in high post settlement mortality rate of larvae and juveniles (Olafsson *et al.*, 1994). For many species, larval development is either direct (e.g. *Corophium volutator*) or lecithotrophic (e.g. *Hydrobia ulvae* and *Hediste diversicolor*) (see *MarLIN* reviews). Certainly for direct development, larval dispersal is limited as is the case for *Corophium volutator (see MarLIN review) although compensated by significant adult mobility. Arenicola and Nephtys larvae settle outside usual habitat preferences away from areas dominated by adults, although juvenile Nephtys can migrate to more favourable areas. Overall recruitment is likely to be patchy and sporadic, with high spat fall occurring in areas devoid of adults, perhaps lost due to predation or storms. Similarly, larvae may be concentrated by the hydrographic regime or swept to neighbouring or removed sites.*

Time for community to reach maturity

Little information was found concerning the development of muddy sand intertidal communities. However, one study in Massachusetts focused on the colonization of different sized defaunated plugs of sediment implanted into a mudflat (silty-sand, median grain size 63-125 µm) (Smith & Brumsickle, 1989). Postlarval immigration was found to be one of the most important factors in recolonization. In the small plugs (50 cm^2), the abundance of the most dominant polychaete species had almost reached background levels 40 days after planting. Rates of colonization of the small plugs, faunal abundance and species numbers were also higher than in the large plugs (1750 cm^2), partly because postlarval immigration was inversely proportional to patch size. However, the experiment was conducted in summer months when most of the abundant polychaetes were available for recruitment. This is a key point concerning community development and colonization and time taken for the community to develop may take significantly longer during other times of the year. Community development is likely to depend on the species present, the hydrographic regime (for example, stronger currents may resuspend and transport larvae and juveniles into the developing area) and recruitment. Colonization may occur through various routes including adult and postlarval migration, and larval settlement. Time taken to reach maturity will also vary spatially and temporally.

Additional information

No text entered

Preferences & Distribution

Habitat preferences

Depth Range	Strandline, Upper shore, Mid shore, Lower shore
Water clarity preferences	Poor clarity / Extreme turbidity, Very high clarity / Very low turbidity
Limiting Nutrients	Nitrogen (nitrates), Phosphorus (phosphates)
Salinity preferences	Full (30-40 psu), Variable (18-40 psu)
Physiographic preferences	
Biological zone preferences	Eulittoral

Substratum/habitat preferences	Muddy sand
Tidal strength preferences	
Wave exposure preferences	Sheltered, Very sheltered
Other preferences	None

Additional Information

No text entered.

Species composition

Species found especially in this biotope

Rare or scarce species associated with this biotope

- *Armandia cirrhosa*
- *Nematostella vectensis*

Additional information

Muddy sand biotopes support communities of relatively low species richness but high abundance. Communities are predominated by sessile polychaetes and bivalves although epibenthic amphipods may also be present (LMS.BatCor). Subtidal species may also occur. The rare and scare species indicated only occur in littoral muddy sands of Fleet, Portland Harbour and Poole Harbour.

Sensitivity review

Explanation

The biotope complex LMS.MS (Muddy sand shores) is composed of three biotopes that differ in the benthic communities present. Therefore, key or important species at the biotope complex level have not been suggested.

Species indicative of sensitivity

Community Importance	Species name	Common Name

Physical Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Substratum Loss	High	Moderate	Moderate	Major decline	High

Although intertidal dredging may only occur at a few sites where LMS.MS has been recorded, sedimentary communities are likely to be highly intolerant of substratum removal, which will lead to partial defaunation, exposure of the underlying sediment and changes in the topography of the area (Dernie *et al.*, 2003). In addition, heart urchins, molluscs and crustaceans are likely to be damaged or killed in dredging operations (Elliot *et al.*, 1998). Dredging operations were shown to affect large infaunal and epifaunal species, decrease sessile polychaetes and reduce the abundance of burrowing heart urchins. Species living in the top layer of the sediment will be removed and subsequently perish. The remaining species, given their new position at the sediment / water interface, may be exposed to conditions to which they are not suited, i.e. unfavourable conditions.

Newell *et al.* (1998) state that removal of 0.5 m depth of sediment is likely to eliminate benthos from the affected area. Dredging activities may result in deep pits or trenches between 0.5 m - 20 m deep depending on the techniques used (Newell *et al.*, 1998). Hall (1994) reported that suction dredging for *Ensis* species in 7 m of water in a Scottish sea loch resulted in pits in the sediment and significant reductions in the abundance of a large proportion of the species at the experimental site. However, no differences in species abundances between the impacted plots and controls were detectable after 40 days. This rapid recovery was probably due to intense wave and storm activity during the experimental period that transported sediment and animals in suspension and in bedload transport (Hall, 1994). In the intertidal, mechanical cockle harvesting resulted in significant losses of common invertebrates in muddy sand and clean sand in the Burry Inlet (Ferns *et al.*, 2000). For example, losses varied from 31% of *Scoloplos armiger* to 83% of *Pygospio elegans*. Populations of *Nephtys hombergii* and *Scoloplos armiger* took over 50 days to recover. However, recovery was more rapid in clean sand than in muddy sand. In muddy sand, *Bathyporeia pilosa* took 111 days to recover while *Pygospio elegans* and *Hydrobia ulvae* had not recovered their original abundance after 174 days (Ferns *et al.*, 2000).

Recoverability will depend on the time taken for the substratum to return to prior conditions, pits or trenches to fill and recolonization to occur. The recoverability of LMS.MS is likely to be high (see additional information).

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Smothering	Intermediate	High	Low	Decline	Moderate

Smothering with 5 cm of sediment (that is, a rapid accumulation of sediment) for a month is unlikely to adversely affect species that can burrow through sediment, although it may clog the feeding apparatus of suspension feeding organisms. Kranz (1972, cited in Maurer, 1981) reported that tube dwelling pelecypods, that use mucous to trap food particles, and labial deposit feeders were most intolerant of burial, whereas epibenthic suspension feeders and boring species could not tolerate an addition of more than 1 cm of sediment. Infaunal non-siphonate suspension feeders escaped 5 cm but were intolerant of less than 10 cm, whereas deep burrowing siphonate species could tolerate up to 50 cm. Mortalities were higher when the smothering sediment was atypical of that area, which would dramatically change the nature of the substratum and hence the communities present, although no mention was made of the type of sediment involved. Overall, it is possible that some species may be killed by smothering at the benchmark level and, therefore, intolerance has been assessed as intermediate. On return to prior conditions, recovery of the intolerant species would most probably be high (see additional information).

Increase in suspended sediment	Low	Very high	Very Low	No change	Moderate

Changes in siltation rate (resulting from changes in the hydrographic regime, runoff from the land or coastal construction) are likely to result in changes in the sediment composition, certainly of the surface layers and hence the communities present. Increased siltation may increase the proportion of mud or silt in the surface layers. Although an increase in inorganic particles may interfere with the feeding apparatus of suspension feeders, and potentially result in a decreased total ingestion over the benchmark period, the majority of fauna would be unaffected and an intolerance of low has been recorded. Recovery is expected to be very high.

Decrease in suspended sediment	Low	Very high	Moderate	No change	Low

Changes in siltation rate (resulting from changes in the hydrographic regime, runoff from the land or coastal construction) are likely to result in changes in the sediment composition, certainly of the surface layers and hence the communities present. Decreased siltation may be associated with overall erosion of intertidal flats (where erosion is not compensated by deposition) although this is unlikely to have a huge effect over the benchmark period. An intolerance of low has been suggested to reflect the likelihood that the sediment dynamics will change. However, recovery is expected to be very high on return to normal conditions.

Dessication	Low	Very high	Very Low	No change	Low

Muddy sands hold water due to capillary action and organisms inhabiting them are unlikely to be exposed to the air, except at the top of the shore and at the surface of sediments. Organisms inhabiting the top few centimetres of sediment may simply burrow deeper to avoid the effects. LMS.BatCor occurs in drier sediments higher on the shore than LMS.Pcer and LMS.LimAre and may be more intolerant of increased desiccation. Overall, a low intolerance has been suggested. Recovery is expected to be very high on return to normal conditions.

Increase in emergence regime	High	High	Moderate	Major decline	High

Increased emergence (e.g. by tidal and storm surge barrages) is likely to increase the desiccation of the sediment, especially at the top of the shore, and may allow terrestrial plants, such as pioneer saltmarsh species e.g. *Salicornia* sp. or *Spartina* spp. to invade. Species richness will most likely decline and favour species more tolerant of desiccation or burrowing species. Providing suitable substratum was available, the extent of the biotopes may extend further down shore but in general, the upper extent of the biotope is expected to decrease and intolerance has been assessed as intermediate. Recovery is expected to be high (see additional information).

Decrease in emergence regime	Intermediate	High	Low	Insufficient information	High

Decreased emergence, for example due to sea level rise or barrages, may move the high water mark further up shore but this is not possible in the presence of sea defenses. The low water mark moves inshore, effectively reducing the area available for intertidal invertebrates and the area in which birds can feed, so called 'coastal squeeze'. The construction of a storm surge barrier at Oosterschelde resulted in loss of 33% of the intertidal habitat and reduced populations of birds dependant on mudflats for feeding (Meire, 1993; Elliot *et al.*, 1998). Resultant increased water depth changes infaunal feeding types and increases the area available to predatory fish. Changes in predator influence will result in a change in the structure of the benthic community and may lead to a shift in species dominance.

At most, and depending on the location, there is likely to be a change in species composition and, although the resultant community may still be characteristic of muddy sand shores, some species may be lost. The biotopes may start to develop into other biotopes such as A5.241 or A5.331 but, overall, intolerance has been assessed intermediate to reflect the likelihood the loss of biotope at its lower shore extent. Recoverability is likely to be high on return to previous levels of emergence.

Increase in water flow rate	High	High	Moderate	Minor decline	High

The nature of the substratum is, in part, determined by the hydrographic regime including water flow rate. Changes in the water flow rate will change the sediment structure and have concomitant effects on the community. Channel modification or seasonal changes in riverine runoff, especially in estuaries, may remove low water areas of mud or sand flats. Furthermore, increased water flow rate may mean that some species have to re-burrow more frequently which would adversely effect the energy budget of some infauna. An increase in water flow rate may lead to the removal of the upper layer of fine silty sediment in muddier sediments. Over the course of one year, there may be some habitat loss and accordingly, intolerance has been assessed as high. Recoverability is expected to be high on return to former conditions.

Decrease in water flow rate	High	Low		No change	High

A decrease in water flow rate is likely to result in the accumulation of sediment. The effects of such a change will depend on the existing sediment. If the sediment is characterized by clean sand, a decrease in flow rate may result in the settlement of finer silt particles. Over the course of one year this is likely to affect the community structure although the resultant community would still be described as LMS.MS. Species richness has been described as not relevant since a change in species composition would not necessarily result in a decline in species richness. Intolerance has been assessed as low to reflect community change. Recovery is expected to be very high.

Increase in temperature	Tolerant	Not relevant	Not sensitive	No change	Moderate

Many intertidal species are adapted to temperature extremes, can alter metabolic activity, burrow deeper in sediment or move to deeper water. Thermal discharges may increase growth of bivalves and fish, increase phytoplankton production (Clark, 1997) and may alter the extent of populations. Temperature change is known to affect the number of generations per year of *Corophium volutator* and an increase in temperature may increase reproduction in *Corophium* *volutator*. In general, the number of species is likely to be highest during summer (M. Kendall, pers. comm.). Beukema (1990) stated that he was unaware of any soft-bottom species that were sensitive to high summer temperatures and, overall, tolerant has been suggested.

Decrease in temperature	Intermediate	High	Low	Decline	Moderate

Many intertidal species are adapted to temperature extremes, can alter metabolic activity, burrow deeper in sediment or move to deeper water. Although adapted to temperature change, severe change may result in seasonal reduction in species richness and abundance. Temperature may also affect microbial activity and microphytobenthic primary production.

Beukema (1990) studied the effects of changing winter temperatures on zoobenthos over a 20 year period in the Wadden Sea. More than one third of macrobenthic infauna were found to be sensitive to cold winters. Species that were unable to move long distances, such as polychaetes and bivalves, probably died whereas the crustacea probably moved offshore. No *Lanice conchilega*, Abra tenuis, Mysella bidentata or *Macomangulus tenuis* were found to survive the coldest winter (in which temperatures fell below -10 °C for about one week and below freezing for up to ca four weeks) and the numbers of *Cerastoderma edule*, *Nephtys hombergii*, *Crangon crangon* and *Carcinus maenas* *were severely depleted. Even in 'cold' winters, where the temperature only fell below –10 °C on a couple of days, survival was very low among these species and again, no Lanice conchilega survived. Crisp (1964a) also reported that all intertidal Lanice conchilega were killed in the severe winter of 1962-63 but that some survived subtidally. At a community level, the impact was found to be more serious on lower tidal flats than on higher ones since the former contained a higher proportion of species less adapted to extremes in temperature.*

Fish and bird species feeding on the macrobenthos will experience a reduction in food availability over the winter months. In cold periods waders and other shore birds have increased energy demands for thermoregulation and require greater food intake and, therefore, are more intolerant of additional disturbance. Bird species with a wider range of prey species will be more tolerant of fluctuations in invertebrate numbers than species with narrow prey preferences.

It is possible that many species will experience a decline in abundance in the case of an acute fall in temperature and accordingly, an intolerance of intermediate has been recommended. However, recoverability is likely to be high. Beukema (1990) found that after a severe winter, recovery of the previous biomass and species richness occurred within one or two years and recruitment was generally higher after the cold winter. However, most of the species could be found in large numbers subtidally and recruitment was possible from nearby via mobile larval stages or immigration of adults.

Increase in turbidity	Tolerant	Not relevant	Not relevant	No change	Not relevant

An increase in turbidity may limit primary productivity from phytoplankton and microphytobenthos. However, the majority of productivity in these communities is secondary (detritus). Incoming tides and wave action resuspend sediment in passing, resulting in high local turbidity. Turbidity in estuaries is often high, measured in g/l. Therefore the microphytobenthos is probably adapted to high turbidity and capable of taking advantage of light availability at low tide. Tolerant has been suggested.

Decrease in turbidity	Tolerant*		Not sensitive	No change	Low

A decrease in turbidity may enhance primary production. For the suspension feeders and deposit feeders feeding on settled phytoplankton, this will mean an increase in available food.

Tolerant*, has therefore been suggested although species richness is not expected to rise.

Increase in wave exposure High Low High Decline High

Storms and intense wave action may move or remove substrata in shallow subtidal or intertidal sedimentary habitats. For example, in shallow subtidal muddy sands in Liverpool Bay, Eagle (1973) reported significant fluctuations in the abundance of dominant species (e.g. *Abra alba*, *Lanice conchilega* and *Lagis koreni*) resulting from wash out during storms. Recolonization occurred rapidly and depended on the availability of larvae in the plankton and redistribution of juveniles or adults by bedload transport (Eagle, 1975; Hall, 1994). Similar observations were reported for *Lagis koreni* and *Abra alba* in the intertidal muddy sands and mobile offshore sands of Red Wharf Bay, Anglesey and the surrounding coast (Rees *et al.*, 1977). Increased wave action will disrupt feeding, burrowing, reduce species abundance, richness and biomass (Elliot *et al.*, 1998). The strength of wave action determines the topography, steepness and shore width of the intertidal, e.g. large areas of surface mud were removed from Severn estuary by exposure to prevailing gales and its large tidal range (Ferns, 1983, cited in Elliot *et al.*, 1998). Changes in wave exposure would change the sediment granulometry and the sediment will become coarser which, although smaller animals find it easier to move through, will result in reduced food availability (M. Kendall, pers. comm.). Muddy sands are typical of sheltered locations and may be particularly intolerant to increased wave exposure. Long term change may favour littoral gravel and sand communities. Intolerance has been assessed as high. Recoverability is likely to be low (see additional information).

Decrease in wave exposure High Low No change High

The strength of wave action determines the topography, steepness and shore width of the intertidal (Elliot *et al.*, 1998). Changes in wave exposure would change the sediment granulometry and the sediment will become finer. Although this will result in increased food availability, suspension feeders are intolerant of sediment increases in silt/clay content and, therefore, the proportion of suspension feeders may decrease in favour of deposit feeders. Long term change may favour littoral mud communities and a high intolerance has been suggested. Recoverability is likely to be low (see additional information).

Noise Low Very high Very Low No change High

Disturbance by noise and visual presence of human activities to birds population will be considered together. Disturbance is species dependant, some species habituating to noise and visual disturbance while other become more nervous. For example brent geese, redshank, bar-tailed godwit and curlew are more 'nervous' than oyster catcher, turnstone and dunlin. Turnstones will often tolerate one person within 5-10 m. However, one person on a tidal flat can cause birds to stop feeding or fly off affecting ca 5 ha for gulls, ca 13 ha for dunlin, and up to 50 ha for curlew (Smit & Visser, 1993). Goss-Custard & Verboven (1993) report that 20 evenly spaced people could prevent curlew feeding over 1000 ha of estuary. Industrial and urban development may exclude shy species from adjacent tidal flats. Disturbance may cause birds to fly away, thereby increasing energy demand. However, the Tees Estuary has a sedimentary intertidal area surrounded by heavy industry and is of international significance to a number of bird species. Furthermore, visual or noise disturbance is unlikely to affect epibenthic or infaunal species. Overall, a low intolerance has been suggested to reflect the possibility that the behavioural patterns of some birds may be momentarily altered. Their recovery, however, is likely to be very high overall and may be immediate for some species.

Visual Presence Low Very high Very Low No change High

Disturbance by noise and visual presence of human activities to birds population will be considered together. Disturbance is species dependant, some species habituating to noise and visual disturbance while other become more nervous. For example brent geese, redshank, bar-tailed godwit and curlew are more 'nervous' than oyster catcher, turnstone and dunlin. Turnstones will often tolerate one person within 5-10 m. However, one person on a tidal flat can cause birds to stop feeding or fly off affecting c. 5 ha for gulls, c.13 ha for dunlin, and up to 50 ha for curlew (Smit & Visser, 1993). Goss-Custard & Verboven (1993) report that 20 evenly spaced people could prevent curlew feeding over 1000 ha of estuary. Industrial and urban development may exclude shy species from adjacent tidal flats. Disturbance may cause birds to fly away, thereby increasing energy demand. However, the Tees Estuary has a sedimentary intertidal area surrounded by heavy industry and is of international significance to a number of bird species. Furthermore, visual or noise disturbance is unlikely to affect epibenthic or infaunal species. Overall, a low intolerance has been suggested to reflect the possibility that the behavioural patterns of some birds may be momentarily altered. Their recovery, however, is likely to be very high overall and may be immediate for some species.

Abrasion & physical disturbance	Intermediate	High	Low	Decline	Moderate

In the intertidal, mechanical cockle harvesting resulted in significant losses of common invertebrates in muddy sand and clean sand in the Burry Inlet (Ferns *et al.*, 2000). For example, losses varied from 31% of *Scoloplos armiger* to 83% of *Pygospio elegans* in dense populations. In muddy sand the abundance of *Cerastoderma edule* was reduced by ca 34%. Populations of *Nephtys hombergii* and Scoloplos armiger took over 50 days to recover. However, recovery was more rapid in clean sand than in muddy sand. In muddy sand, *Bathyporeia pilosa* took 111 days to recover while *Cerastoderma edule*, *Pygospio elegans* and *Hydrobia ulvae* had not recovered their original abundance after 174 days (Ferns *et al.*, 2000). In a similar study, Hall & Harding (1997) found that non-target benthic fauna recovered within 56 days after mechanized cockle harvesting. However, Hall & Harding (1997) study took place in summer while Ferns *et al.* (2000) study occurred in winter.

Despite their apparent robust body form, bivalves are also vulnerable to physical abrasion. For example, as a result of tractor dredging activity, mortality and shell damage has been reported in *Mya arenaria* and *Cerastoderma edule* *(Cotter et al., 1997). Epibenthic species such as amphipods and isopods may be mobile and small enough to avoid damage. The tops of burrows may be damaged and repaired subsequently at energetic cost to their inhabitants.*

Therefore, physical disturbance at the benchmark level is likely to result in mortality or removal of a proportion of the invertebrate macrofauna and an intolerance of intermediate has been recorded. The above evidence suggests that recovery is possible within a year, depending on the season in which the disturbance occurs. However, recruitment in *Cerastoderma edule* is sporadic and recovery, especially in LMS.Pcer could be more protracted. Therefore, a recoverability of high has been suggested.

Displacement	Intermediate	High	Low	Minor decline	Very low

Muddy sand communities are likely to be intolerant of displacement as the infauna will be removed and heart urchin, molluscs and crustaceans are likely to be damaged or killed in dredging operations (Elliot *et al.*, 1998). Although burrowing species and mobile epibenthic species are likely to be able to re-establish themselves in the sediment, their displacement will probably result in significant predation, at either low (birds) or high tide (fish and crabs). Therefore, intolerance has been assessed as intermediate. Recoverability is likely to be high (see additional information).

Chemical Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Synthetic compound contamination	High	Low	High	Major decline	Low

Sheltered, low energy areas in enclosed bays or estuaries act as a sink for sediment and detritus. Low dispersion within these areas also acts as a sink for complex mixtures of pollutants, especially since many become adsorbed onto organic particulates and fine sediments e.g. chlorinated hydrocarbons, DDT (Clark, 1997). Therefore the sediments act as a sink for a wide variety of contaminants, many with a long half life in the environment, e.g. PCBs, dieldrins, and pesticides. Some pollutants may bioaccumulate within the food chain, e.g. PCBs and mercury. The sublethal or toxic effects vary with concentration, the bio-availability of the contaminant, and the physiology of the affected organism (Nedwell, 1997, cited in Elliot *et al*., 1998). Recovery requires dilution, biodegradation or removal of the contaminant from the sediments. Contaminants with long half lives may remain in sediment for decades, especially in sheltered areas with little dispersion. In Southampton Water and the Tees, the benthic communities in intertidal sediments had decreased due to contamination with phenols, oil effluent, sulphides and nitrogen compounds (Elliot *et al*., 1998). Given that LMS.MS occur in sheltered to very sheltered shores, the chemicals may remain in the sediment for some time and, accordingly, recoverability has been assessed as low but with low confidence.

Heavy metal contamination	High	Low	High	Decline	Low

Flocculation, salinity and pH changes within estuaries, in particular, result in the preferential precipitation of some heavy metals, e.g. Fe and Cu (Bryan, 1984). Sediments can act as sinks for contaminants including heavy metals. Heavy metals have been shown to bioaccumulate in wading birds (Parslow, 1973) and the knot, Icelandic redshank and bar-tailed godwit have been shown to display symptoms of lead exposure in the Dutch Wadden Sea (Goede & de Voogt, 1985). Hall & Frid (1997) suggested that metal pollution may have contributed to a reduce species abundance and richness in some areas of the Tyne and Wear estuaries. For example, the number of species in the Tyne was lowest at St Peter's Quay which had some of the highest concentrations of lead and zinc.

It is more than likely that heavy metal pollution will lead to a reduction in species richness and abundance in LMS.MS. More importantly, the resultant community may not resemble an LMS.MS biotope. Intolerance has, therefore, been assessed as high. Given that LMS.MS occur in sheltered to very sheltered shores, the chemicals may remain in the sediment for some time and, accordingly, recoverability has been assessed as low but with low confidence.

Hydrocarbon contamination	High	Low	High	Major decline	Low

Release of refinery effluent to intertidal mudflats may result in anoxic sediment, a degraded infaunal community, and changes to predator-prey interactions, possibly due to tainting (Elliot & Griffiths, 1987). Oil spills result in large-scale damage to intertidal communities. Oil smothers the sediments preventing oxygen exchange, thereby producing anoxia and leading to the death of infauna. Stranded oil is not readily removed in sheltered conditions and penetrates the sediment due to wave and tidal action and destabilizes it. The microbial degradation of the oil increases the biological oxygen demand and produces anoxia. Often the low oxygen environment in sediments will mean that the bacterial degradation takes some time so that the oil remains toxic (Clark, 1997; Elliot *et al*., 1998). The persistent toxicity of

Amoco Cadiz oil in sediment prevented the start of recovery (Clark, 1997). The Florida barge oil spill in Buzzards Bay, Massachusetts, was driven into sediments by wave action, causing an immediate fish kill (e.g. flounders) and the death of a large numbers of lobsters, crabs shrimps and bivalves (e.g. scallops and oysters). Commercial fisheries were closed due to tainting (Clark, 1997; Elliot *et al.*, 1998). Overall, intolerance has been assessed as high. Given that LMS.MS occur in sheltered to very sheltered shores, the chemicals may remain in the sediment for some time and, accordingly, recoverability has been assessed as low but with low confidence.

Radionuclide contamination Insufficient information | Not relevant

Radionuclides will accumulate in the sediment sink in the same way as other heavy metals. However, little information on their biological effects is known (Cole *et al.*, 1999) and insufficient information was available to assess sensitivity to this factor.

Changes in nutrient levels High | Moderate | Moderate | Major decline | High

Enrichment of intertidal sediments (moderate nutrient increase) provides food and increases the abundance and diversity of organisms. In a review of the effects green macroalgal blooms, Raffaelli *et al.* (1998) stated that the increased biomass of algae, to a certain extent, would provide more food for herbivores such as *Hydrobia* and, when the algae starts to decay, for *Macoma* and *Corophium* sp.. Other benefits included the possibility that the algal mat may entrain larvae, leading to increased larval settlement of e.g. *Macoma* and *Nereis* sp., and that the mat may provide a refuge from predators for small species of fish, crustacea and gastropods (Raffaelli *et al.*, 1998). However, the authors highlighted that the effects of nutrient enrichment are far from simple. With increasing nutrient input the diversity declines and the community is increasingly dominated by opportunistic species such as oligochaetes, the polychaete *Capitella capitata* (in sands) and tolerant species such as *Manayunkia aestrurina* (in muds) (muddy sand may be intermediate). Many species are likely to experience drastic reductions in abundance including some species of burrowing bivalve which may be forced to the surface (Raffaelli *et al.*, 1998). Increased nutrients and poor oxygenation lead to slow degradation and anaerobic conditions. Anaerobic microbial activity releases toxic hydrogen sulphide and methane. Remaining macroinfauna may become limited to species able to obtain oxygen from the surface waters, e.g. through burrows. In highly polluted areas the sediment may become defaunated and the surface covered with sulphur-reducing bacteria e.g. *Beggiatoa* spp. The development of algal mats of opportunistic green algae e.g. *Ulva* sp. is symptomatic of enrichment. Algal mats prevent epibenthic predators from feeding and species including *Corophium* sp. may become tangled in the mat and surface deposit feeders may become excluded (Raffaelli *et al.*, 1998). Anoxic sediment may develop beneath the mats. Organic enrichment also changes the composition and density of the benthic diatom community in intertidal brackish mudflats, possible due to reduction in the populations of diatom grazers, e.g. *Corophium volutator*. LMS.MS is expected to be highly intolerant to nutrient enrichment. Given that LMS.MS occur in sheltered to very sheltered shores, the nutrients may remain in the biotope for some time and, accordingly, recoverability has been assessed as moderate but with low confidence.

Increase in salinity Tolerant | Not relevant | Not sensitive | No change | Moderate

LMS.MS can occur in areas of full salinity and, therefore, are thought to be tolerant to an increase in salinity.

Decrease in salinity Low | Very high | Moderate | No change | Low

Intertidal flats are exposed to rainfall at low tide. However, freshwater sits on the surface of denser seawater and interstitial water remains close to full salinity. Species are tolerant of salinity change, may osmoregulate, may stop irrigating their burrow, or may move seaward if mobile or burrow deeper into the sediment (McLusky, 1989). Increased riverine runoff may erode intertidal areas or form creaks of reduced salinities. In estuaries and creeks salinity is a dominant factor resulting in a salinity gradient from the mouth of the estuaries to the freshwater. Estuaries typically demonstrate low diversity of species but high abundances as increasingly fewer marine species penetrate up the estuary (towards freshwater habitats). LMS.MS biotopes are found from variable to full salinity. LMS.LimAre may be exposed to variable salinities in proximity to creaks, however LMS.BatCor and LMS.Pcer prefer full salinity and may be more intolerant. Overall, LMS.MS is likely to be of low intolerance to a reduction in salinity. Recoverability is likely to be very high (see additional information).

Changes in oxygenation	High	Moderate	Moderate	Major decline	Moderate

Muddy sands may have relatively low oxygen concentrations, lower than coarse sands but higher than muds. Deoxygenation due to pollution (see contaminants) and nutrient enrichment (see nutrients) results in significant decline in species numbers and diversity. Therefore it is likely that muddy sands are highly intolerant of deoxygenation, depending on the species.

Biological Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Introduction of microbial pathogens/parasites	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant

Microbial pathogens are generally species specific and not relevant in a discussion of a biotope complex.

Introduction of non-native species	Intermediate	Very low / none	High	Minor decline	Not relevant

Introduction of North American cord grass *Spartina alterniflora* to stabilize and reclaim high intertidal mudflats has significantly altered UK saltmarsh. *Spartina alterniflora* hybridized with native *Spartina marina* producing an infertile hybrid (*Spartina townsendii*) which gave rise to fertile *Spartina anglica*. *Spartina anglica* is fast growing and aggressive and has colonized extensive areas of intertidal mudflats, increasing the area of saltmarsh in the UK but reducing intertidal feeding grounds for shorebirds.

Merceneria mercenaria was successfully introduced from the USA into Southampton Water in 1925. It is found buried in muddy sediment on the lower shore and shallow sublittoral and in bays and estuaries. In Southampton, it filled the niche left by *Mya arenicola* following a severe winter die-off and has prevented the re-establishment of the *Mya* population (Eno *et al.*, 1997). Furthermore, digging and dredging for *Mercenaria* has had adverse effects on the environment, especially *Zostera* beds (Cox, 1991; Anon, 1992, both cited in Eno *et al.*, 1997).

It is likely that some species will experience a reduction in abundance and intolerance has, therefore, been assessed as intermediate. Recovery is likely to be low since an established saltmarsh will lead to a long-term decrease in the extent of the LMS.MS biotope and, in some areas, this may be permanent.

Extraction of this species	Intermediate	High	Low	Minor decline	Low

In general, extraction of fish or shellfish can have the following community effects:

- extraction of juvenile fish and loss of the biotopes nursery function;
- displacement of non-target species;
- reduction in community diversity and species richness, e.g. from bait digging (Brown & Wilson, 1997);
- increased numbers of scavengers and organic enrichment due to discards (Elliot *et al.*, 1998).

Removal of *Cerastoderma edule* (cockles) by targeted fishery may result in an altered community and reduced extent of the LMS.Pcer biotope. In some circumstances, where the superficial sediment is shallow, bait digging can also change surface granulometry (M. Kendall, pers. comm.). In the intertidal, mechanical cockle harvesting resulted in significant losses of common invertebrates in muddy sand and clean sand in the Burry Inlet (Ferns *et al.*, 2000). For example, losses varied from 31% of *Scoloplos armiger* to 83% of *Pygospio elegans* in dense populations. In muddy sand the abundance of *Cerastoderma edule* was reduced by ca 34%. As a result of tractor dredging activity, mortality and shell damage has also been reported in *Mya arenaria* and *Cerastoderma edule* (Cotter *et al.*, 1997). Therefore, targeted extraction of cockles is likely to result in mortality or removal of a proportion of the invertebrate macrofauna and an intolerance of intermediate has been recorded.

Ferns *et al.*, 2000 reported that populations of *Nephtys hombergii* and *Scoloplos armiger* took over 50 days to recover. However, recovery was more rapid in clean sand than in muddy sand. In muddy sand, *Bathyporeia pilosa* took 111 days to recover while *Cerastoderma edule, Pygospio elegans* and *Hydrobia ulvae* had not recovered their original abundance after 174 days (Ferns *et al.*, 2000). In a similar study, Hall & Harding (1997) found that non-target benthic fauna recovered within 56 days after mechanized cockle harvesting. However, Hall & Harding (1997) study took place in summer while Ferns *et al.* (2000) study occurred in winter. The above evidence suggests that recovery is possible within a year, depending on the season in which the disturbance occurs. However, recruitment in *Cerastoderma edule* is sporadic and recovery, especially in LMS.Pcer could be more protracted. Therefore, a recoverability of high has been suggested.

Extraction of other species	Intermediate	Moderate	Moderate	Minor decline	Low

Additional information

Recoverability

Recovery is dependent on the return of suitable sediment and recruitment of individuals. Newell *et al.* (1998) report that dredged pits in the intertidal took 5-10 years to fill in low currents and up to 15 years on tidal flats in the Dutch Wadden Sea. However, intertidal dredging is a rare event. In a study of the effects of dredging for *Ensis* sp. showed that dredging caused significant changes on the community but that the community was not detectably significantly different from controls after 40 days (Hall, 1994). This rapid recovery was probably due to intense wave and storm activity during the experimental period that transported sediment and animals in suspension and in bedload transport (Hall, 1994). When holes are made in a muddy sand assemblage, the recruitment comes from a combination of adult migration and larval immigration with larval importance increasing with hole size (Kendall, pers. comm.). Overall recovery will vary between site location or hydrographic regime and the community may not recover exactly the same species composition as existed prior to disturbance. Once suitable substratum returns, recolonization is likely to be rapid, especially for rapidly reproducing species such as polychaetes, oligochaetes and some amphipods and bivalves. Recolonization and hence recovery may be aided by bedload transport of juvenile polychaetes and bivalves.

It should be noted that where the LMS.MS biotopes are lost, the resultant sediment is unlikely to be defaunate (except in areas of extreme contamination). The assessed LMS.MS communities will probably be replaced by communities more tolerant or adapted to the affected conditions. Due to the fact that LMS.MS occurs in sheltered and very sheltered areas, the recoverability may take much longer for factors such as chemical, metal and hydrocarbon contamination, and wave exposure.

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