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

Bathyporeia pilosa and *Corophium arenarium* in littoral muddy sand

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

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2016-06-14

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/353>]. 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. 2016. [*Bathyporeia pilosa*] and [*Corophium arenarium*] in littoral muddy sand. 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.353.1>

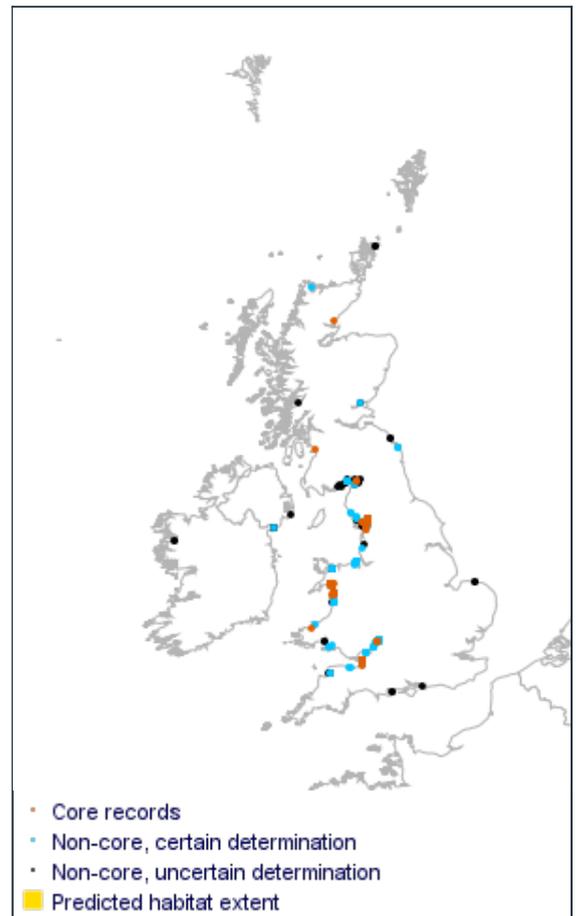


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Cross section through the LMS.BatCor biotope.
 Photographer: D.Mills
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17-09-2018
 Biotope distribution data provided by
 EMODnet Seabed Habitats
 (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin Refereed by Admin

Summary

☰ UK and Ireland classification

EUNIS 2008	A2.244	<i>Bathyporeia pilosa</i> and <i>Corophium arenarium</i> in littoral muddy sand
JNCC 2015	LS.LSa.MuSa.BatCare	<i>Bathyporeia pilosa</i> and <i>Corophium arenarium</i> in littoral muddy sand
JNCC 2004	LS.LSa.MuSa.BatCare	<i>Bathyporeia pilosa</i> and <i>Corophium arenarium</i> in littoral muddy sand
1997 Biotope	LS.LMS.MS.BatCor	<i>Bathyporeia</i> spp. and <i>Corophium</i> spp. in upper shore slightly muddy fine sands

🔍 Description

Wave-sheltered, mainly upper and mid shore flats of medium to fine sand, often muddy sand. The salinity, although predominantly recorded as variable, probably varies little from fully marine in

these broad estuaries. The infauna is characterized by the amphipods *Bathyporeia pilosa*, *Corophium arenarium* and *Corophium volutator*, and the spire shell *Hydrobia ulvae*. Polychaetes and bivalves are limited in their abundance and variety, though the Baltic tellin *Limecola balthica* may occur. Tidal streams may be strong during spring tides, accounting for the presence of amphipod *Bathyporeia pilosa* that is more commonly associated with open coast sandflats (JNCC, 2015).

↓ Depth range

Upper shore, Mid shore

🏛️ Additional information

-

✓ Listed By

- none -

🔗 Further information sources

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Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

The biotope description and characterizing species are taken from JNCC (2015). The biotope is present on wave sheltered, sand or muddy sand flats but where tidal streams may be strong, particularly on spring tides. The infauna is characterized by the amphipods *Bathyporeia pilosa*, *Corophium arenarium* and *Corophium volutator*, and the spire shell *Hydrobia ulvae*. Polychaetes and bivalves are limited in their abundance and variety, though the Baltic tellin *Limecola balthica* may occur. The sensitivity assessments largely focus on the sedimentary habitat and associated environmental factors that structure the biotope and the key characterizing species, *Bathyporeia pilosa* and *Corophium* spp. that are named in the biotope title and considered to define the biotope, the loss of these species may result in a change in biotope classification. The sediments and tidal stream are key factors maintaining the biotope and are considered in the sensitivity assessments where the pressure may alter these.

Resilience and recovery rates of habitat

The characterizing species *Bathyporeia pilosa* is found in sediments subject to physical disturbance, as a result of wave action or in wave sheltered biotopes, strong tidal streams. This species is therefore tolerant of disturbed environments and can recover quickly. *Bathyporeia* spp. are short lived, reaching sexual maturity within 6 months with 6-15 eggs per brood, depending on species. Reproduction may be continuous (Speybroeck *et al.*, 2008) with one set of embryos developing in the brood pouch whilst the next set of eggs is developing in the ovaries. However, specific reproductive periods vary between species and between locations (Mettam, 1989) and bivoltine patterns (twice yearly peaks in reproduction) have been observed (Mettam, 1989; Speybroeck *et al.*, 2008). Adult amphipods are highly mobile in the water column and recolonization by the adults is likely to be a significant recovery pathway. The life history traits of rapid sexual maturation and production of multiple broods annually support rapid local recolonization of disturbed sediments where some of the adult population remains.

Corophium volutator lives for a maximum of one year (Hughes, 1988) and females can have 2-4 broods in a lifetime (Conradi & Depledge, 1999). Populations in southerly areas such as the Dovey Estuary, Wales or Starrs Point, Nova Scotia have two reproductive episodes per year. Those populations in colder, more northerly areas such as the Ythan Estuary, Scotland or in the Baltic Sea only have one (Wilson & Parker, 1996). On the west coast of Wales, breeding takes place from April to October and mating takes place in the burrow. Adult males crawl over the surface of the moist sediment as the tide recedes in search of burrows occupied by mature females. *Corophium volutator* forms an important food source for several species of birds and mobile predators such as fish and crabs (Hughes, 1988; Jensen & Kristensen, 1990; Raffaelli *et al.*, 1991; Flach & De Bruin, 1994; Brown *et al.*, 1999), so this behaviour makes them vulnerable to predation (Fish & Mills, 1979; Hughes, 1988; Forbes *et al.*, 1996). The females can produce 20-52 embryos in each reproductive episode (Fish & Mills 1979; Jensen & Kristensen, 1990). Juveniles are released from the brood chamber after about 14 days, and development is synchronized with spring tides, possibly to aid dispersal. Recruitment occurs within a few centimetres of the parent, although they may disperse later by swimming (Hughes, 1988). In the warmer regions where *Corophium volutator* is found, juveniles can mature in 2 months (Fish & Mills, 1979) and add their own broods to the population. The juveniles born in May undergo rapid growth and maturation to reproduce from July to September and generate the next overwintering population (Fish & Mills, 1979).

Corophium volutator is one of the most abundant organisms in estuarine mudflats reaching densities of 100,000 m⁻² in the Stour Estuary, Suffolk (Hughes, 1988). Densities vary with geographical region and season, having been reported to rise considerably during the summer months in Gullmarsfjorden, Wadden Sea, and in the Crouch Estuary in southeast England (Flach & De Bruin, 1993; Gerdol & Hughes, 1993).

Resilience assessment: Removal of the characterizing *Bathyporeia pilosa* and *Corophium* spp. would result in the biotope being lost and/or re-classified. Both species are known to have long reproductive seasons during their short lifespans. Where perturbation removes a portion of the population or even causes local extinction (resistance 'None', 'Low' or 'Medium') resilience is likely to be 'High' for as long as recruitment from neighbouring areas and/or adult migration is possible. However, in areas of suitable habitat that are isolated, where total extinction of the population occurs (resistance 'None') recovery is likely to depend on favourable hydrodynamic conditions that will allow recruitment from farther away and recruitment to re-colonize impacted area may take longer. However, once an area has been recolonized, restoration of the biomass of both characterizing species is likely to occur quickly and resilience is likely to be 'Medium' (full recovery within 2-10 years).

NB: The resilience and the ability to recover from human induced pressures is a combination of the environmental conditions of the site, the frequency (repeated disturbances versus a one-off event) and the intensity of the disturbance. Recovery of impacted populations will always be mediated by stochastic events and processes acting over different scales including, but not limited to, local habitat conditions, further impacts and processes such as larval-supply and recruitment between populations. Full recovery is defined as the return to the state of the habitat that existed prior to impact. This does not necessarily mean that every component species has returned to its prior condition, abundance or extent but that the relevant functional components are present and the habitat is structurally and functionally recognizable as the initial habitat of interest. It should be noted that the recovery rates are only indicative of the recovery potential.

Hydrological Pressures

	Resistance	Resilience	Sensitivity
Temperature increase (local)	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

Intertidal species are exposed to extremes of high and low air temperatures during periods of emersion. They must also be able to cope with sharp temperature fluctuations over a short period of time during the tidal cycle. In winter air temperatures are colder than the sea, conversely in summer air temperatures are much warmer than the sea. Species that occur in the intertidal are therefore generally adapted to tolerate a range of temperatures, with the width of the thermal niche positively correlated with the height of the shore that the animal usually occurs at (Davenport & Davenport, 2005). The species present in this biotope are present in the mid and/or upper shore and therefore are likely to have broad temperature tolerances and to be tolerant of temperature fluctuations.

Many intertidal species can alter metabolic activity, burrow deeper in sediment or move to deeper water to tolerate or escape unfavourable conditions. At low tide, air temperature becomes critically important to intertidal animals, and on sandy beaches the substratum, from the surface to a depth of several centimetres, can experience large variations in temperature during a single cycle

and throughout the year (Hayward, 1994). For instance, Khayrallah & Jones (1980b) reported the temperature range of sand at a depth of 1 cm during neap tides to be from -2°C in February 1973, to a maximum of 25°C in July 1977. Although adapted to temperature change, severe acute change may result in seasonal reduction in species richness and abundance, but the effects of an acute temperature increase are not necessarily direct and may be more related to the resultant changes in other factors, especially reductions in oxygen resulting from enhanced microbial activity (Hayward, 1994; Eltringham, 1971).

The amphipods that occur within this habitat are mobile and can avoid unfavourable conditions to some extent. *Bathyporeia* life cycles vary between locations and this is related to temperature (Mettam, 1989). Preece (1971) tested temperature tolerances of *Bathyporeia pilosa* in the laboratory. Individuals acclimated to 15°C for 24 hours were exposed to temperature increases (water temperature raised by $0.2^{\circ}\text{C}/\text{minute}$). As test temperature were reached individuals were removed, placed in seawater at 4°C and allowed to recover for 24 hours at which point mortalities were tested. Amphipods were also allowed to bury into sediments and held at test temperatures for 24 hours of 32.5°C , 31.8°C and 29.5°C before being allowed to recover in fresh seawater at 15°C for a further 24 hours, before mortalities were assessed. Upper lethal temperatures (the temperature at which 50% of individuals died for adult males and gravid females of *Bathyporeia pilosa* were 39.4°C . These tests measures short-term exposure only and species had lower tolerance for longer-term (24 hour exposure). No mortality occurred for *Bathyporeia pilosa* individuals held at 29.5°C and 30.8°C ; however 15% of individuals exposed to water temperatures of 31.8°C and 96% at 32.5°C died.

Corophium volutator is widely distributed in the north Atlantic, American and European coasts, from western Norway to the Mediterranean and the Black Sea and Azov Sea (Neal & Avant, 2006). The amphipod is subject to temperatures of 1°C in the winter to 17°C in the summer (Wilson & Parker, 1996) but can resist much higher temperatures (Meadows & Ruagh, 1981).

Temperature increases may lead to indirect effects on populations of the characterizing species, through changes in the distribution and prevalence of parasites and pathogens (see microbial pathogens pressure). Using a simulation model, Mouritsen *et al.* (2005) demonstrated that a 3.8°C increase in ambient temperature would probably result in a parasite-induced collapse of the amphipod population in the Wadden Sea. This indirect effect is assessed in the introduction of microbial pathogens pressure.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary seasonally from 4 - 19°C (Huthnance, 2010). A chronic increase in temperature throughout the year of 2°C may fall within the normal temperature variation and an acute increase in water temperatures from 19 to 24°C for a month may be tolerated by the characterizing species supported by deeper burrowing and/or migration. For *Bathyporeia* spp. temperature increases above 30°C appear to be critical based on Preece (1971). For intertidal biotopes air temperature may be more critical in the hottest parts of the year although nocturnal emergence of *Bathyporeia* spp. and isopods or burrowing life habit may also enhance survival. Biotope resistance is therefore assessed as 'High' and resilience as 'High' so that the biotope is assessed as 'Not sensitive'.

**Temperature decrease
(local)**

High

Q: High A: High C: High

High

Q: High A: High C: High

Not sensitive

Q: High A: High C: High

Intertidal species are exposed to extremes of high and low air temperatures during periods of emersion. They must also be able to cope with sharp temperature fluctuations over a short period

of time during the tidal cycle. In winter air temperatures are colder than the sea, conversely in summer air temperatures are much warmer than the sea. Species that occur in the intertidal are therefore generally adapted to tolerate a range of temperatures, with the width of the thermal niche positively correlated with the height of the shore that the animal usually occurs at (Davenport & Davenport, 2005).

Crisp (1964) reported that species of amphipod and isopods seemed to be unharmed by the severe winter of 1962-1963. This may be due to burial in sediments buffering temperature or seasonal migration to deeper waters to avoid freezing. In the winter migrations have also been observed for *Bathyporeia* spp. (Fish & Fish, 1978; Fish & Preece, 1970).

Preece (1971) tested temperature tolerances of *Bathyporeia pilosa* in the laboratory. Individuals acclimated to 15°C for 24 hours were placed in a freezer in wet sediment. As test temperatures were reached individuals were removed and allowed to recover for 24 hours at which point mortalities were tested. Amphipods were also allowed to bury into sediments and held at test temperatures of -1°C, -3°C and -5°C for 24 hours before being allowed to recover in fresh seawater at 15°C for a further 24 hours before mortalities were assessed. The lower lethal short-term tolerances of *Bathyporeia pilosa* were -13.6°C. *Bathyporeia pilosa* individuals could withstand temperatures as low as -1°C for 24 hours, at -3°C, 5% of *Bathyporeia pilosa* died but this rose to 82% at -5°C.

Corophium volutator is subject to temperatures of 1°C in the winter to 17°C in the summer (Wilson & Parker, 1996). The population may reduce activity and delay reproduction if the temperature drops below 7°C. Sudden pulses of very cold water can disrupt the circa-tidal rhythms of *Corophium volutator* by resetting the onset of swimming behaviour. For example, a 6 hour cold spell would lead to the population trying to swim at low tide and leave them vulnerable to increased predation. However, it took temperatures of 15-20°C below ambient temperature to induce this response (Holmström & Morgan, 1983b).

Drolet *et al.* (2013) sampled two intertidal mudflats in the upper Bay of Fundy, Canada, over two consecutive winters (2009–2011), where sediment temperature, 5 cm deep, reached 2°C. The authors concluded *Corophium volutator* survived winter through physiological adaptations.

Sensitivity assessment. Typical surface water temperatures around the UK coast vary seasonally from 4-19°C (Huthnance, 2010). A chronic decrease in temperature throughout the year of 2°C may fall within the normal temperature variation. An acute decrease in water temperatures from 4°C to -1°C at the coldest part of the year may lead to freezing and lethal effects on exposed individuals but the characterizing species may survive by burrowing deeper into sediments and/or migration. For *Bathyporeia pilosa* seawater temperature decreases below -1°C appear to be critical based on Preece (1971). For intertidal biotopes air temperature may be more important than seawater temperatures in the coldest parts of the year and nocturnal emergence of *Bathyporeia pilosa* may reduce survival although these species are more likely to be quiescent during cold periods or to have migrated to the subtidal. Biotope resistance is therefore assessed as 'High' and resilience as 'High' so that the biotope is assessed as 'Not sensitive'.

Salinity increase (local)

Low

Q: High A: Low C: Low

High

Q: High A: Low C: High

Low

Q: High A: Low C: Low

This biotope is found in full salinity (30-35 ppt) and variable salinity habitats (18-35 ppt) (JNCC, 2015). Biotope examples found in variable salinity are considered to tolerate a change to full

salinity as this falls within the natural range. A change at the pressure benchmark is therefore assessed as a change to hypersaline conditions (>40 ppt) from full salinity. Little evidence was found to assess responses to hypersalinity. However, monitoring at a Spanish desalination facility where discharges close to the outfall reached a salinity of 53, found that amphipods were sensitive to the increased salinity and that species free-living in the sediment were most sensitive. The study area did not host any of the species characterizing this biotope but the results indicate a general sensitivity (De-la-Ossa-Carretero *et al.*, 2016).

Bathyporeia pilosa appears to be confined to intertidal sand sediments. *Corophium volutator* occupies a greater variety of habitats and is found in fine sediments of mud flats, salt marsh pools and brackish ditches. It is therefore exposed in its natural range to salinity extremes, from freshwater flushing during periods of high rainfall and increases in salinity during periods of high evaporation. *Corophium volutator* is, therefore, an exceptionally euryhaline species able to tolerate 2-50 psu (McLusky, 1968) but growth is fastest at 15-20 psu (McLusky, 1967; McLusky, 1970 cited in Meadows & Ruagh, 1981). The interstitial salinity is more important for *Corophium volutator* than that of the overlying water. Sustained periods of increased salinity are required to alter that of the interstitial water and there is a lag between salinity changes and the response of *Corophium volutator* (McLusky, 1968). Sudden increases in salinity delay swimming activity (Harris & Morgan, 1984a). *Corophium volutator* will also migrate from areas of unfavourable salinity (McLusky, 1968). *Corophium arenarium* is more tolerant of *Corophium volutator* to short-term increases in salinity <45‰ (Mills & Fish, 1980).

Sensitivity assessment: The characterizing species of this biotope are euryhaline and likely to be resistant of an increase in salinity. However, a chronic increase at the pressure benchmark level is likely to result in the death of a portion of the individuals in the population. Resistance is therefore assessed as 'Low' and resilience is likely to be 'High' so the biotope is considered to have 'Low' sensitivity to an increase in salinity at the pressure benchmark level.

Salinity decrease (local)

Medium

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

This biotope is found in full salinity (30-35 ppt) and variable salinity habitats (18-35 ppt) (JNCC, 2015). A change at the pressure benchmark refers to a change to low (<18 ppt salinity).

Speybroeck *et al.* (2008) noted that *Bathyporeia pilosa* tends to occur subtidally in estuarine and brackish conditions. *Bathyporeia pilosa* is tolerant of low salinities and it is capable of reproducing at salinities as low as 2 (Khayrallah, 1977). Populations of *Bathyporeia pilosa* within the upper reaches of the Severn Estuary experience wide fluctuations in salinity ranging from 1-22 depending on the season and tidal cycle (Mettam, 1989). The physiological stress resulting from this environment, however, affects size and reproduction (Mettam, 1989).

Corophium volutator is an exceptionally euryhaline species able to tolerate 2-50 psu (McLusky, 1968) but growth is fastest at 15-20 psu (McLusky, 1970 cited in Meadows & Ruagh, 1981). *Corophium volutator* requires a salinity greater than 5 psu in order to moult, since osmoregulation is lost during moulting (McLusky, 1967). A salinity of at least 7.5 psu is required for reproduction (McLusky, 1968). Mills & Fish (1980), found that *Corophium volutator* is more tolerant of low salinity (2 to 10‰) than *Corophium arenarium*. Females undergoing a pre-copulatory moult failed to lay eggs below salinities of 3‰ (*Corophium volutator*) and 10‰ (*Corophium arenarium*), but in both species the lowest salinity at which all females moulted and laid eggs was 20‰. Changes in salinity are very unlikely to cause mortality but may alter population distribution and abundances within

the biotope as the species is likely to move to more favourable conditions or to suffer some effects on reproduction with resulting decreases in abundance.

Sensitivity assessment: Both the characterizing *Bathyporeia pilosa* and *Corophium* spp. are likely to resist a decrease in salinity at the pressure benchmark level, although there may be some decreases in abundance and body size due to physiological stress, depending on the degree of decrease. Resistance is therefore assessed as 'Medium' and resilience as 'High' (following restoration of the usual salinity regime), and biotope sensitivity is assessed as 'Low'.

Water flow (tidal current) changes (local)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Water movement from tidal streams is a key factor physically structuring this biotope (JNCC, 2015). Sediment sorting and mobilization by tidal streams modifies the sediments present and creates a suitable habitat for *Bathyporeia pilosa* that is more typical of wave disturbed habitats. A change in water flow at the pressure benchmark may be significant as sand fractions are not cohesive (particularly where these occur higher on the shore and are coarser and drier) and are eroded at lower current velocities than muds and silts. Sand particles are most likely to be eroded at about 0.20 m/s (based on the Hjulström-Sundborg diagram, Sundborg, 1956).

Bathyporeia spp. are tolerant of disturbed and mobile sandy sediments and can re-position and burrow. They are therefore unlikely to be impacted by an increase at the pressure benchmark even if this results in more sediment disturbance and a change to coarser sands. Changes in sediment from sands to muddy sands following increased deposition or a change from muddy sand to clean sand may alter abundances and distribution of *Corophium volutator* and *Corophium arenarium* due to their differing sediment preferences (see physical change pressures). Decreases in flow rate are not considered to negatively impact *Corophium volutator* which inhabits muddy sediments in low energy environments such as saltmarsh pools.

Sensitivity assessment. The sediments that characterize this biotope and sub-biotopes are mobile medium to fine sands and sometimes muddy sands. A change at the pressure benchmark (increase or decrease) may lead to some changes in sediment sorting. However, it is unlikely that a decrease at the pressure benchmark would lead to the development of a mud sediment as fine silts require lower velocities to deposit than erode. An increase at the pressure benchmark may lead to increased erosion of fine silts but the biotope is likely to persist and some sediment restoration is likely during the slower neap tides. Biotope resistance is therefore assessed as 'High' and resilience as 'High' (by default), so that the biotope is assessed as 'Not sensitive'.

Emergence regime changes

Medium

Q: High A: High C: NR

High

Q: High A: Low C: High

Low

Q: High A: Low C: Low

This biotope is found on the lower, mid and upper shore (JNCC, 2015). On sandy shores (as in rocky shores) zonation of species occurs in relation to tidal height, in general, talitrid amphipods tend to occur higher on the shore where sediments dry out at low tide and macroalgae is deposited, while lower down the shore more species rich assemblages occur and suspension feeding bivalves are more abundant in the damper sediments (McLachlan *et al.*, 1995). The zonation pattern is mediated by local hydrodynamics and the associated sediment characteristics. This biotope is typically found higher up the shore than sandflats with the cockle *Cerastoderma edule* in the large sandy estuaries of the west coast of England and Wales. In moderately exposed

conditions, this biotope can occur on the mid shore below LS.LSa.St.Tal and/or LS.LSa.MoSa. In more sheltered conditions, this biotope may occur above LS.LMu.MEst.NhomLimStr (JNCC, 2015).

Changes in emergence are likely to result in some shifts in the shoreward or landward extent of the biotope group due to changes in the length of time the biotope is uncovered and covered. Decreased emergence could lead to biotopes occurring on the lower shore becoming sub-littoral or colonized by bivalves and more species rich assemblages. Similarly upper shore biotopes that are at the limit of the ebbing tide could revert to strandline biotopes LS.LSa.St.Tal or revert to the species-poor biotope LS.LSa.MoSa or the *Scolelepis squamata* dominated variant (LS.LSa.MoSa.AmSco.Sco) due to that species tolerance for well-drained habitats

Sensitivity assessment. Sandy beaches exhibit vertical zonation of biotopes due to species differing tolerances for emergence. Species within the biotope exhibit physiological and behavioural adaptations to changes and the biotope as a group is unlikely to be very sensitive to changes in emergence that do not alter the shore zone (from mid-eulittoral to supralittoral, for example). Changes in emergence may result in some changes in upper and lower extents of the biotope and the sub-biotopes and biotope resistance is therefore assessed as 'Medium', resilience is assessed as 'High' (following restoration of tidal regime) and biotope sensitivity is therefore 'Low'.

Wave exposure changes (local)

High

Q: High A: Medium C: NR

High

Q: High A: High C: High

Not sensitive

Q: High A: Medium C: Low

This biotope occurs in a range of estimated wave exposures, including; moderately exposed, sheltered, very sheltered and extremely sheltered (JNCC, 2015). Water movement is an important factor that physically structures this biotope through sediment sorting and disturbance, but tidal streams rather than wave action are the key element (JNCC, 2015).

Sensitivity assessment. As the biotope occurs across four wave exposure categories (JNCC, 2015) this is considered to indicate, by proxy, that a change in wave exposure at the pressure benchmark is less than the natural range of wave heights experienced, (particularly as wave height and hence the corresponding change will be small). Biotope resistance to this pressure is therefore assessed as 'High' and resilience as 'High (by default)' so that the biotope is considered to be 'Not sensitive' at the pressure benchmark.

Chemical Pressures

Transition elements & organo-metal contamination

Resistance

Not Assessed (NA)

Q: NR A: NR C: NR

Resilience

Not assessed (NA)

Q: NR A: NR C: NR

Sensitivity

Not assessed (NA)

Q: NR A: NR C: NR

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

Levels of contaminants that exceed the pressure benchmark may cause impacts. For most metals, toxicity to crustaceans increases with decreased salinity and elevated temperature, therefore marine species living within their normal salinity range may be less susceptible to heavy metal pollution than those living in salinities near the lower limit of their salinity tolerance (McLusky *et al.*, 1986).

Corophium volutator is highly intolerant of metal pollution at levels often found in estuaries from industrial outfalls and contaminated sewage. A concentration 38 mg Cu/l was needed to kill 50% of *Corophium volutator* in 96 hour exposures (Bat *et al.*, 1998). Other metals are far more toxic to *Corophium volutator*, e.g. zinc is toxic over 1 mg/l and toxicity to metals increases with increasing temperature and salinity (Bryant *et al.*, 1985b). Mortality of 50% is caused by 14 mg/l (Bat *et al.*, 1998). Although exposure to zinc may not be lethal, it may affect the perpetuation of a population by reducing growth and reproductive fitness. Mercury was found to be very toxic to *Corophium volutator*, e.g. concentrations as low as 0.1 mg/l caused 50% mortality in 12 days. Other metals known to be toxic include cadmium which causes 50% mortality at 12 mg/l (Bat *et al.*, 1998), and arsenic, nickel and chromium which are all toxic over 2 mg/l (Bryant *et al.*, 1984; Bryant *et al.*, 1985a, 1985b).

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.

Contamination at levels greater than the pressure benchmark may adversely impact the biotope. Light fractions (C10 - C19) of oils are much more toxic to *Corophium volutator* than heavier fractions (C19 - C40). In exposures of up to 14 days, light fraction concentrations of 0.1 g/kg sediment caused high mortality. It took 9 g/kg sediment to achieve similar mortalities with the heavy fraction (Brils *et al.*, 2002). In the Forth Estuary, *Corophium volutator* was excluded for several hundred metres around the outfalls from hydrocarbon processing plants. Roddie *et al.* (1994) found high levels of mortality of *Corophium* at sites contaminated with crude oil.

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

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

In general, crustaceans are widely reported to be intolerant of synthetic chemicals (Cole *et al.*, 1999) and intolerance to some specific chemicals has been observed in amphipods. Species of a different genus are likely to differ in their susceptibility to synthetic chemicals and that this may be related to differences in their physiology (Powell, 1979).

Corophium volutator is paralysed by pyrethrum based insecticide sprayed onto the surface of the mud (Gerdol & Hughes, 1993) and pyrethrum would probably cause significant mortalities if it found its way into estuaries from agricultural runoff. Nonylphenol is an anthropogenic pollutant that regularly occurs in water bodies, it is an oestrogen mimic that is produced during the sewage treatment of non-ionic surfactants and can affect *Corophium volutator* (Brown *et al.*, 1999). Nonylphenol is a hydrophobic molecule and often becomes attached to sediment in water bodies. This will make nonylphenol available for ingestion by *Corophium volutator* in estuaries where much of the riverine water-borne sediment flocculates and precipitates out of suspension to form mudflats. Nonylphenol is not lethal to *Corophium volutator* but does reduce growth and has the effect of causing the secondary antennae of males to become enlarged which can make the amphipods more vulnerable to predators (Brown *et al.*, 1999). *Corophium volutator* is killed by 1% ethanol if exposed for 24 hours or more but can withstand higher concentrations in short pulses. Such short pulses, however, have the effect of rephasing the diel rhythm and will delay the timing of swimming activity for the duration of the ethanol pulse (Harris & Morgan, 1984b).

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
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No evidence was found to support an assessment of biotope sensitivity. *Corophium volutator* readily absorbs radionuclides such as americium and plutonium from water and contaminated sediments (Miramand *et al.*, 1982). However, the effect of contamination of the individuals was not known but accumulation through the food chain was assumed (Miramand *et al.*, 1982).

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
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This pressure is **Not assessed**.

De-oxygenation	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High
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Brafield (1964) concluded that the most significant factor influencing the oxygenation is the drainage of the beach which, in turn, is determined by the slope and particle size. Oxygen depletion becomes a severe problem at all states of the tide on only the very finest grained beaches, and as a general rule, if the percentage of particles of less than 0.25 mm median diameter exceeds 10% of a sediment, then the oxygen concentration of its interstitial water will be less than 20% of the air saturation level, and will drop rapidly during low tide periods (Brafield, 1964). Fine sands tend to have lower oxygen levels because their lower permeability leads to the trapping of detritus which, together with the large surface area for microbial colonization, leads to higher oxygen uptake (Eagle, 1983).

Laboratory studies by Khayrallah (1977) on *Bathyporeia pilosa*, indicated that it has a relatively poor resistance to conditions of hypoxia in comparison to other interstitial animals. However, Mettam (1989) and Sandberg (1997) suggest that *Bathyporeia pilosa* can survive short-term hypoxia. In a series of experiments Gamenick *et al.* (1996) suggested that *Corophium volutator* is highly sensitive to hypoxia and suffers 50% mortality after just 4 hours in hypoxic conditions, or in 2 hours if there is rapid build-up of sulphide (Gamenick *et al.*, 1996). These results are largely in concordance with other work by Gamble (1970) who found that survival rates were temperature dependent with individuals surviving longer at lower temperatures. The level of oxygen was not assessed by Gamenick *et al.* (1996) and the description of the experimental set-up suggests that anoxic test conditions were used rather than hypoxic. Gamble (1970) found that at 5°C most individuals were inactive after 30 minutes exposure to anaerobic seawater and that mortality occurred later, the inactivity may have allowed the species to survive longer (Gamble, 1970). At 10°C, *Corophium volutator* survived for 22 h while *Corophium arenarium* survived 25 h.

Sensitivity assessment. Exposure to air and the mixing effect of tidal currents will limit the intensity and duration of exposure to deoxygenated waters. The species characterizing the biotope are also mobile and able to migrate vertically or shorewards to escape unsuitable conditions. Biotope resistance is therefore assessed as 'High' and resilience as 'High' (by default), so that the biotope is considered to be 'Not sensitive'.

Nutrient enrichment	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low
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In-situ primary production is limited to microphytobenthos within and on sediments and the high levels of sediment mobility due to resuspension in strong tidal streams may limit the level of primary production as abrasion would be likely to damage diatoms (Delgado *et al.*, 1991).

Sensitivity assessment. In general primary production is low and this biotope is species poor. Nutrient level is not a key factor structuring the biotope at the pressure benchmark. Biotope resistance is therefore assessed as 'High', resilience as 'High' (by default), and the biotope is considered to be 'Not sensitive'. Changes in nutrient status may indirectly affect this biotope where these result in changes in diatom production and inputs of macroalgal debris.

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

The biotope description for the biotope LS.LSa.MoSa.AmSco (JNCC, 2015) notes that inputs of organic matter seeping from the driftline can result in high abundances of *Bathyporeia pilosa*. Organic matter is unlikely to accumulate as sediment mobility and re-suspension by tidal currents will result in removal of fine organic matter deposits.

An increase in organic enrichment that exceeded the pressure benchmark may impact the habitat and biological assemblage, particularly in more sheltered areas where deposits can accumulate. For instance, prior to the introduction of a sewage treatment scheme in the Firth of Forth (Scotland), the communities of several sandy beaches were considerably modified by gross sewage pollution (Read *et al.*, 1983).

Sensitivity assessment. At the pressure benchmark organic inputs are likely to represent a food subsidy for the characterizing species and are unlikely to significantly affect the structure of the biological assemblage or impact the physical habitat. Biotope sensitivity is therefore assessed as 'High' and resilience as 'High' (by default), and the biotope is therefore considered to be 'Not sensitive'.

A Physical Pressures

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

The biotope is characterized by the sedimentary habitat (JNCC, 2015), a change to an artificial or rock substratum would alter the character of the biotope leading to reclassification and the loss of the sedimentary habitat and the characterizing amphipods and associated species such as the

Baltic tellin, *Limecola balthica*.

Sensitivity assessment. Based on the loss of the biotope, 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

The pressure benchmark refers to the simplified Folk classification developed by Long (2006) and the UK Marine Habitat Classification Littoral and Sublittoral Sediment Matrices (Connor *et al.*, 2004). The biotope is associated with medium to fine sands and muddy sand, a change at the pressure benchmark, therefore, refers to a change to muds and sandy muds or coarse sediments (gravelly sands and sandy gravels and gravels) and mixed sediments. The species present have specific sediment preferences related to burrowing or feeding. Experiments by Van Tomme *et al.* (2013) have shown that the optimal sedimentary habitats for *Bathyporeia pilosa* were fine sands, at a subtidal dredge disposal site the change to a finer muddy sediment led to a reduction in the abundance of *Bathyporeia pilosa* (Witt *et al.*, 2004). Habitat partitioning has been observed between *Corophium volutator* and *Corophium arenarium* on the basis of sediments, although modified by disturbance from *Arenicola marina* and *Cerastoderma edule* (see removal of target species). Where the two *Corophium* species occur together *Corophium arenarium* is associated with areas of sandy sediment whilst *Corophium volutator* prefers muddier sediments (Watkin, 1941; Flach, 1993).

Sensitivity assessment. A change in sediment character would alter the character of the biotope which would be re-classified as another biotope type. A change in sediment type to a coarser, more mobile sediment such as coarse sands would favour *Bathyporeia pilosa* and other species present in mobile coarse sediments such as oligochaetes or the polychaetes *Scolecopsis squamata* and the biotope would be reclassified within the LS.LSa.MoSa group. The presence of gravels could lead to the development of LS.LCS.Sh biotopes. Alternatively, where changes in hydrodynamic factors lead to the establishment of muddy sediment biotopes *Corophium volutator* already present in this biotope may be favoured while the habitat would be unsuitable for *Corophium arenarium* and *Bathyporeia pilosa*. The biotope present may revert to a more species rich, polychaete and bivalve dominated, shore depending on local conditions and larval transport. Based on the loss of the biotope, 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').

Habitat structure changes - removal of substratum (extraction)

None

Q: High A: Low C: High

High

Q: High A: Low C: High

Medium

Q: High A: Low C: High

Removal of the substratum to 30 cm would result in the loss of the characterizing species *Corophium volutator* is characteristic of muddy substrata while *Corophium arenarium* prefers sand; both construct U-shaped burrows in the surface 10 cm of the sediment (Meadows, 1964). *Bathyporeia pilosa* burrows between 0-10 cm in sediments (Nicolaisen & Kannevorff, 1969)

Sensitivity assessment. Removal of the sediment to 30 cm would remove the key characterizing species and their habitat. Resistance is therefore assessed as 'None'. Resilience is assessed as 'High' if adjacent populations are present to support recolonization through adult migration and

reproduction, so that sensitivity is assessed as 'Medium'. However, if populations were removed over a wide area recovery could be prolonged and is assessed as 'Medium', so that sensitivity is assessed as 'Medium'. The less precautionary assessment is considered more representative but the caveats outlined in the resilience section should be considered and this assessment may underestimate sensitivity.

Abrasion/disturbance of the surface of the substratum or seabed

Low

Q: High A: High C: High

High

Q: High A: High C: High

Low

Q: High A: High C: High

The burrowing life habits of *Corophium volutator* are likely to provide some protection from abrasion at the surface only. However, any abrasion or physical disturbance is likely to reduce the density of *Corophium* spp. by emigration and increased mortality. For example, the sediment turnover caused by cockles and lugworms disturbs the burrows of *Corophium volutator* and caused a significant negative effect on *Corophium volutator* density as a result of increased rate of swimming making the amphipod more vulnerable to predation (Flach & De Bruin, 1993, 1994). *Corophium arenarium* is also sensitive to sediment disturbance from bioturbating species (Flach, 1993).

A number of studies have assessed the effects of trampling on other intertidal amphipods and these assessments are used as a proxy. Comparisons between shores with low and high levels of trampling found that the amphipod *Bathyporeia pelagica* is sensitive to human trampling, other species including *Pontocrates arenarius* and the isopod *Eurydice affinis* also decreased in response to trampling but *Bathyporeia pelagica* appeared to be the most sensitive (Reyes-Martínez *et al.*, 2015). Changes in abundance of talitrid amphipods on urban beaches subject to high levels of recreational use was also observed by Bessa *et al.* (2014), this study compared abundances between samples taken ten years apart and thus the trends observed were not directly attributable to trampling vs beach cleaning or other pressures although they illustrate a general trend in density patterns as recreational use increases. Ugolini *et al.* (2008) carried out a controlled trampling experiment on *Talitrus saltator*. Plastic cylinders of 110 cm diameter (area 0.95 m²) were placed in the sand and all individuals trapped and counted, and 400 steps were made in a cylinder in 15 minutes after the amphipods had reburied. The trampling rate was based on observed number of beach users and therefore represents a realistic level of exposure. Alive individuals were counted at the end of the experiment and 24 hours after. Trampling significantly reduced abundance of the amphipods and after 24 hours the percentage of surviving amphipods dropped to almost zero, while survival rates of control (untrampled) amphipods were unaffected. Abrasion and compaction can therefore kill buried amphipods within sediments.

Sensitivity assessment. The trampling experiment (Ugolini *et al.*, 2008) represents a high intensity of abrasion with multiple steps on the sediment within a short time period. The experiment does, however, demonstrate that amphipods are sensitive to abrasion and compaction of the sediment and these results are observed by comparisons between heavily and lightly used areas (Reyes-Martínez *et al.*, 2015; Bessa *et al.*, 2014). *Corophium* spp. are also sensitive to abrasion and sediment disturbance. Resistance to a single abrasion event is therefore assessed as 'Low' based on the characterizing species. Resilience is assessed as 'High', based on migration from adjacent populations and in-situ reproduction by surviving amphipods. Sensitivity is therefore assessed as 'Low'. This assessment may underestimate sensitivity to high-levels of abrasion (repeated events within a short period). The trampling evidence and the evidence for penetration from mobile gears (see below) differ in the severity (resistance) of impact. This may be due to different levels of

intensity (multiple trampling/abrasion events vs single penetration/towed gear impacts) or the nature of the pressure. Abrasion from trampling also involves a level of compaction that could collapse burrows and damage species through compression. Penetration may, however, break sediments open allowing mobile species to escape or species may be pushed forwards from towed gear by a pressure wave where this is deployed subtidally (Gilkinson *et al.*, 1998). This suggests that exposure at different states of tide will mediate impacts. Both risk assessments are considered applicable to single events based on the evidence and the sensitivity assessment for both pressures is the same although resistance differs.

Penetration or disturbance of the substratum subsurface

Low

Q: High A: High C: Medium

High

Q: High A: Low C: High

Low

Q: High A: Low C: Medium

In the Columbia river, no significant difference was found in *Corophium volutator* densities before and after dredging a channel and no difference between the dredged site and a control site (McCabe *et al.*, 1998). Presumably, the dredging did cause mortality of *Corophium volutator* but recolonization was so rapid that no difference was found. The extraction of cockles by sediment raking and mechanical disturbance and digging for lugworms for bait is likely to cause significant mortality of *Corophium volutator*. Bait digging was found to reduce *Corophium volutator* densities by 39%, juveniles were most affected suffering a 55% reduction in dug areas (Shepherd & Boates, 1999).

Bergman and Santbrink (2000) found that direct mortality of gammarid amphipods, following a single passage of a beam trawl (in silty sediments where penetration is greater) was 28%. Similar results were reported from experiments in shallow, wave disturbed areas, using a toothed, clam dredge. *Bathyporeia* spp. experienced a reduction of 25% abundance in samples immediately after intense clam dredging, abundance recovered after 1 day (Constantino *et al.*, 2009). Experimental hydraulic dredging for razor clams resulted in no statistically significant differences in *Bathyporeia elegans* abundances between treatments after 1 or 40 days (Hall *et al.*, 1990), suggesting that recovery from effects was very rapid. Ferns *et al.* (2000) examined the effects of a tractor-towed cockle harvester on benthic invertebrates and predators in intertidal plots of muddy and clean sand. Harvesting resulted in the loss of a significant proportion of the most common invertebrates from both areas. In the muddy sand, the population of *Bathyporeia pilosa* remained significantly depleted for more than 50 days, whilst the population in clean sand recovered more quickly. These results agree with other experimental studies that clean sands tend to recover more quickly than other habitat types with higher proportions of fine sediment (Dernie *et al.*, 2003).

Sensitivity assessment. Based on the evidence above it is considered that *Bathyporeia* spp. may be more resistant but *Corophium* species are likely to have 'Low' resistance to this pressure and resistance of the biotope is therefore assessed as 'Low'. Recovery is assessed as 'High' and sensitivity is therefore categorised 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

The characterizing species live within the sand and are unlikely to be directly affected by an increased concentration of suspended matter in the water column. Within the mobile sands habitat storm events or spring tides may re-suspend or transport large amounts of material and therefore species are considered to be adapted to varying levels of suspended solids.

Bathyporeia spp. feed on diatoms within the sand grains (Nicolaisen & Kannevorff, 1969), an increase in suspended solids that reduced light penetration could alter food supply. However, diatoms are able to photosynthesize while the tide is out and therefore a reduction in light during tidal inundation may not affect this food source, depending on the timing of the tidal cycle. *Bathyporeia* spp. may be regular swimmers within the surf plankton, where the concentration of suspended particles would be expected to be higher (Fincham, 1970a).

Sensitivity assessment. Increased organic solids in suspension may provide food to the key characterizing species. Increased inorganic suspended solids may increase abrasion but it is likely that the infaunal species would be unaffected. The biotope is considered to be 'Not sensitive' to a decrease in suspended solids that does not affect sediment transport and supply to the biotope. Biotope resistance is assessed as 'Medium' as some effects on feeding and diatom productivity may occur from increases in suspended solids, resilience is assessed as 'High', following a return to usual conditions and sensitivity is assessed as 'Low'. This more precautionary assessment is presented in the table. Indirect effects such as deposition, erosion and associated sediment change that may result from changes in suspended solids in the long-term are assessed separately.

Smothering and siltation rate changes (light)

Medium

Q: High A: Medium C: Low

High

Q: High A: Low C: High

Low

Q: High A: Low C: Low

The pressure benchmark for light deposition refers to the addition of a relatively thin layer of deposits in a single event. Species adapted to coarse sediments may not be able to burrow through fine sediments, or experienced reduced burrowing ability. For example, Bijkerk (1988, results cited from Essink, 1999) found that the maximal overburden through which *Bathyporeia* could migrate was approximately 20 cm in mud and 40 cm in sand. No further information was available on the rates of survivorship or the time taken to reach the surface.

Corophium volutator was categorized in AMBI sedimentation Group III – 'species insensitive to higher amounts of sedimentation, but don't easily recover from strong fluctuations in sedimentation' (Gittenberger & Van Loon, 2011). Experimental fences placed on mudflats caused sedimentation rates of 2-2.5 cm/month and reduced *Corophium volutator* densities from approximately 1700 m⁻² to approximately 400 m⁻². In areas without fences, *Corophium volutator* numbers increased from approximately 1700 per m² to 3500 per m² (Turk & Risk, 1981).

Sensitivity assessment. As the biotope is associated with shores exposed to strong tidal streams (JNCC, 2015), some sediment removal will occur, mitigating the effect of deposition. *Bathyporeia pilosa* is likely to be able to burrow through a 5 cm layer of fine sediments. Burrowing ability of *Corophium* spp. was unclear. Biotope resistance was therefore assessed as a precaution as 'Medium' as a deposit of 5 cm could negatively affect *Corophium* spp. Resilience was assessed as 'High' (by default). Biotope sensitivity is therefore assessed as 'Low' to this pressure. Repeated deposits or deposits over a large area or in sheltered systems that were shifted by wave and tidal action may result in sediment change (see physical change pressure).

Smothering and siltation rate changes (heavy)

Low

Q: High A: High C: Low

High

Q: High A: Low C: Medium

Low

Q: High A: Low C: Low

Studies have found that beach 'replenishment' or 'nourishment' that involves the addition of sediments on beaches can have a number of impacts on the infauna (Peterson *et al.*, 2000; Peterson *et al.*, 2006). Impacts are more severe when the sediment added differs

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

Corophium spp. and *Bathyporeia pilosa* are probably sensitive to surface vibrations but little is known about the effects of noise on invertebrates. However, the species are unlikely to be affected by noise pollution and so the biotope is assessed as 'Not sensitive'.

Introduction of light or shading

Medium

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: Low C: Low

As this feature is not characterized by the presence of primary producers it is not considered that shading would alter the character of the habitat. No specific evidence was found to assess sensitivity of the characterizing species to this pressure. Changes in light levels may, however, affect activity rhythms of the invertebrates. *Bathyporeia* spp. emerge at night and therefore an increase in light may inhibit activity, particularly at night when they emerge from the sediment and are most active (Jelassi *et al.*, 2015; Ayari, 2015). Hartwick (1976), for example, found that artificial lighting interfered with learning or orientation cues by Talitrids. *Corophium* spp. live in burrows and may not be affected by changes in light although males emerge and crawl over sediments (Meadows, 1964).

Orientation by light has been well studied for intertidal amphipods (particularly *Talitrus saltator*). Intertidal amphipods orientate themselves by a range of factors that include (but are not limited to) visual cues based on solar or astronomic cues such as the moon and the geomagnetic field (Scapini, 2014). Activity patterns are also linked to internal biological clocks that respond to diel, tidal, lunar and seasonal cycles, so that animals are active during the most suitable time of day or night (Scapini, 2014). The introduction of light or an increase in shading could therefore alter behavioural patterns and navigation. As responses may be species specific or vary according to local factors or individual needs such as feeding, mating, it is not possible to provide a simple assessment for this species. Some sensitivity is however likely if incident light levels were altered. This will depend, however, on the footprint and intensity of impact. Fanini *et al.* (2014) found no difference in abundance of *Talitrus saltator* between Greek beaches that frequently hosts small scale beach-parties with lights at night and those that were not used in this way.

Changes in light and level of shade may indirectly affect the characterizing amphipods through changes in food supply via photosynthesis of diatoms within sediments. Benthic microalgae play a significant role in system productivity and trophic dynamics, as well as habitat characteristics such as sediment stability (Tait & Dipper, 1998). Shading could prevent photosynthesis leading to death or migration of sediment diatoms altering sediment cohesion and food supply to the characterizing amphipods.

Sensitivity assessment. Changes in light are not considered to directly affect the biotope, however, some changes in the behaviour of *Bathyporeia* spp. and food supply for the characterizing amphipods could result. Biotope resistance is assessed as 'Medium' and resilience is assessed as 'High'. Biotope sensitivity is therefore assessed as 'Low'.

Barrier to species movement

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

As the amphipods that characterize this biotope have benthic dispersal strategies (via brooding),

water transport is not a key method of dispersal over wide distances, as it is for some marine invertebrates that produce pelagic larvae. Where populations were removed changes in water transport of adults may, however, be reduced by changes in local hydrodynamics preventing recolonization. Conversely, a barrier may enhance local connectivity by reducing the loss of adults from the system.

Sensitivity assessment. The biotope (based on the brooding life strategy of the characterizing species) is considered to have 'High' resistance to the presence of barriers that lead to a reduction in tidal excursion, resilience is assessed as 'High' (by default) and the biotope is considered to be 'Not sensitive'.

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: Low A: Low C: Low

In substratum choice experiments, *Corophium volutator* preferred substrata independently of whether the dishes were in darkness or illuminated (Meadows, 1964). *Bathyporeia pilosa* emerges from the sediments at night and are unlikely to be disturbed although like many species they may flee from movements. Therefore, visual disturbance is probably '**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 this biotope are not cultivated or translocated. This pressure is therefore considered 'Not relevant' to this biotope group.

Introduction or spread of invasive non-indigenous species

Medium

Q: High A: High C: NR

Very Low

Q: Low A: NR C: NR

Medium

Q: Low A: Low C: Low

The sand sediments characterizing this biotope are likely to be mobile due to strong tidal streams and contain little organic matter, this and the biotope occurrence in variable salinity, limits establishment of marine and coastal invasive non-indigenous species as the habitat conditions are unsuitable for most species, as exemplified by the low species richness characterizing this biotope. On the upper shore colonization of sandy mud flats by cord grass *Spartina anglica* may, however, affect the distribution of amphipods. In the Dovey Estuary the spread of this species has restricted the distribution of *Corophium* spp. to creeks and drainage channels (Fish & Mills, 1979).

Sensitivity assessment. Colonization of the upper shore by *Spartina anglica* may result in loss of the characterizing amphipods. However, this is likely to only affect upper shore examples; biotope resistance is therefore assessed as 'Medium'. Biotope resilience is assessed as 'High' following removal of the invasive cord grass. However, removal may require human intervention of some other disturbance and resilience is therefore assessed as 'Very low'. This biotope is therefore considered to have 'Medium' sensitivity to this pressure.

Introduction of microbial pathogens

Low

Q: Low A: NR C: NR

High

Q: High A: Low C: High

Low

Q: Low A: Low C: Low

Amphipods may be infected by a number of parasites or pathogens that alter population numbers through changes in host condition, growth, behaviour and reproduction (Green Extabe & Ford, 2014). Infection by acanthocephalan larvae, for example, may alter behaviour and responses of gammarid amphipods (Bethel & Holmes, 1977). The amphipod *Orchestia gammarellus* is host to the parasitic protist *Marteilia* which has a feminizing effect on populations, with higher ratios of females and intersex males in infected, estuarine populations (Ginsburger-Vogel & Desportes, 1979).

Corophium volutator is parasitized by several species of trematodes in Europe and North American (McCurdy *et al.*, 2000a; McCurdy *et al.*, 2000b; Mouritsen & Jensen, 1997, cited in Shim *et al.*, 2013). Mass mortalities of *Corophium volutator* have been associated with infestation by trematodes in the Wadden Sea (Jensen & Mouritsen, 1992). A dense field of *Corophium volutator* disappeared completely, and the density of the mud snail *Hydrobia ulvae* declined by 40% during spring 1990 as a result of an epizootic by trematodes. High spring temperature accelerated both the development rate and the release of infective larval stages of an infectious trematode from the snail *Hydrobia ulvae* (Poulin & Mouritsen, 2006). Studies conducted in the Baltic Sea suggested that increased parasitism by trematode species has a detrimental effect on local amphipods (Meissner & Bick, 1999; Mouritsen & Jensen, 1997 cited in Shim *et al.*, 2013).

Sensitivity assessment. Although no records of the biotope being affected by the introduction of microbial pathogens in the British Isles, mass mortality of characterizing species *Corophium volutator* has been observed (Jensen & Mouritsen, 1992). The biotope character is therefore considered to be at some risk and resistance is judged to be 'Low' as *Bathyporeia* spp. and other associated species such as *Hydrobia ulvae* may be affected increasing the overall impact of the biological assemblage. Resilience is assessed as 'High' (where the disease-causing organisms decline) and the biotope is assessed as having 'Low' sensitivity to the introduction of microbial pathogens. Sensitivity will be higher where pathogens persist, preventing recovery.

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

The characterizing species are not directly targeted and therefore this pressure is not considered relevant. Some polychaetes and bivalves that characterize intertidal sand flats and muddy sand habitats such as *Arenicola marina* and *Cerastoderma edule* may reduce abundance of *Corophium volutator* and *Corophium arenarium* (Flach, 1993). Removal of these species through recreational and commercial harvesting may therefore increase the suitability of some areas for the characterizing species. However, this effect is not assessed for this biotope.

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. The characterizing species in this biotope are highly likely to be damaged or directly removed by static or mobile gears that are targeting other species (see abrasion and penetration pressures).

The loss of the key characterizing species through unintentional removal would alter the character of the biotope and may lead to reclassification to a similar, species-poor biotope such as LS.LSa.MoSa.BarSa. The ecosystem services such as secondary production and food for higher trophic levels such as birds provided by the amphipods would be lost. A dense field of *Corophium volutator* in the Wadden Sea disappeared completely during spring 1990 as a result of an epizootic by trematodes. The collapse of its population led to drastic changes in erosion patterns, sediment characteristics, and microtopography, as well as marked changes in the abundance of other macrofaunal species in the mudflat (Poulin & Mouritsen, 2006).

Sensitivity assessment. Biotope resistance to loss of the characterizing species is assessed as 'Low' as the burrowing lifestyle and mobility of characterizing species mean that a proportion of the population may escape incidental removal. Resilience is assessed as 'High' based on in-situ recovery and migration from adjacent populations and sensitivity is therefore assessed as 'Low'.

Bibliography

- Arendse, M.C. & Barendregt, A., 1981. Magnetic orientation in the semi-terrestrial amphipod, *Orchestia cavimana*, and its interrelationship with photo-orientation and water loss. *Physiological Entomology*, **6** (4), 333-342.
- Ayari, A., Jelassi, R., Ghemari, C. & Nasri-Ammar, K., 2015. Locomotor activity patterns of two sympatric species *Orchestia montagui* and *Orchestia gammarellus* (Crustacea, Amphipoda). *Biological Rhythm Research*, **46** (6), 863-871.
- Bat, L., Raffaelli, D. & Marr, I.L., 1998. The accumulation of copper, zinc and cadmium by the amphipod *Corophium volutator* (Pallas). *Journal of Experimental Marine Biology and Ecology*, **223**, 167-184.
- 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.
- Bessa, F., Goncalves, S.C., Franco, J.N., Andre, J.N., Cunha, P.P. & Marques, J.C., 2014. Temporal changes in macrofauna as response indicator to potential human pressures on sandy beaches. *Ecological Indicators*, **41**, 49-57.
- Bethel, W.M. & Holmes, J.C., 1977. Increased vulnerability of amphipods to predation owing to altered behavior induced by larval acanthocephalans. *Canadian Journal of Zoology*, **55** (1), 110-115.
- Bijkerk, R., 1988. Ontsnappen of begraven blijven: de effecten op bodemdieren van een verhoogde sedimentatie als gevolg van baggerwerkzaamheden: literatuuronderzoek: RDD, Aquatic ecosystems.
- Booth, A. M., Hansen, B.H., Frenzel, M., Johnsen, H. & Altin, D., 2015. Uptake and toxicity of methylmethacrylate-based nanoplastic particles in aquatic organisms. *Environmental Toxicology and Chemistry*, **9999**, 1-9.
- Brafield, A.E., 1964. The oxygen content of interstitial water in sandy shores. *Journal of Animal Ecology*, **33**, 97-116.
- Brils, J.M., Huwer, S.L., Kater, B.J., Schout, P.G., Harmsen, J., Delvigne, G.A.L. & Scholten, M.C.T., 2002. Oil effect in freshly spiked marine sediment on *Vibrio fischeri*, *Corophium volutator*, and *Echinocardium caudatum*. *Environmental Toxicology and Chemistry*, **21**, 2242-2251.
- Brown, R.J., Conradi, M. & Depledge, M.H., 1999. Long-term exposure to 4-nonylphenol affects sexual differentiation and growth of the amphipod *Corophium volutator* (Pallas, 1766). *Science of the Total Environment*, **233**, 77-88.
- Bryant, V., Newbery, D.M., McLusky, D.S. & Campbell, R., 1985. Effect of temperature and salinity on the toxicity of arsenic to three estuarine invertebrates (*Corophium volutator*, *Macoma balthica*, *Tubifex costatus*). *Marine Ecology Progress Series*, **24**, 129-137.
- 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/>
- Conradi, M. & Depledge, M.H., 1999. Effects of zinc on the life-cycle, growth and reproduction of the marine amphipod *Corophium volutator*. *Marine Ecology Progress Series*, **176**, 131-138.
- Constantino, R., Gaspar, M., Tata-Regala, J., Carvalho, S., Cúrdia, J., Drago, T., Taborda, R. & Monteiro, C., 2009. Clam dredging effects and subsequent recovery of benthic communities at different depth ranges. *Marine Environmental Research*, **67**, 89-99.
- Davenport, J. & Davenport, J.L., 2005. Effects of shore height, wave exposure and geographical distance on thermal niche width of intertidal fauna. *Marine Ecology Progress Series*, **292**, 41-50.
- de-la-Ossa-Carretero, J., Del-Pilar-Ruso, Y., Loya-Fernández, A., Ferrero-Vicente, L., Marco-Méndez, C., Martínez-García, E. & Sánchez-Lizaso, J., 2016. Response of amphipod assemblages to desalination brine discharge: impact and recovery. *Estuarine, Coastal and Shelf Science*, **172**, 13-23
- Delgado, M., De Jonge, V. & Peletier, H., 1991. Effect of sand movement on the growth of benthic diatoms. *Journal of Experimental Marine Biology and Ecology*, **145** (2), 221-231.
- 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.
- Drolet, D., Kennedy, K. & Barbeau, M.A., 2013. Winter population dynamics and survival strategies of the intertidal mudflat amphipod *Corophium volutator* (Pallas). *Journal of Experimental Marine Biology and Ecology*, **441**, 126-137.
- Eagle, G.A., 1983. The chemistry of sandy beach ecosystems - a review. In *Sandy beaches as ecosystems* (ed. A. McLachlan & T. Erasmus), pp. 203-224. The Hague, Netherlands: Junk.
- Eltringham, S.K., 1971. *Life in mud and sand*. London: The English Universities Press Ltd.
- Essink, K., 1999. Ecological effects of dumping of dredged sediments; options for management. *Journal of Coastal Conservation*, **5**, 69-80.
- Fanini, L., Zampicini, G. & Pafilis, E., 2014. Beach parties: a case study on recreational human use of the beach and its effects on mobile arthropod fauna. *Ethology Ecology & Evolution*, **26** (1), 69-79.
- 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.

- Fincham, A.A., 1970a. Amphipods in the surf plankton. *Journal of the Marine Biological Association of the United Kingdom*, **50**, 177-198.
- Fish, J.D. & Fish, S., 1978. Observations on an annual migration of *Bathyporeia pelagica* (Amphipoda, Haustoriidae). *Crustaceana*, **35**, 215-221.
- Fish, J.D. & Mills, A., 1979. The reproductive biology of *Corophium volutator* and *C. arenarium* (Crustacea: Amphipoda). *Journal of the Marine Biological Association of the United Kingdom*, **59**, 355-368.
- Fish, J.D. & Preece, G.S., 1970. The annual reproductive patterns of *Bathyporeia pilosa* and *Bathyporeia pelagica* (Crustacea: Amphipoda). *Journal of the Marine Biological Association of the United Kingdom*, **50**, 475-488.
- Flach, E.C., 1993. The distribution of the amphipod *Corophium arenarium* in the Dutch Wadden Sea- relationships with sediment composition and the presence of cockles and lugworms. *Netherlands Journal of Sea Research*, **31** (3), 281-290.
- Flach, E.C. & De Bruin, W., 1993. Effects of *Arenicola marina* and *Cerastoderma edule* on distribution, abundance and population structure of *Corophium volutator* in Gullmarsfjorden western Sweden. *Sarsia*, **78**, 105-118.
- Flach, E.C. & De Bruin, W., 1994. Does the activity of cockles, *Cerastoderma edule* (L.) and lugworms, *Arenicola marina* (L.), make *Corophium volutator* Pallas more vulnerable to epibenthic predators: a case of interaction modification? *Journal of Experimental Marine Biology and Ecology*, **182**, 265-285.
- Forbes, M.R., Boates, S.J., McNeil, N.L. & Brison, A.E., 1996. Mate searching by males of the intertidal amphipod *Corophium volutator* (Pallas). *Canadian Journal of Zoology*, **74**, 1479-1484.
- Gamble, J., 1970. Anaerobic survival of the crustaceans *Corophium volutator*, *C. arenarium* and *Tanais chevreuxi*. *Journal of the Marine Biological Association of the United Kingdom*, **50** (03), 657-671.
- Gamenick, I., Jahn, A., Vopel, K. & Giere, O., 1996. Hypoxia and sulphide as structuring factors in a macrozoobenthic community on the Baltic Sea shore: Colonization studies and tolerance experiments. *Marine Ecology Progress Series*, **144**, 73-85.
- Gerdol, V. & Hughes, R.G., 1993. Effect of the amphipod *Corophium volutator* on the colonisation of mud by the halophyte *Salicornia europaea*. *Marine Ecology Progress Series*, **97**, 61-69.
- Gilkinson, K., Paulin, M., Hurley, S. & Schwinghamer, P., 1998. Impacts of trawl door scouring on infaunal bivalves: results of a physical trawl door model/dense sand interaction. *Journal of Experimental Marine Biology and Ecology*, **224** (2), 291-312.
- Ginsburger-Vogel, T. & Desportes, I., 1979. Structure and biology of *Marteilia* sp. in the amphipod *Orchestia gammarellus*. *Marine Fisheries Review*, **41**, 3-7.
- Green Etxabe, A. & Ford, A., 2014. Do demon shrimp carry demon parasites? *Freshwater Biological Association News*, **62**, 10-11.
- Hall, S.J., Basford, D.J. & Robertson, M.R., 1990. The impact of hydraulic dredging for razor clams *Ensis* spp. on an infaunal community. *Netherlands Journal of Sea Research*, **27**, 119-125.
- Harris, G.J. & Morgan, E., 1984a. The effects of salinity changes on the endogenous circa-tidal rhythm of the amphipod *Corophium volutator* (Pallas). *Marine Behaviour and Physiology*, **10**, 199-217.
- Harris, G.J. & Morgan, E., 1984b. The effects of ethanol, valinomycin and cycloheximide on the endogenous circa-tidal rhythm of the estuarine amphipod *Corophium volutator* (Pallas). *Marine Behaviour and Physiology*, **10**, 219-233.
- Hartwick, R., 1976. Beach orientation in talitrid amphipods: capacities and strategies. *Behavioral Ecology and Sociobiology*, **1** (4), 447-458.
- Hayward, P.J. 1994. *Animals of sandy shores*. Slough, England: The Richmond Publishing Co. Ltd. [Naturalists' Handbook 21.]
- Hughes, R.G., 1988. Dispersal by benthic invertebrates: the *in situ* swimming behaviour of the amphipod *Corophium volutator*. *Journal of the Marine Biological Association of the United Kingdom*, **68**, 565-579.
- Huthnance, J., 2010. Ocean Processes Feeder Report. London, DEFRA on behalf of the United Kingdom Marine Monitoring and Assessment Strategy (UKMMAS) Community.
- Jelassi, R., Bohli-Abderrazak, D., Ayari, A. & Nasri-Ammar, K., 2015. Endogenous activity rhythm in *Talitrus saltator*, *Britorchestia brito* (Crustacea, Amphipoda) and *Tylos europaeus* (Crustacea, Isopoda) from Barkoukech Beach (Tabarka, Tunisia). *Biological Rhythm Research*, **46** (6), 873-886.
- Jensen, K.T. & Kristensen, L.D., 1990. A field experiment on competition between *Corophium volutator* (Pallas) and *Corophium arenarium* Crawford (Crustacea: Amphipoda): effects on survival, reproduction and recruitment. *Journal of Experimental Marine Biology and Ecology*, **137**, 1-24.
- Jensen, K.T. & Mouritsen K.N., 1992. Mass mortality in two common soft bottom invertebrates, *Hydrobia ulvae* and *Corophium volutator*, the possible role of trematodes. *Helgolander Meeresuntersuchungen*, **46**, 329-339.
- 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/>
- Khayrallah, N.H. & Jones, A.M., 1980b. The ecology of *Bathyporeia pilosa* (Amphipoda: Haustoriidae) in the Tay Estuary. 2. Factors affecting the micro-distribution. *Proceedings of the Royal Society of Edinburgh. B*, **78**, 121-130.
- Khayrallah, N.H., 1977. *Studies on the ecology of Bathyporeia pilosa in the Tay Estuary.*, PhD thesis, University of Dundee.
- Long, D., 2006. BGS detailed explanation of seabed sediment modified Folk classification. Available from:

http://www.emodnet-seabedhabitats.eu/PDF/GMHM3_Detailed_explanation_of_seabed_sediment_classification.pdf

- Maurer, D., Keck, R.T., Tinsman, J.C. & Leathem, W.A., 1981. Vertical migration and mortality of benthos in dredged material: Part II—crustacea. *Marine Environmental Research*, **5** (4), 301-317.
- McLachlan, A., Jaramillo, E., Defeo, O., Dugan, J., de Ruyck, A. & Coetzee, P., 1995. Adaptations of bivalves to different beach types. *Journal of Experimental Marine Biology and Ecology*, **187** (2), 147-160.
- McLusky, D.S., 1967. Some effects of salinity on the survival, moulting, and growth of *Corophium volutator* (Amphipoda). *Journal of the Marine Biological Association of the United Kingdom*, **47**, 607-617.
- McLusky, D.S., 1968. Some effects of salinity on the distribution and abundance of *Corophium volutator* in the Ythan estuary. *Journal of the Marine Biological Association of the United Kingdom*, **48**, 443-454.
- McLusky, D.S., Bryant, V. & Campbell, R., 1986. The effects of temperature and salinity on the toxicity of heavy metals to marine and estuarine invertebrates. *Oceanography and Marine Biology: an Annual Review*, **24**, 481-520.
- Meadows, P., 1964. Substrate selection by *Corophium* species: the particle size of substrates. *The Journal of Animal Ecology*, **33**, 387-394.
- Meadows, P.S. & Ruagh, A.A., 1981. Temperature preferences and activity of *Corophium volutator* (Pallas) in a new choice apparatus. *Sarsia*, **66**, 67-72.
- Mettam, C., 1989. The life cycle of *Bathyporeia pilosa* Lindström (Amphipoda) in a stressful, low salinity environment. *Scientia Marina*, **53**, 543-550.
- Mills, A. & Fish, J., 1980. Effects of salinity and temperature on *Corophium volutator* and *C. arenarium* (Crustacea: Amphipoda), with particular reference to distribution. *Marine Biology*, **58** (2), 153-161.
- Miramand, P., Germain, P. & Camus, H., 1982. Uptake of americium and plutonium from contaminated sediments by three benthic species: *Arenicola marina*, *Corophium volutator* and *Scrobicularia plana*. *Marine Ecology Progress Series*, **7**, 59-65.
- Nicolaisen, W. & Kanneworff, E., 1969. On the burrowing and feeding habits of the amphipods *Bathyporeia pilosa* Lindström and *Bathyporeia sarsi* Watkin. *Ophelia*, **6** (1), 231-250.
- Peterson, C.H., Bishop, M.J., Johnson, G.A., D'Anna, L.M. & Manning, L.M., 2006. Exploiting beach filling as an unaffordable experiment: benthic intertidal impacts propagating upwards to shorebirds. *Journal of Experimental Marine Biology and Ecology*, **338** (2), 205-221.
- Peterson, C.H., Hickerson, D.H. & Johnson, G.G., 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. *Journal of Coastal Research*, 368-378.
- Poulin, R. & Mouritsen, K.N., 2006. Climate change, parasitism and the structure of intertidal ecosystems. *Journal of Helminthology*, **80** (2), 183-192.
- Powell, C.E., 1979. Isopods other than cyathura (Arthropoda: Crustacea: Isopoda). In *Pollution ecology of estuarine invertebrates* (ed. C.W. Hart & S.L.H. Fuller), 325-338. New York: Academic Press.
- Preece, G.S., 1971. The swimming rhythm of *Bathyporeia pilosa* (Crustacea: Amphipoda). *Journal of the Marine Biological Association of the United Kingdom*, **51**, 777-791.
- Raffaelli, D., Limia, J., Hull, S. & Pont, S., 1991. Interactions between the amphipod *Corophium volutator* and macroalgal mats on estuarine mudflats. *Journal of the Marine Biological Association of the United Kingdom*, **71**, 899-908.
- Read, P.A., Anderson, K.J., Matthews, J.E., Watson, P.G., Halliday, M.C. & Shiells, G.M., 1983. Effects of pollution on the benthos of the Firth of Forth. *Marine Pollution Bulletin*, **14**, 12-16.
- Reyes-Martínez, M.J., Ruíz-Delgado, M.C., Sánchez-Moyano, J.E. & García-García, F.J., 2015. Response of intertidal sandy-beach macrofauna to human trampling: An urban vs. natural beach system approach. *Marine Environmental Research*, **103**, 36-45.
- Roddie, B., Kedwards, T., Ashby-Crane, R. & Crane, M., 1994. The toxicity to *Corophium volutator* (Pallas) of beach sand contaminated by a spillage of crude oil. *Chemosphere*, **29** (4), 719-727.
- Scapini, F., 2014. Behaviour of mobile macrofauna is a key factor in beach ecology as response to rapid environmental changes. *Estuarine Coastal and Shelf Science*, **150**, 36-44.
- Shepherd, P.C.F. & Boates, S.J., 1999. Effects of commercial baitworm harvest on semipalmated sandpipers and their prey in the Bay of Fundy hemispheric shorebird reserve. *Conservation Biology*, **13**, 347-356.
- Shim, K.C., Koprivnikar, J. & Forbes, M.R., 2013. Variable effects of increased temperature on a trematode parasite and its intertidal hosts. *Journal of Experimental Marine Biology and Ecology*, **439**, 61-68.
- Speybroeck, J., Van Tomme, J., Vincx, M. & Degraer, S., 2008. In situ study of the autecology of the closely related, co-occurring sandy beach amphipods *Bathyporeia pilosa* and *Bathyporeia sarsi*. *Helgoland Marine Research*, **62** (3), 257-268.
- Sundborg, Å., 1956. The River Klarälven: a study of fluvial processes. *Geografiska Annaler*, **38** (2), 125-237.
- Tait, R.V. & Dipper, R.A., 1998. *Elements of Marine Ecology*. Reed Elsevier.
- Tomanová, K. & Vácha, M., 2016. The magnetic orientation of the Antarctic amphipod *Gondogeneia antarctica* is cancelled by very weak radiofrequency fields. *Journal of Experimental Biology*, **219**, 1717-1724.
- Turk, T.R. & Risk, M.J., 1981. Invertebrate populations of Cobequid Bay, Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences*, **38**, 642-648.

- Ugolini, A., Ungherese, G., Somigli, S., Galanti, G., Baroni, D., Borghini, F., Cipriani, N., Nebbiai, M., Passaponti, M. & Focardi, S., 2008. The amphipod *Talitrus saltator* as a bioindicator of human trampling on sandy beaches. *Marine Environmental Research*, **65** (4), 349-357.
- Van Tomme, J., Eede, S.V., Speybroeck, J., Degraer, S. & Vincx, M., 2013. Macrofaunal sediment selectivity considerations for beach nourishment programmes. *Marine Environmental Research*, **84**, 10-16.
- Watkin, E.E., 1941. The yearly life cycle of the amphipod, *Corophium volutator*. *The Journal of Animal Ecology*, **10**, 77-93.
- Wilson, W.H. & Parker, K., 1996. The life history of the amphipod, *Corophium volutator*: the effects of temperature and shorebird predation. *Journal of Experimental Marine Biology and Ecology*, **196**, 239-250.
- Witt, J., Schroeder, A., Knust, R. & Arntz, W.E., 2004. The impact of harbour sludge disposal on benthic macrofauna communities in the Weser estuary. *Helgoland Marine Research*, **58** (2), 117-128.