Fucus serratus and piddocks on lower eulittoral soft rock

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***Fucus serratus* and piddocks on lower eulittoral soft rock**
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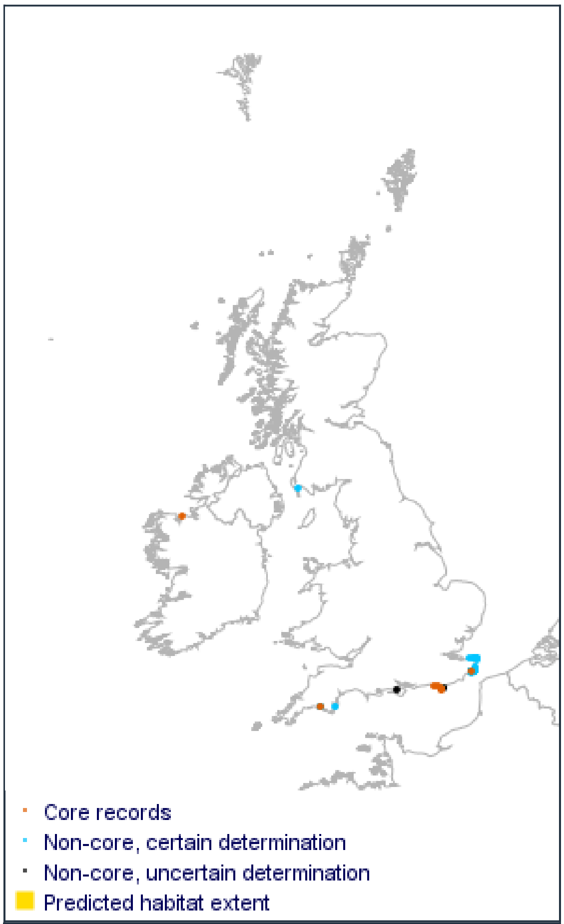

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Biotope distribution data provided by EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu)

Researched by Dr Heidi Tillin & Frances Perry **Refereed by** Admin

Summary

UK and Ireland classification

EUNIS 2008	A1.2143	*Fucus serratus* and piddocks on lower eulittoral soft rock
JNCC 2015	LR.MLR.BF.Fser.Pid	*Fucus serratus* and piddocks on lower eulittoral soft rock
JNCC 2004	LR.MLR.BF.Fser.Pid	*Fucus serratus* and piddocks on lower eulittoral soft rock
1997 Biotope	LR.MLR.BF.Fser.Pid	*Fucus serratus* and piddocks on lower eulittoral soft rock

Description

The lower eulittoral zone on soft rock shores (e.g. chalk) characterized by the wrack *Fucus serratus*. Much of the community associated with this biotope is the same as the biotope Fserr.FS, but certain taxa are specific to the soft underlying substrata. Rock-boring fauna including the piddocks *Barnea* spp., *Pholas dactylus* and *Hiatella arctica* can occur in dense aggregations. Burrowing polychaetes such as *Polydora* spp. can also occur in high numbers only visible due to their long, slender palps waving in the water as they occupy holes in the top few centimetres of the rock. A dense red algal turf occurs beneath the *Fucus serratus* and includes *Gelidium pusillum*, *Osmundea pinnatifida*, *Palmaria palmata*, *Lomentaria articulata* and *Rhodothamniella floridula*, but also calcareous algae such as *Corallina officinalis* and coralline crusts including the red-violet encrusting algae *Phymatolithon lenormandii* are present. Infaunal taxa such as various amphipods may be common amongst the seaweeds. The empty piddock holes may provide a refuge for species such as the anemone *Actinia equina* and the mussel *Mytilus edulis* while the barnacle *Semibalanus balanoides*, the limpet *Patella vulgata* can be present on the surface of the soft rock. The whelk *Nucella lapillus*, the winkles *Littorina littorea* and *Littorina mariae* and the top shell *Gibbula cineraria* are all present on the soft rock among the seaweeds. The high number of characterising species is partly caused by the low number of records used to define this biotope. The high percentage frequency of occurrence is partly a result of the low number of records. More data is needed to validate this biotope description (Connor *et al*., 2004; JNCC, 2015).

Depth range

Mid shore, Lower shore

Additional information

-

Listed By

- none -

Further information sources

Search on:

G G JNCC

Sensitivity review

Sensitivity characteristics of the habitat and relevant characteristic species

This biotope is found on the lower eulittoral zone on soft rock shores (e.g. chalk). Much of the community associated with this biotope is the same as the biotope Fserr.FS, but the soft underlying substrata also allows characterizing rock-boring bivalves including the piddocks *Barnea* spp., *Pholas dactylus* and *Hiatella arctica* to occur in this habitat (Connor *et al*., 2004). Burrowing polychaetes such as *Polydora* spp. can also occur in high numbers. A dense red algal turf occurs beneath the *Fucus serratus* canopy. and includes *Gelidium pusillum*, *Osmundea pinnatifida*, *Palmaria palmata*, *Lomentaria articulata* and *Rhodothamniella floridula*, but also calcareous algae such as *Corallina officinalis* and coralline crusts including *Phymatolithon lenormandii* are present. Infaunal taxa such as various amphipods may be common amongst the seaweeds and the empty piddock holes may provide a refuge for species. Other common rocky shore species can be present on the surface including the barnacle *Semibalanus balanoides*, the limpet *Patella vulgata*, the whelk *Nucella lapillus*, the winkles *Littorina littorea* and *Littorina mariae* and the top shell *Gibbula cineraria.*

The sensitivity assessments are based on the algae *Fucus serratus* as it is considered a key characterizing species that also structures the habitat by providing a physical habitat for attached epibionts and by sheltering other species that occur beneath the canopy where they are provided with some protection from wave action, light, temperature changes and dessication (Hill *et al*., 1998). *Fucus serratus* is also considered a key functional species, providing food for grazers. The piddocks are key characterizing species that define the biotope and provide some structure to the habitat by creating holes that may eventually be utilised by other species and thus increase biodiversity (Pinn *et al*., 2008). Development of this biotope is highly dependent on the presence of suitable substratum, the sensitivity assessments therefore also specifically consider the sensitivity of the soft rock substratum to the pressures, where appropriate.

The red algae and animal species associated with the biotope are commonly found on many different shore types and are either mobile or rapid colonizers. Although these species contribute to the structure and function of the biotope they are not considered key species and are not specifically assessed although sensitivity is discussed generally (more information on many of these can be found for other biotopes on this website).

Resilience and recovery rates of habitat

No evidence for recovery rates of this specific biotope were found. The algae within the biotope can regrow damaged fronds and blades and may regrow from perennial holdfasts or crustose bases, where these remain. The key characterizing species, *Fucus serratus* and piddocks are attached or sedentary as adults and therefore recovery of populations from impacts will be dependent on recolonization by juveniles. No direct information for recovery rates of the piddocks to perturbations was found and limited information on population dynamics and relevant life history characteristics is available. Adult piddocks remain within permanent burrows and are therefore difficult to observe and sample without destroying the burrows which has limited the extent of observation and experimentation. Greater information on dispersal and recovery was found *for Fucus serratus* and generic observations of long-term dynamics of rocky shore assemblages are relevant to this species and the associated biological assemblage.

Adults of the mobile species present in the biotope, such as limpets and littorinids may recolonize through adult migration into the habitat from adjacent populations following disturbance or via larval recolonization. Animals within the biotope such as *Semibalanus balanoides*, produce high numbers of pelagic larvae which are widely distributed by water currents, supporting recolonization from surrounding populations following disturbances. Conversely the characterizing red and brown macroalgae generally produce eggs which sink rapidly to the substratum in the vicinity of the adult plants and dispersal distances are short (Dudgeon *et al*., 2001). Recovery of algal populations may be rapid where adults remain but prolonged where populations are entirely removed.

Fucus serratus normally lives up to 3 years (Rees, 1932) although in very sheltered areas the plant may live for another couple of years and in very exposed areas may live to only 2 years. High rates of mortality and replacement at all life stages were recorded by Knight & Parke (1950). *Fucus serratus* is dioecious, perennial and reproduces sexually producing high numbers of eggs (Knight & Parke, 1950 estimated that large plants produce over a million eggs during the breeding season). Reproduction commences in late spring/early summer, with the proportion of first-year plants reproducing varying by latitude (Knight & Parke, 1950) and continues through summer and autumn, peaking in August - October. Eggs and sperm are released into the water and fertilisation occurs in the water column. The zygote then develops into a minute plant that can then settle onto the substratum. Arrontes (1993) determined that the dispersal of *Fucus serratus* gametes and fertilized eggs was restricted to within 1–2 m from the parent. Average annual expansion rates for *Fucus serratus* have been estimated at 0.3 to 0.6 km per year (Coyer *et al*., 2006; Brawley *et al*., 2009). Dispersal is highly limited as the negatively buoyant eggs are fertilized almost immediately after release and dispersal by rafting reproductive individuals is unlikely (Coyer et al., 2006). Fucus serratus does not float, and thus mature detached individuals cannot transport reproductive material to distant sites as might be the case for other brown algae. However *Fucus serratus* is found on all British and Irish coasts so there are few mechanisms isolating populations. While poor dispersal is true for medium or large spatial scales (hundreds of metres to kilometres), recruitment at short distances from parental patches is very efficient, as most propagules settle in the vicinity of parent plants (Arrontes, 2002). Many minute germlings are likely to be present under the parent plants (Knight & Parke, 1950).

Clearance experiments s in the UK using cleared areas of 1m^2 and clearance of broad strips showed that a population of *Fucus serratus* restablished in one year and increased to almost pre-clearance levels of biomass by the second year (Knight & Parke, 1950). Recruitment in some instances occurred under a canopy of *Ulva* spp., which protected the young plants from wave action (Knight & Parke, 1950). The same results were obtained by Hawkins & Harkin, 1985), who found that after experimental (small scale 2 m^2) canopy removal of *Fucus serratus* on a moderately exposed shore, the *Fucus serratus* cover recovered within one year. Similarly, in a set of clearance experiments (2 x 2m^2 plots) on shores in the Isle of Man, that were dominated by *Ascophyllum nodosum*, Jenkins *et al*., (2004), found that 2 years after clearance *Fucus serratus* had colonized, on average, just under 50% of the cleared plots. Once established, the *Fucus serratus* stands persisted at approximately 50 % mean cover in the cleared areas for the next 10 years of observations, excluding colonization of the plots by *Ascophyllum nodosum*.

In piddocks the sexes are separate and fertilisation is external, with gametes released into the water column (Pinn *et al*., 2005 and references therein). The fecundity of female *Petricolaria pholadiformis* is estimated to be between 3 - 3.5 million eggs per year (Duval, 1963a). Studies report that larval release occurs from April to September (e.g. Pelseneer, 1924; El-Maghraby, 1955; Purchon 1955; Duval 1962; Knight 1984). Knight (1984) reported that the resulting planktonic larval stage spends 45 days in the plankton. No information was found on the factors that induce piddocks to settle. Pinn *et al*., (2005) observed newly settled individuals between November and February. Pinn *et al*. (2005) found the smallest sexually mature *Pholas dactylus* was a one year old measuring 27.4 mm, information on age at sexual maturity was not reported for other species.Although rare in the Romanian Black Sea, Micu (2007) reported the first observations of *Pholas dactylus* in 34 years at three locations illustrating the recovery potential of this species and ability to colonize or recolonize suitable habitat. The vulnerability of piddocks to episodic events such as the deposition of sediments (Hebda, 2011) and storm damage of sediments (Micu, 2007) and the on-going chronic erosion of suitable sediments (Pinn *et al*., 2005) indicate that larval dispersal and recruitment of new juveniles from source populations is an effective recovery mechanism allowing persistence of piddocks in suitable habitats.

Richter & Sarnthein (1976) studied the re-colonization of different sediments by various molluscs on suspended platforms in Kiel Bay, Germany. The platforms were suspended at 11, 15 and 19 m water depth, each containing three round containers filled with clay, sand, or gravel. Substratum type was found to be the most important factor for the piddock *Barnea candida*, although for all other species it was depth. This highlights the significance of the availability of a suitable substratum to the recovery of piddock species and suggests that larvae have some mechanisms for selection of suitable substratum. Richter & Sarnthein (1976) found that within the two year study period the piddocks grew to represent up to 98% of molluscan fauna on clay platforms. Piddock species have also shown very high growth rates of up to 54 mm in 30 months in the laboratory (Arntz & Rumohr, 1973). However, the process of colonization on clay at 15 and 19 m was found to be highly discontinuous, as reflected by the repeated growth and decrease of specimen numbers.

In the Arctic *Hiatella arctica* may be very long-lived with the oldest individual estimated to be 126 years old (based on annual growth rings) and maximum length was estimated to be achieved at 35 years. Populations in warmer waters are likely to be faster growing (Sejr *et al*., 2002). In the White Sea, Russia, *Hiatella arctica* reached a maximum age of 6 years and achieved sexual maturity at 1 year (Matveeva & Maksimovich, 1977, abstract only). In study sites in County Clare, Ireland, Trudgill & Crabtree (1987) found the mean age to be 5 years and 6 years on exposed and sheltered shores, respectively, (estimated based on growth rings). In the Clyde larvae are found all year, (Russell-Hunter 1949) although Lebour (1938) report that maximum abundances of planktonic larvae occurred from July to November.

Red algae in general have complex life histories and exhibit distinct morphological stages over the reproductive life history. Some red algae found within the biotope have life stages that include prostrate creeping bases e.g. encrusting corallines and *Osmundea pinnatifida* whereas in other species such as *Palmaria palmata*, the thallus or fronds arise from a small discoid holdfast. The basal crusts and crustose tetrasporphytes are perennial, tough, resistant stages that may prevent other species from occupying the rock surface and allow rapid regeneration. They may therefore provide a significant recovery mechanism. *Osmundea pinnatifida* turfs may also expand vegetatively where upright fronds bend over, produce rhizoids and colonize adjacent areas of bare rock by acting as stolons (Godin, 1981).

Where holdfasts and basal crusts are removed, recovery will depend on recolonization via spores. Norton (1992) reviewed dispersal by macroalgae and concluded that dispersal potential is highly variable, recruitment usually occurs on a much more local scale, typically within 10 m of the parent plant. Hence, it is expected that the algal turf would normally rely on recruitment from local individuals and that recovery of populations via spore settlement, where adults are removed, could be protracted. Observed expansion rates of *Osmundea pinnatifida* turfs are very low: 0.015 mm/month in limpet exclusion areas and 0.003 mm/month with limpets (Prathep, 2001).

Corallina officinalis was shown to settle on artificial substances within 1 week of their placement in the intertidal in New England summer (Harlin & Lindbergh, 1977). However, settlement plates laid out in the autumn were not recolonized until the next spring. In the lower rocky intertidal in southern California dominated by *Corallina officinalis* with foliose overstorey algae present, Littler & Kauker (1984) experimentally cleared plots and followed the recovery for 12 months. Some areas were scraped allowing the basal crusts to remain whereas others were completely sterilised (removal of all material and surfaces then scorched with a blow torch to remove bases). In scraped plots up to 15% cover of *Corallina officinalis* fronds returned within 3 months after removal of fronds and all other epiflora/fauna (Littler & Kauker, 1984) while in sterilized plots (all basal crusts removed) appearance of articulated fronds occurred 6 months following clearance. At the end of the 12 month observation period *Corallina officinalis* cover had increased to approximately 18% in plots where basal crusts remained and to approximately 10% in sterilised plots. Similarly Bamber & Irving (1993) reported that new plants grew back in scraped transects within 12 months, although the resistant crustose bases were probably not removed.

Coralline crust refers to nongeniculate (crustose) species from the family Corallinacea that could include *Lithophyllum incrustans* which is noted to form thick crusts in tidepools, especially in the south west (Adey & Adey, 1973). Although ubiquitous in marine coastal systems little is understood about the taxonomy, biology and ecology of this taxa (Littler & Littler, 2013). Studies by Edyvean & Forde (1987) on populations of *Lithophyllum incrustans* in Pembroke south-west Wales suggest that reproduction occurs on average early in the third year. Reproduction may be sexual or asexual. Populations release spores throughout the year but spore abundance varies seasonally. Spore survival is extremely low with only a tiny proportion of spores eventually recruiting to the adult population (Edyvean & Ford, 1986). Edyvean & Ford (1984a) found that the age structure of populations sampled from Orkney (Scotland) Berwick (northern England) and Devon (England) were similar, mortality seemed highest in younger year classes with surviving individuals after the age of 10 years appear relatively long-lived (up to 30 years). In St Mary's Northumberland, the population was dominated by the age 6-7 year classes (Edyvean & Ford, 1984a). Some repair of damaged encrusting coralline occurs through vegetative growth. Chamberlain (1996) observed that although *Lithophyllum incrustans* was quickly affected by oil during the Sea Empress spill, recovery occurred within about a year. The oil was found to have destroyed about one third of the thallus thickness but regeneration occurred from thallus filaments below the damaged area. Recolonization by propagules is an important recovery mechanism.

Where individuals are removed from a small area, adult limpets and *Littorina saxatilis* may recolonize from surrounding patches of habitat where these are present. The barnacles and limpets and the winkle *Littorina littorea* are common, widespread species that spawn annually producing pelagic larvae that can disperse over long distances. It is therefore likely that adjacent populations will provide high numbers of larvae, although recruitment may be low due to habitat unsuitability and the presence of algae preventing settlement on rock surfaces. *Littorina saxatilis* brood young and do not have a pelagic life stage, recovery will therefore depend on the presence of adults in close proximity to impacted areas. *Gibbula cineraria*, another grazer within the biotope, is a fast growing species with a short-lifespan (Schöne *et al*., 2007) and pelagic dispersal stages (Underwood, 1972).

It is likely that habitats where this biotope occurs may undergo annual variation mediated by disturbance (particularly loss of adult macroalgae from storms due to the erodibility of the substratum, Connor *et al*., 2004), competition for space and grazing. The grazers are a key component of this biotope and will influence the dynamics of the biotope. Changes and recovery trajectories following the removal of species are unpredictable and interactions between the characterizing and associated species may be positive or negative. Due to species interactions, recovery trajectories cannot be predicted by life history characteristics alone. Red algae that form turfs, especially *Corallina officinalis*, are often highly resilient to disturbance, and can recover and reach greater abundance compared to prior disturbance conditions (Bulleri *et al*., 2002; Bertocci *et al*., 2010). Turf algae can then prevent recovery of fucoids and other species by inhibiting recruitment. Mrowicki *et al*., (2014) found that limpet and barnacle removal allowed ephemeral and fucoid macroalgae to establish on sheltered and wave exposed shores in Ireland. Experimental studies have shown that limpets and other grazers control the development of macroalgae by consuming microscopic phases (Jenkins *et al*., 2005) or the adult stages (Davies *et al*., 2007) and can therefore structure biotopes through feeding preferences (Underwood, 1980; Hawkins & Hartnoll, 1985) Exclusion of grazing limpets, on shores in southern Britain (Swanage and Heybrook), led to the colonization of red algal turfs by *Himanthalia elongata* and *Fucus serratus* within 2 years (Boaventura *et al*., 2002). MacFarlane (1952) also recorded a shift to a *Corallina officinalis* and encrusting coralline biotope following over raking (for harvesting) of *Chondrus crispus* turf, in these areas gastropods had increased in abundance and prevented the recovery of *Chondrus crispus* by grazing. A change in the abundance of *Patella vulgata* or other grazers could therefore prevent or alter the recovery of this biotope. Opportunistic ephemeral green algae such as *Ulva* sp. can rapidly colonize gaps). These green ephemeral algae are major competitors of *Fucus serratus* for space colonization and nutrient uptake. Blooms of ephemeral algae facilitated by disturbance, particularly where grazers are removed may then slow the development of longer-lived perennial algae, especially fucoids. On the wave exposed and scoured shores that this biotope occurs on, grazing may limit initial settlement of macroalgae but wave action will limit the presence of adults and larger species through breakage and drag effects leading to loss. Limpets and littorinids may enhance barnacle settlement by grazing and removing algae (Hawkins, 1983) or by depositing pedal mucus trails that attract barnacle larvae (Holmes *et al*., 2005). Barnacles may enhance survival of small limpets by moderating environmental stresses but they may also have negative effects on recruitment by occupying space and by limiting access to grazing areas (Lewis & Bowman (1975).

Resilience assessment. If resistance is assessed as ‘High’ resilience is considered to be ‘High’, based on no impact to recover from. Where small patches of *Fucus serratus* are impacted or where disturbance removes the upper or lower margins of the bed, adjacent adults will supply propagules for recolonization. If the entire population of *Fucus serratus* is lost other species may come to dominate. Where resistance is ‘medium’, loss of (<25% of populations of key species) , resilience of *Fucus serratus* and red algal turfs is assessed as ‘High’, based on rapid regrowth and recolonization due to efficient fertilization rates and recruitment over short distances. Removal of some of the adult canopy will allow the understorey germlings to grow faster. However, if the population of *Fucus serratus* is removed (resistance is ‘None’), recovery may take longer, perhaps up to 10 years so the resilience would be scored as ‘Medium’. Recovery rates of red algae will be greatly influenced by whether the crust or holdfasts remain from which the thalli can regrow. Where the bases remain and resistance is assessed as ‘Medium’ (loss of <25% of individuals or cover) then recovery is assessed as ‘High’ based on regrowth from crusts and remaining plants. Where resistance is assessed as ‘Low’ or ‘None’ and a high proportion of bases are lost then recovery may be more protracted.

The sedentary nature of adult piddocks and their vulnerability to episodic impacts such as smothering and chronic erosion suggest that piddocks have evolved effective strategies of larval dispersal and juvenile recruitment with some selectivity for suitable habitats. As recovery of biomass and a typical age-structured population depends on recolonization and subsequent growth to adult size, resilience of the piddocks is assessed as 'Medium' (2-10 years) where resistance is None, Low or Medium.

Caveats regarding possible state shifts where species are removed should be considered when applying sensitivity assessments. Identifying tipping points for shifts to alternate stable states is problematic, therefore although the recovery rates based on examples and life history traits are used in the assessments these may underestimate or overestimate recovery time, which will be influenced by pressure and site-specific factors

The biotope is present in soft rock habitats such as chalk. These are formed in prehistoric periods and are therefore unlike sedimentary habitats which may be renewed by water transport of sediment particles. Following removal of the substratum no recovery of habitat is possible, although sub-surface layers of the same substratum type may be exposed. Resilience of the substratum following complete removal is therefore considered to be 'Very Low' (>25 years).

Hydrological Pressures

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

Species found in the intertidal 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 this intertidal biotope are therefore generally adapted to tolerate a range of temperatures, although the timing of site-specific factors such as low tides will influence local acclimation. For intertidal species increased temperatures may also result in desiccation when exposed (see changes in emergence pressure). Local populations may be acclimated to the prevailing temperature regime and may therefore exhibit different tolerances to other populations subject to different conditions and therefore caution should be used when inferring tolerances from populations in different regions.

Most fucoids are cold-temperate species (Lüning, 1984), and temperatures above 20 °C are generally considered unsuitable for these algae (Zou *et al*., 2012). The effect of high temperature stress on photosynthesis in brown algae is related to inactivation of enzymes and the induction of reactive oxygen species (ROS), leading to photoinhibition (Suzuki & Mittler, 2006). Growth rates of adult brown macroalgae may be affected by temperature through the increase in metabolic rates (Nygard & Dring, 2008). However, *Fucus serratus* is found along the Atlantic coast of Europe from Svalbard to Portugal and on the shores of north-east America. The seaweed is thus well within its thermal range in the British Isles. Nielsen *et al*. (2014) found no negative effects on growth rates of adult *Fucus serratus* to water temperatures of 22 °C (based on a laboratory experiment with specimen collected from Firth of Forth, Scotland) and Arrontes (1993) observed that *Fucus serratus* survived in laboratory experiments for 1 week at 25 °C. Nielsen *et al*. (2014) did, however, report that germlings were negatively affected by increased temperature indicating that early life stages are more vulnerable than mature algae to this pressure.

Several studies have observed adverse effects of *Fucus serratus* as a result of warm thermal stress in terms of growth, physiological performance and reproductive output in Spain and Portugal (Pearson *et al*., 2009; Viejo *et al*., 2011; Martínez *et al*., 2012). Jueterbock *et al*. (2014) determined that these negative impacts can be explained by restricted within-population genetic diversity. South west Ireland and Brittany are hot-spots of genetic diversity (Coyer *et al*., 2003; Hoarau *et al*., 2007) and may thus be more resilient to changes in temperature. Phenotypic plasticity therefore plays an important role in determining the sensitivity of individual populations to changes in temperature.

Little direct evidence was found to assess the effects of increased temperature on piddocks and the assessment is based on distribution records and evidence for spawning in response to temperature changes. The American piddock *Petricolaria pholadiformis* has a wide distribution and is found north as far as the Skaggerak, Kattegat and Limfjord (Jensen, 2010) and is also present in the Mediterranean, Gulf of Mexico and Caribbean (Huber & Gofas, 2015). *Pholas dactylus* occurs in the Mediterranean and the East Atlantic, from Norway to Cape Verde Islands (Micu, 2007). *Barnea candida* is distributed from Norway to the Mediterranean and West Africa (Gofas, 2015).The current distribution of *Hiatella arctica* is predominantly arctic and boreal (Sejr *et al*., 2004; Gordillo, 2001) and palaeecological reviews describe the genus as ‘consistently linked to cool temperate and polar regions’ (Gordillo, 2001). However, populations of *Hiatella arctica* occur in the Mediterrannean and have clearly acclimated to the warmer temperatures (Oberlechner, 2008). Laboratory experiments on filtration rates of *Hiatella arctica* found that activity was strongly linked to temperature (Ali, 1970). Activity rates rose steadily between 0 °C to a maximum between 15 °C and 17 °C and fell sharply to almost no activity at 25 °C (Ali, 1970). Although activity may be reduced *Hiatella arctica* have very low metabolic rates and may be able to sustain a period of reduced activity. Regression models developed by Bourget *et al*. (2003) found that temperature and water transparency (measured in metres and indicating the level of inorganic suspended solids) explained only 40% of the variation in biomass of *Hiatella arctica* fouling navigation buoys in the Gulf of St Lawrence system (Canada). These findings suggest that other variables play a more significant role in determining settlement, survival and growth over a year in this system. However the models did indicate that biomass is higher where temperatures were greater (around 14 °C) although a causal link was not identified (Bourget *et al*., (2003).

There is some evidence that temperature influences the timing of reproduction in *Pholas dactylus*, which usually spawns between July and August. Increased summer temperatures in 1982 induced spawning in July on the south coast of England (Knight, 1984). Spawning of the piddock *Petricolaria pholadiformis* is initiated by increasing water temperature (>18 °C) (Duval, 1963a), so elevated temperatures outside of usual seasons may disrupt normal spawning periods. The spawning of *B. candida* was also reported to be disrupted by changes in temperature. *Barnea candida* normally spawns in September when temperatures are dropping (El-Maghraby, 1955). However, a rise in temperature in late June of 1956, induced spawning in some specimens of *Barnea candida* (Duval, 1963b). Disruption from established spawning periods, caused by temperature changes, may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by elevated temperatures.

Littler & Kauker (1984) suggested that the crustose bases of *Corallina officinalis* are more resistant of desiccation or heating than fronds. Lüning (1990) reported that *Corallina officinalis* from Helgoland survived one week exposure to temperatures between 0 °C and 28 °C. Latham (2008) investigated the effects of temperature stress on *Corallina officinalis* through laboratory tests on samples collected in the Autumn in Devon, (England) from rockpools Samples were kept at 15 °C for three days and then exposed to temperatures of 5 °C, 15 °C, 20 °C, 25 °C and 30 °C (the normal range of temperature experienced was suggested to be between 5 and 15 °C). At 35 °C the *Corallina was* completely bleached after 3 days with a sample kept at 30 °C beginning to bleach.

After 7 days (the end of the experiment) the sample kept at 30 °C was partially bleached. Samples kept at 5, 15, 20 and 25 °C showed little change in chemicals produced in reaction to thermal stress and no bleaching suggesting the temperatures in that range had not induced stress reactions.

In an exceptionally hot summer (1983, with an increase of between 4.8 and 8.5 °C), Hawkins & Hartnoll (1985) observed no temperature bleaching of adult *Himanthalia elongata* (although some buttons were bleached) or other canopy forming species. However, understorey red algae showed more signs of damage with bleached *Corallina officinalis* observed around the edges of pools due to desiccation. Occasional damaged specimens of *Palmaria palmata*, *Osmundea pinnatifida* and *Mastocarpus stellatus* were observed. *Palmaria palmata* does well in low temperatures, with an optimum between 6 and 15°C, consistent with a distribution in northern temperate and arctic waters. This species is also found in warmer temperate waters as far south as Portugal in Europe and with localized large populations in northern Spain (Garbary *et al*., 2012 and references therein). Temperatures at or above 15 °C may induce physiological stress (Werner & Dring, 2011; Morgan *et al*., 1980). In tank cultures of *Palmaria palmata* at 20°C and above, all plants were dead within a week (Morgan *et al*., 1980). Populations may be acclimated to typical conditions but it is likely that *Palmaria palmata* may be bleached or damaged by higher than usual temperatures. Fronds of *Osmundea pinnatifida* bleach and die-back in summer, while the crustose holdfasts remain, suggesting that the bases are more resistant. The factors responsible for the die-back are a combination of temperature (Flores-Moya, 1992, abstract only) desiccation and irradiance (Prathep, 2001).

Limpets, *Patella vulgata* and littorinids also occur within this biotope. Laboratory studies suggest that adults of these species can tolerate temperature increases. The median upper lethal temperature limit in laboratory tests on *Littorina littorea*, *Littorina saxatilis* was approximately 35 °C (Davenport & Davenport, 2005). *Patella vulgata* can also tolerate high temperatures. The body temperature of *Patella vulgata* can exceed 36°C in the field, (Davies, 1970); adults become non-responsive at 37-38 C and die at temperatures of 42 °C (Evans, 1948). *Semibalanus balanoides* and *Patella vulgata* are 'northern' with their range extending from Portugal or Northern Spain to the Arctic circle. Populations in the southern part of England are therefore relatively close to the southern edge of their geographic range. Reproductive and recruitment success in both species is linked to temperature and long-term changes in temperature (exceeding the duration of the pressure benchmark) may to lead to replacement by the warm water species *Chthamalus montagui* and *Chthamalus stellatus* (Southward *et al*., 1995). In Northern Portugal warming seas appear to be linked to a shortening of the reproductive period and the lack of multiple spawning events in *Patella vulgata* and other northern species (Ribeiro *et al*., 2009). Increases in temperature above 12°C induce spawning in *Gibbula cineraria* (Underwood, 1972; Clare, 1990). Individuals from a population from North East England spawned between late June and early September although females (but not males) could be induced to spawn in winter in response to a temperature increase but males could not (Clare, 1990). An acute increase in temperature that induced spawning in females but not males or that resulted in spawning and fertilization when other conditions were unsuitable would reduce recruitment success (Clare, 1990). This effect, at the duration of the pressure benchmark, is considered to be sub-lethal to the adult population

Sensitivity assessment. *Fucus serratus* are found in the middle of their natural temperature range in the British Isles and are therefore not likely to be affected by an increase in temperature at the pressure benchmark. An increase in acute or chronic temperature above average British and Irish temperatures is not likely to have a detrimental effect of *Fucus serratus* and associated communities, based on global distribution. However, it should be noted that phenotypic plasticity will influence the tolerance of individual population. Some of the understorey of red algae, such as

Palmaria palmata may be lost during acute temperature increases if these occur in the summer when plants are already close to the limit of thermal tolerances. however, this will not alter classification of the biotope.The global distribution of the piddock species, *Petricolaria pholadiformis*, *Pholas dactylus* and *Barnea candida*, suggest that these species can tolerate warmer waters than currently experienced in the UK and may therefore be tolerant of a chronic increase in temperature. Short-term acute increases may, (depending on timing) interfere with temperature driven spawning cues for piddocks and Patella vulgata and Semibalanus balanoides (and possibly other species). The effects will depend on seasonality of occurrence and the species affected. Adult populations may be unaffected and, in such relatively long-lived species, an unfavourable recruitment may be compensated in a following year. Resistance to an acute change in temperature is therefore assessed as 'High' (based on *Fucus serratus* and piddocks) and recovery as 'High' (within two years) and the biotope is considered 'Not Sensitive'. For all species it should be noted that the timing of acute changes may lead to greater impacts, temperature increases in the warmest months may exceed thermal tolerances whilst changes in colder periods may stress individuals acclimated to the lower temperatures.

Temperature decrease (local)	High Q: High A: Medium C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: Medium C: Medium

Many intertidal species are tolerant of freezing conditions as they are exposed to extremes of 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 (Davenport & Davenport, 2005). Local populations may be acclimated to the prevailing temperature regime and may therefore exhibit different tolerances to other populations subject to different salinity conditions and therefore caution should be used when inferring tolerances from populations in different regions. *Mytilus edulis* is a eurytopic species found in a wide temperature range from mild, subtropical regions to areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek, 1992).

Lüning (1984) reported that *Fucus serratus* survived in the laboratory for a week a range temperature between 0°C and 25°C. *Fucus serratus* is found along the Atlantic coast of Europe from Svalbard to Portugal and on the shores of north-east America. The seaweed is, thus, well within its thermal range in the British Isles.

Little empirical evidence was found to assess the effects of decreased temperature on piddocks and the assessment is based on distribution records and evidence for spawning in response to temperature changes.The American piddock *Petricolaria pholadiformis* has a wide distribution and is found north as far as the Skaggerak, Kattegat and Limfjord (Jensen, 2010) (Huber & Gofas, 2015). *Pholas dactylus* occurs in the Mediterranean and the East Atlantic, from Norway to Cape Verde Islands (Micu, 2007). *Barnea candida* is distributed from Norway to the Mediterranean and West Africa (Gofas, 2015). Temperature changes have been observed to initiate spawning by *Pholas dactylus*, which usually spawns between July and August. Increased summer temperatures in 1982 induced spawning in July on the south coast of England (Knight, 1984). Spawning of *Petricolaria pholadiformis* is initiated by increasing water temperature (>18 °C) (Duval, 1963a), so decreased temperatures may disrupt normal spawning periods where this coincides with the reproductive season. The spawning of *Barnea candida* was also reported to be disrupted by changes in temperature. *Barnea candida* normally spawns in September when temperatures are dropping (El-Maghraby, 1955). Disruption from established spawning periods, caused by decreased temperatures may be detrimental to the survival of recruits as other factors influencing their survival may not be optimal, and some mortality may result. Established populations may otherwise remain unaffected by decreased temperatures.

Gordillo & Aitken (2000) in a review of environmental factors relevant to re-interpreting Late Quaternary environments from fossil collections suggest that *Hiatella arctica* is eurythermal, based on Aitken (1990) and Peacock (1993). The current distribution of *Hiatella arctica* is predominantly arctic and boreal (Sejr *et al*., 2004; Gordillo, 2001) and palaeecological reviews describe the genus as ‘consistently linked to cool temperate and polar regions’ (Gordillo, 2001) suggesting that within temperate regions this species would not be sensitive to a decrease in temperature at the pressure benchmark. Regression models developed by Bourget *et al*. (2003) found that temperature and water transparency (measured in metres and indicating the level of inorganic suspended solids) explained only 40% of the variation in biomass of *Hiatella arctica* fouling navigation buoys in the Gulf of St Lawrence system (Canada). These findings suggest that other variables play a more significant role in determining settlement, survival and growth over a year in this system. However the models did indicate that biomass is higher where temperatures were greater (around 14 °C) although a causal link was not identified (Bourget *et al*., (2003).

No evidence was found for tolerance of decreased temperatures by *Osmundea pinnatifida*.Under extremely low temperatures, components of the community demonstrate tolerance. Lüning (1990) reported that *Corallina officinalis* from Helgoland survived 0 °C when exposed for one week. New Zealand specimens were found to tolerate -4 °C (Frazer *et al*., 1988). Lüning (1990) suggested that most littoral algal species were tolerant of cold and freezing. The associated species *Mastocarpus stellatus* has a broad geographical distribution (Guiry & Guiry, 2015) and throughout its range experiences wide variation in temperatures (although local populations may be acclimated to the prevailing thermal regime). The photosynthetic rate of *Mastocarpus stellatus* higher on the shore fully recovered from 24 hrs at -20 °C (Dudgeon *et al*.,1989). Photosynthesis in *Mastocarpus stellatus* also recovered quickly after experimental freezing (Dudgeon *et al*., 1989, 1995). *Palmaria palmata* does well in low temperatures, with an optimum between 6 and 15°C, consistent with a distribution in northern temperate and arctic waters. In the laboratory, plants only became fertile if left at temperatures between 5-7 °C with a short light period (Van der Meer, 1979). Acute or chronic changes in temperature below 5°C may therefore reduce reproductive success although reproduction and vegetative growth in warmer months should compensate for any reduction in output. The green algae, *Ulva* spp. are eurytopic, found in a wide temperature range and in areas which frequently experience freezing conditions and are vulnerable to ice scour (Seed & Suchanek 1992).

The cold tolerance of *Semibalanus balanoides* collected in the winter (and thus acclimated to lower temperatures) was tested in the laboratory. The median lower lethal temperature tolerance was -14.6 °C (Davenport & Davenport, 2005). A decrease in temperature at the pressure benchmark is therefore unlikely to negatively affect this species. The same series of experiments indicated that median lower lethal temperature tolerances for *Littorina saxatilis* and *Littorina littorea* were -16.4 and -13 °C respectively. Adults of *Patella vulgata* are also largely unaffected by short periods of extreme cold. Ekaratne & Crisp (1984) found adult limpets continuing to grow over winter when temperatures fell to -6 °C, and stopped only by still more severe weather. However, loss of adhesion after exposure to -13 °C has been observed with limpets falling off rocks and therefore becoming easy prey to crabs or birds (Fretter & Graham, 1994). However, in the very cold winter of 1962-3 when temperatures repeatedly fell below 0 °C over a period of 2 months large numbers of *Patella vulgata* were found dead (Crisp, 1964). Periods of frost may also kill juvenile *Patella vulgata*, resulting in recruitment failures in some years (Bowman & Lewis, 1977). In colder conditions an active migration by mobile species found within the turf may occur down the shore to a zone where exposure time to the air (and hence time in freezing temperatures) is less.

Sensitivity assessment. A decrease in acute or chronic temperature above average British and Irish temperatures is not likely to have a detrimental effect of *Fucus serratus* and associated communities, based on global distribution. However, it should be noted that phenotypic plasticity will influence the tolerance of individual population.The global distribution of the piddock species and *Hiatella arctica* suggest that these species can tolerate cooler waters than currently experienced in the UK and may therefore be tolerant of a chronic decrease in temperature at the benchmark level. Decreased temperatures may, depending on timing, interfere with spawning cues which appear to be temperature driven. The effects will depend on seasonality of occurrence and the species affected. Adult populations may be unaffected and, in these relatively long-lived species, an unfavourable recruitment may be compensated for in a following year. Based on the characterizing species, resistance to an acute and chronic decrease in temperature at the pressure benchmark is therefore assessed as 'High' and recovery as 'High' (within two years) and the biotope is considered 'Not Sensitive'. Based on the characterizing and associated species, this biotope is considered to have 'High' resistance and 'High resilience (by default) to this pressure and is therefore considered to be 'Not sensitive'. The timing of changes and seasonal weather could result in greater impacts on species.

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

Little direct evidence was found to assess sensitivity to this pressure.Local populations may be acclimated to the prevailing salinity regime and may therefore exhibit different tolerances to other populations subject to different salinity conditions and therefore caution should be used when inferring tolerances from populations in different regions. This biotope is found in full (30-35 ppt) salinity (Connor *et al*., 2004). Biotopes found in the intertidal will naturally experience fluctuations in salinity where evaporation increases salinity and inputs of rainwater expose individuals to freshwater. Species found in the intertidal are therefore likely to have some form of behavioural or physiological adaptations to changes in salinity. Fucoids are able to compensate for changes in salinity by adjusting internal ion concentrations. However this will occur at a cost, reducing photosynthetic rate and hence affecting the growth rate of the seaweed. *Fucus serratus*, commonly inhabit narrow fjords where salinity can vary widely along a spatial (kms) and/or temporal (hours to daily) scale. Growth rates for *Fucus serratus* are maximal at a salinity of 20 psu with the critical limit for recruitment set at 7 psu (Malm *et al*., 2001). An increase in salinity at the pressure benchmark could therefore impact growth.

No evidence for the range of physiological tolerances to salinity changes were found for piddocks. Filipov *et al*., (2003, abstract only) tested the salinity tolerances of *Hiatella arctica* obtained from the White Sea. The salinity tolerance of individuals kept at 25 ppt was 17-36 ppt. Acclimation of *Hiatella arctica* allowed them to adapt to higher or lower salinities with the potential tolerance range of acclimated individuals assessed as 13-42 ppt.

Tolerances of the red algae vary between species. *Corallina officinalis* is found in tide pools where salinities may fluctuate markedly during exposure to the air. Kinne (1971) cites maximal growth rates for *Corallina officinalis* between 33 and 38 psu in Texan lagoons. Laboratory experiments have defined the upper and lethal lower limits for *Palmaria palmata* as 15 psu and 50 psu, (Karsten *et al*., 2003) with optimal salinity defined as 23-34 psu (Robbins, 1978). No evidence was found to assess the salinity tolerances of *Osmundea pinnatifida*. Edyvean & Ford (1984b) suggest that populations of *Lithophyllum incrustans* are affected by temperature changes and salinity and that temperature and salinity 'shocks' induce spawning but no information on thresholds was provided (Edyvean & Ford, 1984b). Populations of *Lithophyllum incrustans* were less stable in rockpools with a smaller volume of water that were more exposed to temperature and salinity changes due to lower buffering capacity. Sexual plants (or the spores that give rise to them) were suggested to be more susceptible than asexual plants to extremes of local environmental variables (temperature, salinity etc.) as they occur with greater frequency at sites where temperature and salinity were more stable (Edyvean & Ford, 1984b).

In the laboratory, *Semibalanus balanoides* was found to tolerate salinities between 12 and 50 psu (Foster, 1970). Young *Littorina littorea* inhabit rock pools where salinity may increase above 35psu. Thus, the associated species may be able to tolerate some increase in salinity.

Sensitivity assessment. Although some increases in salinity may be tolerated by the species present these are generally short-term and mitigated during tidal inundation. This biotope is considered, based on distribution of *Fucus serratus*, piddocks and the associated red algal species on the mid to lower shore to be sensitive to a persistent increase in salinity to > 40 ppt (although *Hiatella arctica* is considered to have greater tolerance). Resistance is therefore assessed as 'Low' and recovery as 'Medium' (based on recovery of piddocks, fucoids and algal turfs following restoration of usual salinity). Sensitivity is therefore assessed as 'Medium'.

Salinity decrease (local)	Low Q: High A: Low C: Medium	Medium Q: High A: Low C: Medium	Medium Q: High A: Low C: Medium

Local populations may be acclimated to the prevailing salinity regime and may therefore exhibit different tolerances to other populations subject to different salinity conditions and therefore caution should be used when inferring tolerances from populations in different regions. This biotope is found in full (30-35 ppt) salinity (Connor *et al*., 2004). A change in full to reduced (18-30 ppt) salinity (the pressure benchmark) may lead to changes in the composition of the biotope. However, biotopes found in the intertidal will naturally experience fluctuations in salinity where evaporation increases salinity and inputs of rainwater expose individuals to freshwater. Species found in the intertidal are therefore likely to have some form of behavioural or physiological adaptations to changes in salinity.

Fucoids are able to compensate for changes in salinity by adjusting internal ion concentrations. However this will occur at a cost, reducing photosynthetic rate and hence affecting the growth rate of the seaweed. Growth rates for *Fucus serratus* are maximal at a salinity of 20 psu with the critical limit for recruitment set at 7 psu (Malm *et al*., 2001).Sufficient salinity is essential for successful fertilization and germination in *Fucus* (e.g., Brawley, 1992a; Serrão *et al*., 1999). Malm *et al*. (2001) found that fertilization success in *Fucus serratus* decreased substantially with strongly reduced salinity. Indeed the study found that fertilisation success was 87% at 9 psu but declined to 5% at 6 psu (Malm *et al*., 2001). Reduced salinity does also affect dispersal by decreasing swimming performance of fucoid sperm (Serrão *et al*., 1996).

No information was found for the salinity tolerance of the of *Pholas dactylus*. A change in full to reduced (18-30 ppt) salinity (the pressure benchmark) may lead to changes in the composition of the piddock population with replacement of *Pholas dactylus* (if it is sensitive) by piddocks more tolerant of lower salinities particularly *Petricolaria pholadiformis*. *Petricolaria pholadiformis* is particularly common off the Essex and Thames estuary, e.g. the River Medway (Bamber, 1985) suggesting tolerance of brackish waters. Zenetos *et al*. (2009) suggest that at all sites where *Petricolaria pholadiformis* has been found there is some freshwater inflow into the sea. According to the literature, the species in its native range inhabits environments with salinities between 29 and 35ppt, while in the Baltic Sea it is reported from salinities 10-30 psu (Gollasch & Mecke, 1996, cited from Zenetos *et al*. 2009). According to Castagna & Chanley (1973, cited from Zenetos *et al.* 2009) the lower salinity tolerance of *Petricolaria pholadiformis* is 7.5-10 psu. It thus appears that reduced salinity facilitates its establishment (Zenetos *et al*., 2009). *Barnea candida* is reported to extend in to estuarine environments in salinities down to 20 psu (Fish & Fish, 1996). Filipov *et al*., (2003, abstract only) tested the salinity tolerances of *Hiatella arctica* obtained from the White Sea. The salinity tolerance of individuals kept at 25 ppt was 17-36 ppt. Acclimation of *Hiatella arctica* allowed them to adapt to higher or lower salinities with the potential tolerance range of acclimated individuals assessed as 13-42 ppt. Gordillo & Aitken (2000) in a review of environmental factors relevant to re-interpreting Late Quaternary environments from fossil collections suggest that the normal minimum salinity tolerance of *Hiatella arctica* is 20 ppt, based on Aitken (1990) and Peacock (1993).

Laboratory experiments have defined the upper and lethal lower limits for *Palmaria palmata* as 15 psu and 50 psu, (Karsten *et al*., 2003) with optimal salinity defined as 23-34 psu (Robbins, 1978). *In-situ Palmaria palmata* from the Arctic Kongsfjord (Spitsbergen) exposed for four days to salinities of 15 psu following freshwater run-off suffered high levels of mortality (Karsten *et al*., 2003). In Danish waters where salinities are lowered by freshwater inputs, cultivation experiments found that *Palmaria palmata* growth over a seven month period was greatest at a site where mean salinity was 21±3 psu, while no growth occurred at a site where mean salinity was 17±5 psu (Bak, 2014). A decrease in salinity may lead to replacement of more sensitive red algal turf forming species by those more tolerant of the changed conditions. *Chondrus crispus* occurs in areas of 'low' salinity. For example, the species occurs in estuaries in New Hampshire, USA, where surface water salinity varies from 16-32 psu (Mathieson & Burns, 1975). Mathieson & Burns (1971) recorded maximum photosynthesis of *Chondrus crispus* in culture at 24 psu, but rates were comparable at 8, 16 and 32 psu. Tasende & Fraga (1999) cultured *Chondrus crispus* spores from north west Spain and concluded that growth was correlated with salinity between 23 and 33 psu. No evidence was found to assess the salinity tolerances of *Osmundea pinnatifida*. *Corallina officinalis* is found in tide pools where salinities may fluctuate markedly during exposure to the air. Kinne (1971) cites maximal growth rates for *Corallina officinalis* between 33 and 38 psu in Texan lagoons. *Ulva* species can survive hypersaline conditions in supralittoral rockpools subjected to evaporation and is considered to be a very euryhaline species, tolerant of extreme salinities ranging from 0 psu to 136 psu (Reed & Russell, 1979). Edyvean & Ford (1984b) suggest that populations of *Lithophyllum incrustans* are affected by temperature changes and salinity and that temperature and salinity ‘shocks’ induce spawning but no information on thresholds was provided (Edyvean & Ford, 1984b). Populations of *Lithophyllum incrustans* were less stable in tide pools with a smaller volume of water that were more exposed to temperature and salinity changes due to lower buffering capacity. Sexual plants (or the spores that give rise to them) were suggested to be more susceptible than asexual plants to extremes of local environmental variables (temperature, salinity etc.) as they occur with greater frequency at sites where temperature and salinity were more stable (Edyvean & Ford, 1984b).

Semibalanus balanoides are tolerant of a wide range of salinity and can survive periodic emersion in freshwater, e.g. from rainfall or freshwater run-off, by closing their opercular valves (Foster, 1971b). They can also withstand large changes in salinity over moderately long periods of time by falling into a ‘salt sleep’ and can be found on shores (example from Sweden) with large fluctuations in salinity around a mean of 24 (Jenkins *et al*., 2001). In areas of permanently reduced salinity the Australian barnacle *Austrominius* (formerly *Elminius*) modestus may be favoured, as this species is more tolerant of lower salinities), although this is balanced against its lower tolerance of wave exposure. *Littorina littorea* is found in waters of full, variable and reduced salinities (Connor *et al*., 2004) and so populations are not likely to be highly intolerant of decreases in salinity. Therefore, it appears that the biotope would have low intolerance to a decrease in salinity. On return to normal conditions recovery is likely to be very rapid. *Patella vulgata* can tolerate varying salinities and its distribution extends into the mouths of estuaries surviving in salinities down to about 20 psu. However, growth and reproduction may be impaired in reduced salinity. Little *et al.* (1991), for example, observed reduced levels of activity in limpets after heavy rainfall and in the laboratory activity completely stopped at 12 psu. The species can endure periods of low salinity and was found to die only when the salinity was reduced to 3-1 psu (Fretter & Graham, 1994). In experiments where freshwater was trickled over the shell, Arnold (1957) observed limpets withdrawing and clamping the shell onto the substratum. There appears to be an increasing tolerance of low salinities from the lower to the upper limit of distribution of the species on the shore (Fretter & Graham, 1994).

Sensitivity assessment, Most of the literature found on this topic considered short-term (days to weeks) impacts of changes to salinity whilst the benchmark refers to a longer-term change. A reduction in salinity at the level benchmark (e.g. from 'Full' to 'Reduced' for one year) could have beneficial effects *on Fucus serratus* as growth rates are maximal below full saline conditions. Prolonged reduction in salinity at the pressure benchmark is likely to reduce the species richness of the biotope due to loss of less tolerant piddock species, red algae and some intolerant invertebrates. The sensitivity of *Palmaria palmata* for example, appears to be greater than some other turf-forming species. A change in salinity at the pressure benchmark is considered to lead to some mortality of *Palmaria palmata* although the tolerance threshold reported in laboratory and cultivation studies is slightly lower than the assessed benchmark. It is considered that the benchmark decrease in salinity would not result in mortality of the key characterizing *Fucus serratus* species in biotopes that were previously fully marine although some changes in biotope composition may occur and the piddocks or *Hiatella arctica* may be impacted. Biotope resistance is therefore assessed as 'Low' as the piddocks are a key characterizing componenet and resilience is assessed as 'Medium' , so that biotope sensitivity is assessed as 'Medium'.

Water flow (tidal current) changes (local)	High Q: High A: Low C: Medium	High Q: High A: High C: High	Not sensitive Q: High A: Low C: Medium

Established adult piddocks are, to a large extent, protected from direct effects of increased water flow, owing to their environmental position within the substratum. Increases or decreases in flow rates may affect suspension feeding by altering the delivery of suspended particles or the efficiency of filter feeding. However, no evidence was found to inform the sensitivity assessment although other biotopes characterized by piddocks (IR.MIR.KR.Ldig.Pid and CR.MCR.SfR.Pid) have been found in areas where tidal flows vary between 0.5 -1.5 m/s (Connor *et al*., 2004), suggesting that changes in flow rates within this range will not negatively impact piddocks. Adult piddocks may become exposed should physical erosion occur at a greater rate than burrowing, and lost from the substratum. At higher densities bioerosion by piddocks may destabilise the substratum increasing vulnerability to erosion and resulting in loss of habitat and *Fucus serratus* and red algal turf.

Moderate water movement is beneficial to seaweeds as it carries a supply of nutrients and gases to the plants and removes waste products. Propagule dispersal, fertilization, settlement, and recruitment are also influenced by water movement (Pearson & Brawley, 1996). Increased water flow can increase scour through increased sediment movement. Small life stages of macroalgae are likely to be affected by removal of new recruits from the substratum reducing successful recruitment (Devinny & Volse, 1978) (see 'siltation' pressures). A reduction in water flow can cause a thicker boundary layer resulting in lower absorption of nutrients and CO_2 by the macroalgae. Slower water movement can also cause oxygen deficiency directly impacting the fitness of algae (Olsenz, 2011).

Higher water flow rates increase mechanical stress on macroalgae by increasing drag. This can result in individuals being torn off the substratum. Jonsson *et al.* (2006) found that flow speed of 7-8 m/s completely dislodged *Fucus vesiculosus* individuals larger than 10 cm. Smaller individuals are likely to better withstand increased water flow as they experience less drag. Biogenic habitat structures reduce the effects of water flows on individuals by slowing and disrupting flow. The fronds of *Fucus serratus* and the red algal turf will reduce the flow experienced by the turf. Boller and Carrington (2006), for example, found that the canopy created by the taller turf of *Chondrus cripsus* reduced drag forces on individual plants by 15-65%. The crustose holdfasts of *Osmundea pinnatifida*, *Corallina officinalis* and the coralline crusts are securely attached and as these are relatively flat, are subject less drag than upright fronds and are likely to tolerate changes in water flows at the pressure benchmark. Moderate water movement is beneficial to seaweeds as it carries a supply of nutrients and gases to the plants and removes waste products. However, if flow becomes too strong, plants may become dislodged.

Growth and reproduction of *Semibalanus balanoides* is influenced by food supply and water velocity (Bertness *et al*., 1991). Laboratory experiments demonstrate that barnacle feeding behaviour alters over different flow rates but that barnacles can feed at a variety of flow speeds (Sanford *et al*., 1994). Flow tank experiments using velocities of 0.03, 0.07 and 0.2 m/s showed that a higher proportion of barnacles fed at higher flow rates (Sanford *et al*., 1994). Feeding was passive, meaning the cirri were held out to the flow to catch particles; although active beating of the cirri to generate feeding currents occurs in still water (Crisp & Southward, 1961). Field observations at sites in southern New England (USA) that experience a number of different measured flow speeds, found that *Semibalanus balanoides* from all sites responded quickly to higher flow speeds, with a higher proportion of individuals feeding when current speeds were higher. Barnacles were present at a range of sites, varying from sheltered sites with lower flow rates (maximum observed flow rates <0.06- 0.1 m/s), a bay site with higher flow rates (maximum observed flows 0.2-0.3 m/s) and open coast sites (maximum observed flows 0.2-0.4 m/s). Recruitment was higher at the site with flow rates of 0.2-0.3 m/s (although this may be influenced by supply) and at higher flow microhabitats within all sites. Both laboratory and field observations indicate that flow is an important factor with effects on feeding, growth and recruitment in *Semibalanus balanoides* (Sanford *et al*., 1994, Leonard *et al*., 1998), however, the results suggest that flow is not a limiting factor determining the overall distribution of barnacles as they can adapt to a variety of flow speeds.

Patella vulgata inhabits a range of tidal conditions and is therefore, likely to tolerate a change in water flow rate. The streamlined profile of limpet shells is of importance in increasing their tolerance of water movement, and this is undoubtedly one factor in determining the different shape of limpets at different exposures. With increasing exposure to wave action the shell develops into a low profile reducing the risk of being swept away. The strong muscular foot and a thin film of mucus between the foot and the rock enables *Patella vulgata* to grip very strongly to the substratum (Fretter & Graham, 1994). The ability of limpets to resist accelerating, as distinct from constant currents, may set a limit to the kind of habitat which they can occupy and limit the size to which they can grow.

Shell morphology within littorinids varies according to environmental conditions, in sheltered areas, where *Carcinus maenas* is more prevalent, shell apertures are small to inhibit predation. In exposed areas the foot surface is larger to allow greater attachment and the shell spire is lower to reduce drag (Raffaelli 1982, Crothers, 1992). *Gibbula cineraria* also appear to tolerate a range of wave exposures from exposed sites to those that are very sheltered (Frid & Fordham, 1994), suggesting it can aslo adapt to different water velocities. As with *Littorina littorea*, the morphology of the shell varies according to wave exposure, allowing individuals to adapt to different conditions in the habitat in which the larvae settle (Frid & Fordham, 1994). *Gibbula cineraria* is, however, absent from areas with very strong and turbulent flow.

Sensitivity assessment. Based on the exposure of *Fucus serratus* and red algal turfs and piddocks to water flows between 0.5 and 1.5 m/s in other biotopes (Connor *et al*., 2004), the biotope is considered to be unimpacted by changes within this range as long as these do not lead to increased erosion of the substratum. Resistance is therefore assessed as 'High' and resilience as 'High' (based on no impact to recover from), so that the biotope is considered to be ‘Not sensitive’.

Emergence regime changes	Medium Q: High A: Medium C: Medium	Medium Q: High A: Low C: Medium	Medium Q: High A: Low C: Medium

Emergence regime is a key factor structuring intertidal biotopes. Changes in emergence can lead to greater exposure to desiccation, temperature and salinity variation, reduced levels of time for filter feeding and nutrient uptake and photosynthesising opportunities for the characterizing species. Changes in emergence can also alter competitive interactions and trophic interactions such as grazing and predation. This biotope occurs in the mid shore (Connor *et al*., 2004). This biotope usually occurs immediately below either a *Fucus vesiculosus*-barnacle mosaic (FvesB) or a *Mytilus edulis* and piddocks-dominated biotope (MytPid) on moderately exposed shores or a dense canopy of *F. vesiculosus* (Fves) or *Ascophyllum nodosum* (Asc.FS) on sheltered shores. The littoral fringe below are on moderately exposed shores dominated by the kelp *Laminaria digitata* (Ldig.Pid), while the kelp *Laminaria saccharina* may co-dominate on sheltered shores (Slat.Ldig; Slat.Ft) (JNCC, 2015).

Adult piddocks and the algae that characterize this biotope have no mobility and cannot therefore migrate up or down shore to adapt to changes in emergence. Within the chalk substratum, adult piddocks will be afforded some protection from desiccation and temperature increases, following increased emergence, by their burrows which will retain some moisture. The shells of piddocks do not completely enclose the animals however , and therefore cannot be closed to prevent water loss. The tolerance of piddocks to increased and decreased emergence varies between species. *Pholas dactylus* inhabits the shallow sub-tidal and lower shore and *Barnea candida* and *Petricolaria pholadiformis* live slightly higher up the shore than *Pholas dactylus* (Duval, 1977) . During extended periods of exposure, *Pholas dactylus* squirt some water from their inhalant siphon and extend their gaping siphons into the air (Knight, 1984). This may result in increased detection and predation by birds. *Hiatella arctica* occur within the intertidal and subtidally and that the presence of suitable substratum rather than emergence regime is a more significant factor determining the distribution.*Fucus serratus* is more susceptible to desiccation than other *Fucus* species that are located further up the shore and subjected more frequently to aerial exposure (Schonbeck & Norton, 1978). In experiments, (Schonbeck & Norton, 1978; *Fucus serratus* did not survive transplantation further up the shore, e.g. in the *Fucus spiralis* belt. The critical water content for *Fucus serratus* is estimated at 40% with water losses past this point causing irreversible damage. Beer *et al*. (2014) found that *Fucus serratus* could not regain any positive photosynthetic rates after rehydrating from 10% water content. The upper shore extent of *Fucus serratus* populations may be replaced by species more tolerant of desiccation and more characteristic of the mid-eulittoral such as *Fucus vesiculosus* or *Ascophyllum nodosum*.

The red algae within the biotope are likely to be sensitive to increased emergence a. *Corallina officinalis* are sensitive to desiccation (Dommasnes, 1969) and are generally not found on open rock unless protected by algal canopies or where the surfaces are damp or wet. At Hinkley Point (Somerset, England), for example, seawater run-off from deep pools high in the intertidal supports dense turfs of *Corallina* spp. lower on the shore (Bamber & Irving, 1993). Fronds are highly intolerant of desiccation and do not recover from a 15 % water loss, which might occur within 40-45 minutes during a spring tide in summer (Wiedemann, 1994). Bleached corallines were observed 15 months after the 1964 Alaska earthquake which elevated areas in Prince William Sound by 10 m. Similarly, increased exposure to air caused by upward movement of 15 cm due to nuclear tests at Armchitka Island, Alaska adversely affected *Corallina pilulifera* (Johansen, 1974). During an unusually hot summer, Hawkins & Hartnoll (1985) observed damaged *Corallina officinalis* and other red algae. Littler & Kauker, (1984) suggest that the basal crustose stage is adaptive, allowing individuals to survive periods of physical stress as well as physiological stress such as desiccation and heating. The basal crust stage may persist for extended periods with frond regrowth occurring when conditions are favourable.

Osmundea pinnatifida turfs growing on the upper extent of its usual zone in the Isle of Man experience greater desiccation and are shorter and less dense than those lower on the shore (Prathep, 2001), suggesting that habitat quality (measured through growth) decreases with increasing shore height. In laboratory experiments short-term photosynthesis of *Osmundea pinnatifida* was inhibited where fronds had lost more than 50% of their water content (Prathep, 2001). Following resubmergence fronds that had lost 50 % of water content had fully recovered (measured as photosynthesis reaching maximal value) after 1 hour while fronds exposed to 70% water loss took 5 hours to recover (Prathep, 2001). Repeated exposure to high levels of desiccation would clearly impact growth.

Experimental grazer removal has allowed algae including *Palmaria palmata*, *Ceramium* sp. and *Osmundea* (as *Laurenci*a) *pinnatifida* to grow higher on the shore (during winter and damp summers) than usual suggesting that grazing also limits the upper shore extent of this biotope (Hawkins & Hartnoll, 1985). *Palmaria palmata* grew more abundantly higher up the shore following the massive mortality of molluscan grazers after the Torrey Canyon oil spill (Hawkins & Hartnoll, 1983). *Palmaria palmata* also grew more abundantly higher up the shore following the massive mortality of molluscan grazers after the Torrey Canyon oil spill (Hawkins & Hartnoll, 1983). These observations and further grazer removal experiments by Boaventura *et al*., (2003), indicate that grazing, in combination with physiological tolerances, limits the upper shore extent of biotopes characterized by red algal turfs on moderately and more exposed shores, where grazing is greater than on sheltered shores (Hawkins & Hartnoll, 1983, Boaventura *et al*., 2003). These results concord with other studies that show grazing and emersion stress limit the height to which red algal turfs can extend (Underwood, 1980, Boaventura, 2000).

Occurrence of encrusting coralline algae seems to be critically determined by exposure to air and sunlight. Colonies survive in damp conditions under algal canopies or in pools but not on open rock where desiccation effects are important. Increased emergence leading to drying out of shallow pools would reduce habitat suitability for this group. Spore release by the crusting coralline *Lithophyllum incrustans* is triggered by small changes in salinity and temperature and therefore changes in emergence may alter patterns in reproduction and recruitment (see relevant pressures for further information). However, this species does occur both high and low in the intertidal (Edyvean & Ford, 1986) and presumably such impacts are limited

A decrease in emergence will reduce exposure to desiccation and extremes of temperature and allow the resident *Pholas dactylus*, *Barnea candida* and *Petricolaria pholadiformis* to feed for longer periods and hence grow faster. No information was found on factors controlling the lower limit of piddock populations and it is possible, for example, that predation (predominantly siphon nipping by gobies, and other species, Micu, 2007) may increase at the lower edge of the biotope. Competition for space with species better adapted to the changed conditions may also alter habitat suitability for this biotope.

Mobile epifauna are likely to relocate to more suitable habitats. Species such as *Patella vulgata* and *Littorina littorea* that are found throughout the intertidal zone are adapted to tolerate desiccation to some extent. For example, littorinids can seal the shell using the operculum while limpets clamped tightly to rock will reduce water loss.

Sensitivity assessment. The biotope occurs in the eulittoral zone, where it experiences regular immersion and emersion. Species present are therefore tolerant of periods of emergence to some extent, however changes in emergence regime may alter habitat suitability and increase levels of predation and competition. Other species better able to tolerate desiccation are likely to competitively displace *Fucus serratus* following increased emergence. A significant, long-term, increase in emergence is therefore considered likely to lead to replacement of this biotope with one that is similar but more typical of the changed conditions with less red algae. *Corallina officinalis* and associated red algae are intolerant of desiccation but basal crusts may allow individuals to persist in conditions that are unfavourable to frond development until the emergence regime is re-established. Following a decrease in emergence *Fucus serratus* may be replaced by *Laminaria digitata* leading to biotope reclassification. Based on these considerations, resistance to changes in emergence is assessed as 'Medium' as changes may alter the upper or lower margins of the biotope. Resilience is assessed as 'Medium' for piddocks so that sensitivity is assessed as 'Medium'.

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

No direct evidence was found to assess sensitivity to this pressure. The biotope typically occurs in moderately wave exposed locations (Connor et al., 2004). The piddocks and *Hiatella arctica* are unlikely to be directly affected by changes in wave exposure, owing to their environmental position within the substratum, which protects them. Trudgill & Crabtree(1987) found *Hiatella arctica* at both sheltered and wave exposed sites, suggesting that substratum, rather than wave action is a more significant factor determining distribution. On chalk and clay substrates, it is possible however, that wave action actively erodes the substratum at a faster rate than the piddocks can burrow leaving them exposed to predators or displaced. At higher densities bioerosion by piddocks may destabilise the substratum increasing vulnerability to erosion.

Fucus serratus is highly flexible but not physically robust and wave action leads to frequent mechanical damage, breaking fronds or even dislodging algae from the substratum (Knight & Parke, 1950). Fucoids are permanently attached to the substratum and are not able to re-attach if removed. An increase or reduction in wave action at the pressure benchmark is considered to have little effect as *Fucus serratus* is naturally found in both sheltered conditions and on moderately exposed and exposed shores. Wave action plays a role in determining the shore level at which *Fucus serratus* is found, with stands tending to occur lower on the shore where it is exposed to greater wave action (Southward & Orton, 1954). Modelled predictions of the change in percentage cover of *Fucus serratus* in response to climate change induced increases in wind speed (and hence wave height), suggest that *Fucus serratus* would be resilient to 20% and 40% increases in wind speed (Hawkins *et al*., 2009). Although this is not directly related to the pressure benchmark it suggests that *Fucus serratus* occurs across a range of wave exposures and thus wave heights. The *Fucus serratus* canopy will provide some protection from wave action to the under canopy species assemblage.

As water velocity increases algae can flex and reconfigure to reduce the size of the alga when aligned with the direction of flow, this minimises drag and hence the risk of dislodgement (Boller & Carrington, 2007). Within a canopy the friction between the fronds and water slows flow reducing drag. On exposed shores, larger, dense patches of *Osmundea pinnatifida* were more able to withstand increased wave action in winter than small patches, which were severely damaged, presumably due to the number and density of stolons (Prathep, 2001) These characteristics allow these species to persist on shores that experience a range of wave action levels. Flat growth forms also minimise drag and crustose bases and encrusting corallines are able to withstand high levels of water movement. Colonies of *Lithophyllum incrustans* appear to thrive in conditions exposed to strong water movement and Irvine & Chamberlain (1994) observe that the species is best developed on wave exposed shores.

A decrease in wave exposure may ultimately reduce *Patella vulgata* abundance because the species does not favour thick algal cover that is often present on more sheltered shores. Alternatively an increase in significant wave height, linked to increased exposure, may result in population changes with fewer macroalgae and with more *Chthamalus* sp. present than *Semibalanus balanoides* (Ballantine, 1961) and the limpet *Patella ulyssiponensis* present, or present in greater numbers, rather than P*atella vulgata* (Thompson, 1980). These changes are not considered to lead to a significant change in biotope character as species replacements are functionally similar.

Potentially the most damaging effect of increased wave heights would be the erosion of the clay substratum as this could eventually lead to loss of the habitat. Increased erosion would lead to the loss of habitat and removal of piddocks. No evidence was found to link significant wave height to erosion. Some erosion will occur naturally and storm events may be more significant in loss and damage of clays than changes in wave height at the pressure benchmark. Micu (2007) for example observed numerous Pholas dactylus that had been washed out of the clay substratum or exposed due to storm damage to the clay in the Romanian Black Sea.

Sensitivity assessment. No direct evidence was found to assess this pressure at the benchmark.Based on the distribution of *Fucus serratus* on shores of varying exposure and the modelled data , *Fucus serratus* is considered to have 'High' resistance' and 'High' resilience to this pressure. This species is therefore considered to be 'Not sensitive' at the pressure benchmark. The algal turf and piddocks are also considered to have 'High' resistance to changes at the pressure benchmark where these do not lead to increased erosion of the substratum. Resilience is therefore assessed as 'High' and the biotope is considered to be 'Not sensitive', at the pressure benchmark.

Chemical Pressures

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

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

However, exposure to contaminants at levels greater than the benchmark may lead to impacts, although no evidence was found for sensitivity of piddocks. Bryan (1984) suggested that the general order for heavy metal toxicity in seaweeds is: Organic Hg > inorganic Hg > Cu > Ag > Zn > Cd > Pb. Cole *et al.* (1999) reported that Hg was very toxic to macrophytes. The sub-lethal effects of Hg (organic and inorganic) on the sporelings of another intertidal red algae, *Plumaria elegans*, were reported by Boney (1971), where 100% growth inhibition was caused by 1 ppm Hg in his study. However, no information concerning the effects of heavy metals on *Palmaria palmata* was found. Heavy metals have the potential to accumulate in plant tissue, therefore it may take some time for tissue levels to fall before recovery can begin.

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.

However, exposure to contaminants at levels greater than the benchmark may lead to impacts, although no evidence was found for sensitivity of piddocks. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil or dispersant contamination, possibly due to the susceptibility of phycoerythrins to destruction, but that the filamentous forms were the most sensitive. Laboratory studies of the effects of oil and dispersants on several red algae species, including *Palmaria palmata* (Grandy, 1984 cited in Holt *et al.* 1995) concluded that they were all sensitive to oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages.

In areas of moderate oil deposit, up to about 1/2cm thick, on rocks after the *Torrey Canyon* oil spill, limpets had survived unscathed over a month after the event and feeding continued even though a coating of oil smothered their food source of algae and diatoms (Smith, 1968). Limpets can ingest thick oil and pass it through their gut. However, thick layers of oil smothering individuals will interfere with respiration and spoil normal food supplies for *Patella vulgata*. After the *Braer* oil spill, in common with many other oil spills, the major impact in the intertidal zone was on the population of limpets and other grazers. In West Angle Bay, where fresh oil from the *Sea Empress* tanker reached rocky shores within one day of the spill, limpet mortality was 90% (Glegg *et al*., 1999). Thus *Patella vulgata* has higher intolerance to fresh oil which has a high component of volatile hydrocarbons remaining. A significant reduction in the density of juvenile limpets was also observed at all sites known to have been oiled by the *Sea Empress* spill (Moore, 1997). In longer term studies into the environmental effects of oil refinery effluent discharged into Littlewick Bay, Milford Haven, the number of limpets, usually found in substantial numbers on this type of shore, were considerably reduced in abundance on areas close to the discharge (Petpiroon & Dicks, 1982). In particular only large individuals were found close to the outfall point and juveniles were completely absent, suggesting that observed changes in abundance resulted from effluent effects on larval stages rather than upon adults directly.

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.

However, exposure to synthetic chemical at levels greater than the benchmark may lead to impacts, although no evidence was found for sensitivity of piddocks. O'Brien & Dixon (1976) suggested that red algae were the most sensitive group of algae to oil contamination, although the filamentous forms were the most sensitive. Laboratory studies of the effects of oil and dispersants on several red algae species (Grandy, 1984 cited in Holt *et al.*, 1995) concluded that they were all intolerant of oil/ dispersant mixtures, with little differences between adults, sporelings, diploid or haploid life stages. Cole *et al.* (1999) suggested that herbicides, such as simazina and atrazine were very toxic to macrophytes. Hoare & Hiscock (1974) noted that all red algae was excluded from Amlwch Bay, Anglesey by acidified halogenated effluent discharge.

Limpets are extremely intolerant of aromatic solvent based dispersants used in oil spill clean-up. During the clean-up response to the *Torrey Canyon* oil spill nearly all the limpets were killed in areas close to dispersant spraying. Viscous oil will not be readily drawn in under the edge of the shell by ciliary currents in the mantle cavity, whereas detergent, alone or diluted in seawater, would creep in much more readily and be liable to kill the limpet (Smith, 1968). A concentration of 5ppm killed half the limpets tested in 24 hours (Southward & Southward, 1978; Hawkins & Southward, 1992). Acidified seawater affects the motility of *Patella vulgata*. At a pH of 5.5 motility was reduced whilst submerged but individuals recovered when returned to normal seawater. At a pH of 2.5 total inhibition of movement occurred and when returned to normal seawater half had died (Bonner *et al.*, 1993). Reduced motility reduces time for foraging and may result in decreased survival of individuals. Acidified seawater can also change the shell composition which will lead to a decrease in its protective nature and hence survival (Bonner *et al.*, 1993). Short periods (48 hours) are unlikely to have much effect on a population but long periods (1 year) may cause reduced grazing and an increase in algal growth. However, seawater is unlikely to reach pH 2.5 therefore intolerance to slight changes in pH will be low. Hoare & Hiscock (1974) reported that in Amlwch Bay *Patella vulgata* was excluded from sites within 100-150m of the discharge of acidified, halogenated effluent.

Radionuclide contamination	No evidence (NEv) Q: NR A: NR C: NR	Not relevant (NR) Q: NR A: NR C: NR	No evidence (NEv) Q: NR A: NR C: NR

No evidence was found to assess this pressure at the benchmark. Algae bioaccumulate radionuclides (with extent depending on the radionuclide and the algae species). Adverse effects have not been reported at low levels.

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

This pressure is **Not assessed**.

De-oxygenation	High Q: Low A: NR C: NR	High Q: High A: High C: High	Not sensitive Q: Low A: Low C: Low

Specific information concerning oxygen consumption and reduced oxygen tolerances were not found for important characterizing species within the biotope. Cole *et al.* (1999) suggested possible adverse effects on marine species below 4 mg O_2/l and probable adverse effects below 2mg O_2/l .

This biotope would only be exposed to low oxygen in the water column intermittently during periods of tidal immersion. In addition, in areas of wave exposure and/or moderately strong current flow, low oxygen levels in the water are unlikely to persist for very long as oxygen levels will be recharged by the incorporation of oxygen in the air into the water column or flushing with oxygenated waters.

Duval (1963a) observed that conditions within the borings of *Petricolaria pholadiformis* were anaerobic and lined with a loose blue/black sludge, suggesting that the species may be relatively tolerant to conditions of reduced oxygen.

Reduced oxygen concentrations have been shown to inhibit both photosynthesis and respiration in macroalgae (Kinne, 1977). Despite this, macroalgae are thought to buffer the environmental conditions of low oxygen, thereby acting as a refuge for organisms in oxygen depleted regions especially if the oxygen depletion is short-term (Frieder *et al.*, 2012).

The associated invertebrate species also show high tolerances for reduced oxygen at levels that exceed the pressure benchmark. *Semibalanus balanoides* can respire anaerobically, so they can tolerate some reduction in oxygen concentration (Newell, 1979). When placed in wet nitrogen, where oxygen stress is maximal and desiccation stress is low, *Semibalanus balanoides* have a mean survival time of 5 days (Barnes *et al.*, 1963). Limpets can also survive for a short time in anoxic seawater; Grenon & Walker, (1981) found that in oxygen free water limpets could survive up to 36 hours, although Marshall & McQuaid (1989) found a lower tolerance for *Patella granularis*, which survived up to 11 hours in anoxic water. *Patella vulgata* and littorinids are able to respire in air, mitigating the effects of this pressure during the tidal cycle.

Sensitivity assessment. As the biotope will only be exposed to this pressure when emersed and respiration of characterizing and associated will occur in air, biotope resistance was assessed as ‘High’ and resilience as ‘High’ (no effect to recover from), resulting in a sensitivity of 'Not sensitive'.

Nutrient enrichment	High Q: High A: Medium C: High	High Q: High A: High C: High	Not sensitive Q: High A: Medium C: High

This pressure relates to increased levels of nitrogen, phosphorus and silicon in the marine environment compared to background concentrations. The benchmark is set at compliance with WFD criteria for good status, based on nitrogen concentration (UKTAG, 2014). No evidence was found to assess the sensitivity of piddocks to this pressure and it is unlikely that they, and other animal species present in the biotope, would be directly affected by this pressure.

Marine algae are often nutrient limited, by nitrogen in particular, so an increase in nutrient levels usually results in increase growth and fecundity. In the Bay of Fundy, for example, where there is a tidal flux of nutrients from the marshes there is luxurious growth of *Palmaria palmata*. However, very high levels of nutrients can be toxic to macroalgae. (Morgan *et al.*, 1980). In general, the great majority of reports refer to an increase in the number of green algae associated with eutrophicated waters, usually at the expense of red and brown algae. Stimulation of annual ephemerals may accentuate the competition for light and space and hinder perennial species development or harm their recruitment (Kraufvelin *et al.*, 2007). Kraufvelin *et al.* (2006) found only minor effect on the fucoid community structure as a response to high nutrient levels during the first 3 years of an enrichment experiment. During the 4th year of exposure however, *Fucus serratus* started to decline and population consequently crashed in the 5th year. The study observed full recovery of algal canopy and animal community in less than 2 year after conditions returned to normal. The results indicate that established rocky shore communities of perennial algae with associated fauna are able to persist for several years, even at very high nutrient levels, but that community shifts may suddenly occur if eutrophication continues. They also indicate that rocky shore communities have the ability to return rapidly to natural undisturbed conditions after the termination of nutrient enhancement.

Atalah & Crowe (2010) added nutrients to rockpools occupied by a range of algae including encrusting corallines, turfs of *Mastocarpus stellatus*, *Chondrus crispus* and *Corallina officinalis* and green and red filamentous algae. The invertebrates present were mostly *Patella ulyssiponensis*, the winkle *Littorina littorea* and the flat top shell *Gibbula umbilicalis*. Nitrogen and phosphorous enhancement was via the addition of fertilisers, as either 40 g/litre or 20 g/litre. The treatments were applied for seven month and experimental conditions were maintained every two weeks. The experimental treatments do not directly relate to the pressure benchmark but indicate some general trends in sensitivity. The cover of green filamentous algae was significantly increased both by reduced grazing and increased nutrients, although the effect size was synergistically magnified by the combined effect of grazer removal and nutrients. Nutrient enrichment caused an absolute increase in the average cover of green filamentous algae of 19% (±3.9 S.E.) respect to the control treatments while the cover of red turfing algae was not affected by nutrient addition (Atalah & Crowe, 2010)

Sensitivity assessment. The pressure benchmark is relatively protective and may represent a reduced level of nutrient enrichment in previously polluted areas. Resistance to this pressure is therefore assessed as 'High' and resilience as 'High' so that the biotope is assessed as 'Not sensitive'.

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

Organic enrichment and nutrient enrichment commonly co-occur, for example sewage deposits or outputs from fish farms may enhance nitrogen and phosphorous and organic matter. Nutrient enrichment alters the selective environment by favouring fast growing, ephemeral species such as *Ulva lactuca* and *Ulva intestinalis* (Berger *et al.*, 2004, Kraufvelin, 2007). Rohde *et al.*, (2008) found that both free growing filamentous algae and epiphytic microalgae can increase in abundance with nutrient enrichment. This stimulation of annual ephemerals may accentuate the competition for light and space and hinder perennial species development or harm their recruitment (Berger *et al.*, 2003; Kraufvelin *et al.*, 2007). Nutrient enrichment can also enhance fouling of *Fucus* fronds by biofilms (Olsenz, 2011). Nutrient enriched environments can not only increase algae abundance, but the abundance of grazing species (Kraufvelin, 2007). High nutrient levels may directly inhibit spore settlement and hinder the initial development of *Fucus vesiculosus* (Bergström *et al.*, 2003). Bellgrove *et al.* (2010) found that coralline turfs out-competed fucoids at a site associated with organic enrichment caused by an ocean sewage outfall.

No evidence was found to assess the sensitivity of piddocks to this pressure.

Sensitivity assessment. The algae within the biotope are not considred likely to be directly affected by an increase in organic matter at the pressure benchmark. The fronds of algae may intercept particles and may remove these from the chalk surfaces, when emmersed, by the movement of fronds. Suspension feeders inccluding barnacles and piddocks may be able to ustilise particles as food. Piddocks are likely to be able to withstand a small level of deposition of organic matter (at the pressure benchmark). Resistance is assessed as 'High' and resilience as 'High' so that the biotope is considered to be 'Not sensitive'.

Physical Pressures

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

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

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

This biotope is characterized by the soft chalk substratum which supports populations of burrowing piddocks (JNCC, 2015). A change to a sedimentary or hard impenetrable substratum would result in the loss of piddocks significantly altering the character of the biotope. The biotope is therefore considered to have 'No' resistance to this pressure, the change at the pressure benchmark is permanent and resilience is therefore assessed as 'Very low' and sensitivity is assessed as 'High'.

Physical change (to another sediment type)	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. This pressure is relevant only to sedimentary biotopes.

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

The removal of substratum to 30cm depth will remove the entire biological assemblage in the impact footprint. Resistance is therefore assessed as ‘None’, recovery of the biological assemblage (following habitat restoration) is considered to be 'Medium' (2-10 years) but see caveats in the recovery notes. The biotope is dependent on the presence of chalk or other soft rock, when lost restoration would not be feasible and recovery is therefore categorised as 'Very low'. Sensitivity is therefore assessed as 'High', based on the lack of recovery on substratum.

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

Within this biotope the algae and epifauna could be damaged and removed by surface abrasion. Some species protruding from the surface, e.g. *Polydora* spp. may also be removed. Although the piddocks are afforded some protection from surface abrasion by living in their burrows, damage to the chalk may leave individuals, especially those near the surface, vulnerable to damage and death through exposure, sediment damage and compaction. Micu (2007) for example observed that after storms in the Romanian Black Sea, the round goby, *Neogobius melanostomus*, removed clay from damaged or exposed burrows to be able to remove and eat piddocks.

The most significant impact may be on the chalk substratum by removing or damaging surface layers resulting in the chalk being more vulnerable to erosion. Natural erosion processes are, however, likely to be on-going within this habitat type. Where abundant the boring activities of piddocks contribute significantly to bioerosion, which can make the substratum habitat more unstable and can result in increased rates of coastal erosion (Evans 1968a; Trudgill 1983; Trudgill & Crabtree, 1987). Pinn *et al.* (2005) estimated that over the lifespan of a piddock (12 years), up to 41% of the shore could be eroded to a depth of 8.5 mm.

Sensitivity assessment. Surface abrasion may remove the algae and epifauna and result in the loss of some piddocks and damge to habitat. Resistance is therefore assessed as 'Low' for the algae and 'Medium' for piddocks and substratum. The algal mat and surface infauan are predicted to recover within 2 years, so that resilience is considered to be 'High' and sensitivity is 'Low'. As the substratum cannot recover, resilience is assessed as 'Very Low' and the sensitivity of the overall biotope is considered to be 'Medium'. The more precautionary assessments, based on the substratum, are presented in the risk assessment table.

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

Penetration and disturbance below the surface of the substratum will damage and remove the algae and surface fauna and could damage and expose piddocks. Piddocks in damaged burrows or those that are removed from the substratum are unlikely to be able to rebury and will be predated by fish and other mobile species (Micu, 2007). The most significant impact may be the damage and removal of the chalk substratum. Where abundant the boring activities of piddocks can make the substratum habitat more unstable and can exacerbate erosion (Evans 1968a; Trudgill 1983; Trudgill & Crabtree, 1987). Pinn *et al.* (2005) estimated that over the lifespan of a piddock (12 years), up to 41% of the shore could be eroded to a depth of 8.5 mm. this would make the substratum more vulnerable to damage and removal.

Sensitivity assessment. Sub-surface penetration and disturbance will remove and damage algae and surface dwelling fauna and result in the loss of piddocks and damage to the habitat. Resistance is therefore assessed as 'Low'. The algae and epifauna are predicted to remover relatively rapidly and the piddocks within 2-10 years so that resilience of the biological assemblage is considered to be ‘Medium’ and sensitivity is ‘Medium’. As the substratum cannot recover, resilience is assessed as ‘Very Low’ and sensitivity of the overall biotope is considered to be ‘High’. The more precautionary assessment has been entered into the risk assessment table.

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

Intertidal biotopes will only be exposed to this pressure when submerged during the tidal cycle and thus have limited exposure. Siltation, which may be associated with increased suspended solids and the subsequent deposition of these is assessed separately (see siltation pressures). In general, increased suspended particles reduce light penetration and increase scour and deposition. Changes in suspended solids may enhance food supply to filter or deposit feeders (where the particles are organic in origin) or decrease feeding efficiency (where the particles are inorganic and require greater filtration efforts). This biotope is sand or silt affected (Connor *et al.*, 2004) and may therefore experience episodes with relatively high levels of turbidity from resuspension, an increase at the pressure benchmark for extended periods may exceed tolerances of sensitive species.

Changes in suspended solids affecting water clarity will have a direct impact on photosynthesis in *Fucus serratus*. Irradiance below the light compensation point of photosynthetic species can compromise growth (Middelboe *et al.*, 2006). However turbidity is only relevant when the biotope is covered with water as seaweed photosynthesis declines on emersion and recommences when recovered with water. Increased siltation may cover the frond surface of *Fucus serratus* and other macroalgae with a layer of sediment further reducing photosynthesis and growth rate. Sediment deposition can also interfere with attachment of microscopic stages of seaweeds reducing recruitment (see ‘siltation’ pressures). In extreme turbidity, such as found in the Bristol Channel, *Fucus serratus* is excluded from the bottom of the intertidal (below 2m above chart datum) due to the lack of light for sustained growth (Chapman, 1995).

Increases in the cover of sediment trapping, turf forming red algae at the expense of canopy forming species has been observed worldwide in temperate systems and has been linked to increased suspended solids linked to human activities worldwide (Airoldi, 2003). As turfs of *Osmundea pinnatifida* trap sediments (Prathep *et al.*, 2003), it is clear that this species has some resistance to abrasion and scour from sediment particles. *Corallina* species accumulate more sediment than any other alga (Hicks, 1985). Hence an increase in suspended sediment is likely to accumulate in the patches of *Corallina officinalis*. A significant increase may result in smothering (see siltation pressures). An accumulation of sediment within the turf may attract more sediment dwelling interstitial invertebrates such as nematodes, harpacticoids and polychaetes, although in more wave exposed locations accumulation of sediment is likely to be minimal. Increased suspended sediment may also result in increased scour, which may adversely affect *Fucus vesiculosus* and foliose red algae, and interfere with settling spores and recruitment if the factor is coincident with their major reproductive period. However, coralline algae, especially the crustose forms are thought to be resistant of sediment scour (Littler & Kauker, 1984), and will probably not be adversely affected at the benchmark level.

Red algae and coralline algae especially are known to be shade tolerant and are common components of the understorey on seaweed dominated shores. Limited shading from suspended sediments is therefore not considered to negatively affect this genus. *Palmaria palmata* is often found under partially shaded conditions as an epiphyte on the stems of *Laminaria* spp. (Morgan *et* *al*. 1980) in the sublittoral zone (Lüning 1990). In the Bay of Fundy where the tidal flux of nutrients from the marshes includes a high level of suspended sediment, *Palmaria palmata* grows well despite high turbidity. Irvine (1983), observed morphological adaptation of the plant in fairly sheltered, silty conditions; sometimes the blade divisions are wedge-shaped and finely dissected above or the blade has numerous linear divisions throughout. It is likely that this form reduces possible smothering that may result from increased siltation resulting from increased levels of suspended sediments. In the absence of nutrients short-term increase in turbidity may affect growth and reproduction, however, as a perennial, the adults will probably survive. Other red algal species have high tolerances for high levels of suspended solids. *Chondrus crispus* occurs in areas of sand covered rock in the subtidal biotope IR.HIR.KSed.ProtAhn suggesting it is very resistant to high levels of turbidity and scour associated with high levels of resuspended particles.

On sites affected by high levels of resuspended colliery waste particles, Hyslop *et al*., (1997) found that *Palmaria palmata* and *Ulva* spp. were reduced or absent, although the more tough fucoids were less affected. It is not clear how the levels of suspended solids experienced by these sites relate to the pressure benchmark.

No direct evidence was found to assess this pressure for piddocks and other invertebrate species. Increased suspended particles will decrease light penetration, may enhance food supply (where these are organic in origin) or decrease feeding efficiency (where the particles are inorganic and require greater filtration efforts). Very high levels of silt may clog respiratory and feeding organs of some suspension feeders. Increased levels of particles may increase scour and deposition in the biotope depending on local hydrodynamic conditions. The piddocks are protected from scour within burrows and increased organic particles will provide a food subsidy. *Pholas dactylus* occurs in habitats such as soft chalks where turbidity may be high and is therefore unlikely to be affected by an increase in suspended sediments at the pressure benchmark. Piddocks, in common with other suspension feeding bivalves, have efficient mechanisms to remove inorganic particles via pseudofaeces. Experimental work on *Pholas dactylus* showed that large particles can either be rejected immediately in the pseudofaeces or passed very quickly through the gut (Knight, 1984). Similarly *Petricolaria pholadiformis* is able to tolerate high-levels of suspended solids through the production of pseudofaeces (Purchon, 1955). Increased suspended sediments may impose sub-lethal energetic costs on piddocks by reducing feeding efficiency and requiring the production of pseudofaeces with impacts on growth and reproduction.

A significant decrease in suspended organic particles may reduce food input to the biotope resulting in reduced growth and fecundity of piddocks. However, local primary productivity may be enhanced where suspended sediments decrease, increasing food supply. Decreased suspended sediment may increase macroalgal competition enhancing diversity but is considered unlikely to significantly change the character of the biotope.

Sensitivity assessment. The exposure of this biotope to suspended sediments in the water column will be limited to immersion periods, and wave action will reduce accumulation. The biotope is considered to be 'Not sensitive' to a reduction in suspended solids, although this may reduce food supply to piddocks, barnacles and other filter and deposit feeders that occur in this biotope. The piddocks are considered 'Not sensitive' to an increase in suspended solids, although this may lead to some sub-lethal abrasion of fronds of *Fucus serratus* and some reduction in photosynthesis while submerged with some effects on recruitment. Evidence globally indicates that increase suspended solids favour the turf-forming algae that occur within this biotope (Airoldi, 2003). Resistance is therefore assessed as 'Low-Medium' and resilience as 'High' so that sensitivity of the biotope is considered to be 'Low'. An increase in suspended solids at the pressure benchmark may result in a change in species composition with an increase in species seen in very turbid, silty environments e.g. *Rhodothamniella floridula* which are already found in some examples of this biotope.

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

Fucus serratus and the red algae present in this biotope are attached to the substratum by a holdfast is thus not able to relocate in response to increased sedimentation. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. Sedimentation of bedrock can impede attachment of *Fucus* embryos as well as decrease survival and growth of juvenile through both scour and burial (Schiel *et al*., 2006). An increase in the vertical sediment overburden can also reduce growth whilst hindering the regeneration abilities of adults (Umar *et al*., 1998). The state of the tide will mediate the extent of impact. If smothering occurs at low tide when the algae is lying flat on the substratum, then most of the organism as well as the associated community will be covered by the deposit of fine material at the level of the benchmark. However, if smothering occurs whilst the alga is submerged standing upright then the photosynthetic surfaces of adult plants will be left uncovered. The resistance of this biotope group to this pressure may thus vary with time of day. Germlings however are likely to be smothered and killed in both scenarios and are inherently most susceptible to this pressure. Smothering will cause direct mortalities in the associated community, particularly in sessile organisms unable to relocate. Lower densities of herbivores such as *Patella vulgata* have also been attributed to increased sedimentation as silt will reduce their feeding activity and limit their movements (Airoldi & Hawkins, 2007; Schiel *et al*., 2006).

The burrowing mechanisms of the piddocks *Pholas dactylus* and *Barnea candida* and other Pholads, mean that the burrows have a narrow entrance excavated by the juvenile. As the individual grows and excavates deeper the burrow widens resulting in a conical burrow from which the adult cannot emerge. *Petricolaria pholadiformis* excavates a cylindrical burrow (Ansell, 1970) and hence may be able to relocate in sandy sediments, however although burrowing mechanisms have been studied, however no evidence was found to suggest this species can re-emerge through sediments and re-bury. Piddocks cannot therefore emerge from layers of deposited silt as other more mobile bivalves can.

No examples of direct empirical evidence or experiments on mortality rates have been found. Sometimes the substratum in which piddocks reside is covered by a thin layer of loose sandy material, through which the piddocks maintain contact with the surface via their siphons. It is likely that the piddocks would be able to extend their siphons through loose material, particularly where tidal movements shift the sand around. *Pholas dactylus* have been found living under layers of sand in Aberystwyth, Wales, (Knight, 1984) and in Eastbourne, with their siphons protruding at the surface (Pinn *et al*., 2008). *Barnea candida* has also been found to survive being covered by shallow layers of sand in Merseyside (Wallace & Wallace, 1983). Wallace & Wallace (1983) were unsure as to how long the *Barnea candida* could survive smothering but noted that, on the coast of the Wirral, the piddocks have survived smothering after periods of rough weather. Where smothering is constant, survival can be more difficult. The redistribution of loose material following storms off Whitstable Street, in the Thames Estuary, is thought to be responsible for the suffocation of many *Petricolaria pholadiformis* and it is possible that this species may be the most intolerant of the three piddock species associated with this biotope. However, it was not known how deep the layer of 'loose material' was, nor how long it lasted for or what type of material it was made up of.

Indirect indications for the impacts of siltation are provided by studies of Witt *et al*., (2004) on the impacts of harbour dredge disposal. *Petricola pholadiformis* was absent from the disposal area, and Witt *et al*., (2004) cite reports by Essink (1996, not seen) that smothering of *Petricola pholadiformis* from siltation could lead to mortality within a few hours. Hebda (2011) also identified that sedimentation may be one of the key threats to *Barnea truncata* populations. At Agigea (Micu, 2007) reported that smothering of clay beds by sand and finer sediments had removed populations of *Pholas dactylus*. In this area sand banks up to 1m thick frequently shift position driven by storm events and currents (Micu, 2007). Similar smothering was described in the case of *Barnea candida* populations boring into clay beds (Gomoiu & Muller 1962, cited from Micu, 2007).

Species comprising, and living within the dense algal mat are likely to be intolerant of smothering. Sporelings would certainly be adversely affected as Vadas *et al*. (1992) stated that algal spores and propagules are adversely affected by a layer of sediment, which can exclude up to 98% of light.

Sensitivity assessment. As piddocks are essentially sedentary and as siphons are relatively short, siltation from fine sediments rather than sands, even at low levels for short periods could be lethal. Resistance to siltation is assessed as ‘Low’ for piddocks and the algal mat although effects would be mitigated where water currents and wave exposure rapidly removed the overburden and this will depend on shore height and local hydrodynamic conditions. Resilience is assessed as ‘Medium’ (2-10 years) for piddocks and sensitivity is therefore assessed as ‘Medium’.

Smothering and siltation rate changes (heavy)	None Q: Low A: NR C: NR	Medium Q: High A: Low C: Medium	Medium Q: Low A: Low C: Low

Fucus serratus and the red algae present in this biotope are attached to the substratum by a holdfast is thus not able to relocate in response to increased sedimentation. Smothering will prevent photosynthesis resulting in reduced growth and eventually death. Sedimentation of bedrock can impede attachment of *Fucus* embryos as well as decrease survival and growth of juvenile through both scour and burial (Schiel *et al*., 2006). An increase in the vertical sediment overburden can also reduce growth whilst hindering the regeneration abilities of adults (Umar *et al*., 1998). The state of the tide will mediate the extent of impact. If smothering occurs at low tide when the algae is lying flat on the substratum, then most of the organism as well as the associated community will be covered by the deposit of fine material at the level of the benchmark. However, if smothering occurs whilst the alga is submerged standing upright then the photosynthetic surfaces of adult plants will be left uncovered. The resistance of this biotope group to this pressure may thus vary with time of day. Germlings however are likely to be smothered and killed in both scenarios and are inherently most susceptible to this pressure. Smothering will cause direct mortalities in the associated community, particularly in sessile organisms unable to relocate. Lower densities of herbivores such as *Patella vulgata* have also been attributed to increased sedimentation as silt will reduce their feeding activity and limit their movements (Airoldi & Hawkins, 2007; Schiel *et al*., 2006).

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Sensitivity assessment. Siltation at the pressure benchmark is considered to remove most or all of the piddocks and the surface algae and fauna. Resistance to siltation is therefore assessed as ‘None' although effects could be mitigated where water currents and wave exposure rapidly removed the overburden and this will depend on shore height and local hydrodynamic conditions. Resilience is assessed as ‘Medium’ (2-10 years) for piddocks and sensitivity is therefore assessed as ‘Medium’.

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

Not assessed.

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

No evidence.

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

Not relevant.

Introduction of light or shading	Low Q: Low A: NR C: NR	High Q: High A: Low C: Medium	Low Q: Low A: Low C: Low

Increased levels of diffuse irradiation correlate with increased growth in macroalgae (Aguilera *et al*., 1999). Macroalgae require light to photosynthesisare so that changes in light intensity are likely to affect photosynthesis, growth, competition and survival. Chapman (1995) noted that too little or too much light are likely to be stresses. There is considerable literature on the light compensation point of marine algae (see Lüning, 1990) but it is difficult to correlate such evidence with 'shading', as light saturation and compensation points depend on light availability, light quality, season and turbidity. As fucoids are out-competed in sublittoral conditions, it is likely that permanent shading woud affect their growth and allow them to be out-competed by other, more shade tolerant species, within the affected area.

Red algae, in general, are shade tolerant, often occurring under a macroalgal canopy that reduces light penetration. In areas of higher light levels, the fronds may be lighter in colour due to bleaching (Colhart & Johansen, 1973). Other red algae in the biotope are flexible with regard to light levels. Canopy removal experiments in a rocky sub tidal habitat in Nova Scotia, Canada by Schmidt & Scheibling (2007) did not find a shift in understorey macroalgal turfs (dominated by *Corallina officinalis*, *Chondrus crispus* and *Mastocarpus stellatus*) to more light-adapted species over 18 months.

Pholas dactylus can perceive and react to light (Hecht, 1928) however there is no evidence that this pressure would impact the piddocks within the biotope.

Sensitivity assessment. As fucoids are out-competed in sublittoral conditions, it is likely that permanent shading would affect their growth and allow them to be out-competed by other, more shade tolerant species, such as red algae within the affected area. The loss of *Fucus serratus* would lead to biotope reclassification, therefore a biotope resistance of ' Low' is suggested, with low confidence. Resilience is assessed as 'High' so that sensitivity is 'Low.

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

Not relevant.

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	High Q: High A: High C: High	High Q: High A: High C: High	Not sensitive Q: High A: High C: High

This pressure is not relevant to the algae within the biotope. Most animals will be able to sense changes in light but atre unlikelyt o be affected by visual disturbance. *Pholas dactylus* reacts quickly to changes in light intensity, after a couple of seconds, by withdrawing its siphon (Knight, 1984). This reaction is ultimately an adaptation to reduce the risk of predation by, for example, approaching birds (Knight, 1984). However, its visual acuity is probably very limited and it is unlikely to be sensitive to visual disturbance. Birds are highly intolerant of visual presence and are likely to be scared away by increased human activity, therefore reducing the predation pressure on piddocks. Therefore, visual disturbance may be of indirect benefit to piddock populations and the biotope is considered to be ‘Not sensitive’. Resistance and resilience are therefore assessed as ‘High’ by default.

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

The species characterizing this biotope are not farmed or translocated and therefore this pressure is 'Not relevant' to this biotope.

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

The surface of the chalk is friable and subject to on-going erosion and therefore the suitability of this habitat for large, long-lived, attached species is limited. The red algal mat characterizing this biotope consists of small, ephemeral species, replacement of these species by invasive non-indigenous algal species could occur and alter the character of the biotope. However, no evidence was found in the literature to suggest that invasive non-indigenous species are present in UK marine and coastal peat habitats.

The presence of The American piddock, *Petricolaria pholadiformis* is a non-native, boring piddock that was unintentionally introduced from America with the American oyster, *Crassostrea virginica*, not later than 1890 (Naylor, 1957). Rosenthal (1980) suggested that from the British Isles, the species has colonized several northern European countries by means of its pelagic larva and may also spread via driftwood, although it usually bores into clay, peat or soft rock shores. In Belgium and The Netherlands *Petricolaria pholadiformis* almost completely displaced the native piddock, *Barnea candida* (ICES, 1972). However, this has not been observed elsewhere, and later studies have found that *Barnea candida* is now more common than *Petricolaria pholadiformis* in Belgium (Wouters, 1993) and there is no documentary evidence to suggest that *Barnea candida* has been displaced in the British Isles (J. Light & I. Kileen pers. comm. to Eno *et al*., 1997). *Petricolaria pholadiformis* is considered unlikely to displace *Pholas dactylus* which is more likely to occur subtidally. Should *Petricolaria pholadiformis* is be present in this biotope it is not considered to alter the character or ecological function of the biotope.

Although not currently established in UK waters, the whelk *Rapana venosa*, may spread to habitats. This species has been observed predating on *Pholas dactylus* in the Romanian Black Sea by Micu (2007).

Sensitivity assessment. Based on the lack of records of invasive non-indigenous species in this biotope, and the unsuitability of the habitat for algae and other attached epifauna this biotope is considered to have 'High' resistance to this pressure and, by default 'High' resilience, this biotope is therefore considered to be 'Not sensitive'. This assessment may need revising in light of future invasions, e.g. the introduction of the whelk *Rapana venosa*.

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

Very little is known about infections in *Fucus* (Wahl *et al*., 2012). Coles (1958) identified parasitic nematodes that caused galls on *Fucus serratus* in south west Britain. More recently, Zuccaro *et al*. (2008) detected a number of fungal species associated with *Fucus serratus*. So far no mortalities have been associated to the introduction of microbial pathogens. However, the potential for increased biotic interactions involving parasites or pathogens is on the rise in many marine systems (Torchin *et al*., 2002).

Sensitivity assessment. Based on the lack of evidence for major pathogens or significant mortalities of the key characterizing species this biotope is considered to have 'High' resistance and hence 'High' resilience and is classed as 'Not sensitive' at the pressure benchmark.

Removal of target species	Low Q: High A: High C: Medium	Medium Q: High A: Medium C: Medium	Medium Q: High A: Medium C: Medium

Piddocks may be removed as bait and across Europe they have traditionally been harvested for food, however high levels of habitat damage are associated with the removal of boring molluscs (Fanelli *et al*., 1994) and this practice has largely been banned. The most sensitive component of this biotope to targeted harvesting is the chalk substratum which may be damaged and removed if piddocks were excavated from their burrows, this effect is considered through the physical damage pressures, abrasion and penetration and sub-surface damage.

Fucus serratus is one of several harvested and exploited algal species. The commercial harvest removes seaweed canopies which will have direct and indirect effects on the wider ecosystem (Stagnol *et al*., 2013). Red algae that occur in this biotope may also be harvested. *Palmaria palmata* (known as dulse) is harvested from the wild both commercially and recreationally. Garbary *et al*., (2012) studied harvested and non-harvested shores in Nova Scotia, Canada containing stands of *Palmaria palmata*. They also conducted experimental removal of *Palmaria palmata* and assessed simulated removal of *Palmaria palmata* by an experienced commercial harvester. Simulated commercial harvesting reduced cover of *Palmaria palmata* from 70% to 40%, although experimental removal on shores not usually harvested reduced cover to 20% (Garbary *et al*., 2012). Harvesting of *Osmundea pinnatifida* for drying and use as a spice occurs primarily in Scotland, Ireland, and on the Atlantic coast of Canada (www.seaweedindustry.com).

The red crustose corraline algae *Phymatolithon lenormandii* is found in rock pools and shaded areas, removal of the *Fucus serratus* and red algal turf canopy could result in desiccation leading to bleaching and mortality, depending on the temperatures experienced and degree of insolation.

Sensitivity assessment. Removal of the *Fucus serratus* canopy and red algae will have a negative impact on the primary productivity of the area. As these species are attached and easy to select and remove, resistance is assessed as 'Low'. If some *Fucus serratus* population remain recovery will be fairly rapid. However recruitment mortality, grazing by limpets and the presence of turfs and encrusting algae can slow down and limit recovery. A switch to a disturbance community will also slow the recovery of *Fucus serratus* and associated community. Resilience is thus assessed as 'Medium'. The biotope therefore scores a 'Medium' sensitivity to this pressure.

If the entire population of *Fucus serratus* is removed, other species may come to dominate and the recovery will take considerably longer. Re-establishment of the seaweed may depend on the ability to out-compete other species and this may be dependent on suitable environmental conditions.

Removal of non-target species	Low Q: Low A: NR C: NR	Medium Q: High A: Low C: Medium	Medium Q: Low A: Low C: Low

Direct, physical impacts from harvesting are assessed through the abrasion and penetration of the seabed pressures. The sensitivity assessment for this pressure considers any biological/ecological effects resulting from the removal of non-target species on this biotope. The loss of characterizing and associated species due to incidental removal as by-catch would alter the character of the habitat from the biotope description. The ecological services such as primary production and habitat structure would also be lost. The red crustose corraline algae *Phymatolithon lenormandii* is found in rock pools and shaded areas, removal of the *Fucus serratus* and red algal turf canopy could result in desiccation leading to bleaching and mortality, depending on the temperatures experienced and degree of insolation.

Sensitivity assessment. Removal of a large percentage of the characterizing species, resulting in bare rock would alter the character of the biotope, species richness and ecosystem function. Resistance is therefore assessed as ‘Low’ and resilience as ‘Medium’, (based on the loss of fronds and holdfasts and piddocks, but see resilience section for caveats) so that sensitivity is assessed as 'Medium'. If a high proportion of holdfasts remained, recovery would be assessed as ‘High’ and sensitivity would be assessed as ‘Low’.

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