

## MarLIN Marine Information Network

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

# *Leptometra celtica* assemblage on Atlantic upper bathyal coarse sediment

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

Ellen Last, Laura Robson and Samantha Garrard

2019-07-04

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

**Please note**. This MarESA report is a dated version of the online review. Please refer to the website for the most up-to-date version [https://www.marlin.ac.uk/habitats/detail/1186]. All terms and the MarESA methodology are outlined on the website (https://www.marlin.ac.uk)

This review can be cited as:

Last, E.K., Robson, L.M. & Garrard, S.L. 2019. [Leptometra celtica] assemblage on Atlantic upper bathyal coarse sediment. In Tyler-Walters H. and Hiscock K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. DOI https://dx.doi.org/10.17031/marlinhab.1186.1



The information (TEXT ONLY) provided by the Marine Life Information Network (MarLIN) is licensed under a Creative Commons Attribution-Non-Commercial-Share Alike 2.0 UK: England & Wales License. Note that images and other media featured on this page are each governed by their own terms and conditions and they may or may not be available for reuse. Permissions beyond the scope of this license are available here. Based on a work at www.marlin.ac.uk



(page left blank)



Leptometra celtica assemblage Photographer: Anon. Copyright: Defra, JNCC, Marine Institute, BGS, UoP 2007



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

Posoarchod by	Ellen Last, Laura Robson and Samantha
Researched by	Garrard

Refereed by

Dr Marc Eléaume & Prof. Charles Messing

### **Summary**

#### UK and Ireland classification

**EUNIS 2008** 

**JNCC 2015** M.AtUB.Co.CriCom.LepCel *Leptometra celtica* assemblage on Atlantic upper bathyal coarse sediment

JNCC 2004 1997 Biotope

#### Description

These biotopes consist of dense aggregations of the crinoid *Leptometra celtica* on sand or coarse sediment in the upper bathyal or mid bathyal. They occur at the shelf edge and in the heads of canyons. It is likely that the fast currents associated with the heads of canyon systems provide a favourable habitat for suspension feeding organisms such as crinoids. Any associated species are likely to differ among the different substrata and depth zones in which the assemblage occurs. The characterizing species identified refer to all *Leptometra celtica* assemblages. The deep-sea specific assemblages occur at temperatures between 9 and 12°C, and at depths of 180-792 m. (Information from JNCC, 2015).

#### ↓ Depth range

200-600 m

#### **<u><u></u>** Additional information</u>

The northern feather star *Leptometra celtica* is a Priority Marine Feature (PMF) in Scotland.

#### ✓ Listed By

- none -

#### % Further information sources

Search on:



## Sensitivity review

#### Sensitivity characteristics of the habitat and relevant characteristic species

Leptometra celtica assemblages occur on sand and coarse sediment in both the Atlantic upperbathyal zone and the Atlantic mid-bathyal zone. The sensitivity of these Leptometra celtica dominated biotopes is, therefore, assessed as a group, on the assumption that their sensitivity is very similar in terms of the substrata and functional groups present. Any differences in species or biotope response to pressures are highlighted.

The predominant species for these biotopes is *Leptometra celtica* and loss of this species may result in loss or degradation of the biotopes. Therefore, the sensitivities of the biotopes are dependent on the sensitivity of *Leptometra celtica*. Other species present in the assemblages can include other Crinoidea and *Munida*. *Munida* is a ubiquitous mobile scavenger, so is not specific to the biotopes, and is therefore not considered significant to the assessment of sensitivity. More information on this species can be found in other biotope assessments available on this website. The sensitivity of other Crinoidea species that may occur within the biotope is discussed, as the assessment of *Leptometra celtica* has been heavily based upon the sensitivity of other Crinoidea species due to the availability of evidence. However, the presence of other Crinoidea species is not essential for the classification of the biotopes.

#### Resilience and recovery rates of habitat

Evidence on the resistance and resilience of *Leptometra celtica* is limited. As such, some evidence has been based on the congeneric species *Leptometra phalangium*, which has similar functional traits. Fonseca *et al.* (2013) and Colloca *et al.* (2004) noted that *Leptometra celtica* is vicariant to *Leptometra phalangium* in the Atlantic Ocean. This indicates that these are ecologically and biologically similar species, where their geographical isolation has caused speciation. Mironov *et al.* (2014) similarly note that *Leptometra celtica* and *Leptometra phalangium* may be synonymous. If so, *Leptometra phalangium* (Müller, 1841) is the senior name. *Leptometra celtica* is also found in circalittoral waters, most commonly in Scottish sea lochs, so some parts of the literature review have been based on shallower communities, where more evidence is available. The lower confidence due to the use of proxy or shallower-water species should be noted.

*Leptometra celtica* lives in dense aggregations but individuals are apparently separated from each other at an arm's length (see images). Observations of swimming behaviour in Scotland and in the Bay of Biscay (Scottish Natural Heritage, pers. comm., in Mazik *et al.*, 2015; M. Eleaume, 2019, pers. comm., 5 May 2019), indicate that *Leptometra celtica* adults can swim, probably by moving the arms up and down through the water (Hill, 2008), but the distance is unknown. *Leptometra phalangium*, a congeneric species, is also able to swim up into the water column and move across the seabed (Smith *et al.*, 2000). *Leptometra celtica* is likely to be a suspension/filter-feeder, which uses its podia (on their arms) for feeding, respiration and sensory perception (Flammang, 1995). *Leptometra celtica* raises its arms to feed on suspended particles within areas of current and can quickly collapse them to the seafloor when objects, e.g. a submersible, approach (Morais *et al.*, 2007).

The longevity of *Leptometra celtica*, or the dense aggregations it forms, is unknown, although Fell (1966, in Holland, 2001) states that adult crinoids live at least several years. Crinoids have flexible calcified skeletons and can regenerate lost or damaged arms. Feather stars can regenerate almost everything except the central organ. So a bisected feather star can regenerate a new animal from

the larger part but when an animal is cut into two equal halves, both die (Przibram, 1901, cited in Holland, 1991). It is also highly probable, however, that they will not be able to regenerate if too much of their tissue is removed. Some crinoid species are prey for fish, echinoids, asteroids, and possibly crabs (Baumiller, 2008; Baumiller *et al.*, 2008; Bowden *et al.*, 2011), although no evidence of this exists for *Leptometra celtica*.

Relatively low fecundities are likely to be typical of most crinoid species (McEdward et al., 1988, in Holland, 1991). The annual fecundity of a typical female Antedon bifida is relatively low, ranging from 9000 to 15,000 eggs (Lahaye, 1987, in Holland, 1991). Gonads in the great majority of extant crinoids, including Leptometra celtica, are located on specialized genital pinnules (on the arms). Although some crinoids brood embryos (e.g., Haig et al., 2012; Messing, 1984; Pertossi et al., 2019) most release sperm or eggs into the surrounding water (Barnes, 1982 cited in Gallego et al., 2013). Fertilized eggs then hatch to release a larva, which attaches onto preferential substratum within a few days (estimated to be between one to ten days), then metamorphoses into a benthic postlarva that will detach from its stalk after a period of time (e.g. Lahaye and Jangoux, 1987) (Gallego et al., 2013). It is unknown if the larvae are buoyant or benthic. Limited information exists on spawning times for Leptometra celtica. Gallego et al. (2013) modelled the potential distribution of Leptometra celtica larvae from inshore Marine Protected Areas (MPAs) where Leptometra celtica was present. They found that the potential distribution of offspring was low due to the short pelagic larval duration (PLD). Leptometra celtica may, therefore, be at greater risk from local pressures due to their low connectivity resulting in short PLD (Gallego et al., 2013). Deep-water locations were not included in the modelling work undertaken by Gallego et al. (2013). However, the prevailing circulation patterns off Scotland and the short PLD of Leptometra celtica led Gallego et al. (2013) to conclude that it is unlikely that a significant exchange of organisms occurs between the inshore areas and deep waters off Scotland. This lack of connectivity means that the populations of Leptometra celtica in these areas are likely to be distinct.

The settlement of *Leptometra celtica* individuals requires adequate fixation substratum, and specific hydrodynamics for filter-feeding from organic matter in suspension, i.e. bottom currents creating a turbulent environment (Fonseca *et al.*, 2013). *Leptometra phalangium* crinoid beds at depths of 120-170 m at the shelf break and canyon head areas under bottom currents in the central Mediterranean are indicators of highly productive areas that can sustain large biomasses of benthopelagic fish and recruits (Gofas *et al.*, 2014).

**Resilience assessment.** Where resistance is 'None' or 'Low', and an element of habitat recovery is required, resilience is assessed as '**Medium**' (2-10 years). This is based upon Cook *et al.* (2013), who showed that a significant decline in abundance of *Antedon bifida* occurred one year after a trawling event on a protected reef, suggesting a recovery period of longer than one year. Depending on the level of damage, crinoids can regenerate lost or damaged arms, or regenerate from the larger piece of a bisected animal (Przibram, 1901, cited in Holland, 1991). There is no information on time taken for recovery of *Leptometra celtica* or its habitat. However, assuming adequate fixation substratum remains (Fonseca *et al.*, 2013), recovery can occur from the regeneration of surviving individuals, new individuals moving into the area, and through larval recruitment (as discussed below). The confidences associated with this score are 'Medium' for the quality of evidence (proxy used and some expert judgement on recovery time), 'Medium' for applicability (studies from the Mediterranean) and 'High' for the degree of concordance.

Where resistance of the characterizing species is 'Low' or 'Medium', and the habitat has not been altered, resilience is assessed as '**Medium**' (2-10 years). This is based upon crinoids being able to regenerate lost or damaged arms or regenerate from the larger piece of a bisected animal

(Przibram, 1901 cited in Holland, 1991). Although longevity is unknown, adult crinoids live at least several years (Fell, 1966, in Holland, 2001), so are fairly short-lived. The ability of *Leptometra celtica* to swim (Scottish Natural Heritage pers. comm., in Mazik *et al.*, 2015; M. Eleaume, 2019, pers. comm., 5 May 2019), also means individuals can move back into an area following removal. However, *Leptometra celtica* is likely to have the low fecundity typical of most crinoids (McEdward *et al.*, 1988, in Holland, 1991). Furthermore, Gallego *et al.* (2013) suggest the species has low connectivity, resulting from a short pelagic larval duration. Although *Leptometra celtica* occurs inshore as well as in the deep sea offshore, significant exchange of organisms between these areas is unlikely, meaning that the populations are likely to be distinct (Gallego *et al.*, 2013). Recruitment of new individuals following disturbance is, therefore, likely to be more limited. The confidences associated with this score are 'High' for the quality of evidence, 'High' for applicability of and 'High' for the degree of concordance.

#### **O** Climate Change Pressures

	Resistance	Resilience	Sensitivity
Global warming	High	High	Not sensitive
(extreme)	Q: Low A: Low C: NR	Q: High A: High C: High	Q: Low A: Low C: Low

Deep waters off the continental shelf (200 - 2500 m) are expected to see a lower temperature rise ( $\approx 1^{\circ}$ C) by the end of this century than shallow water habitats, regardless of scenario (FAO (Fisheries and Aquaculture Organisation), 2019). *Leptometra celtica* is thought to be found from 46 m to more than 1279 m (Koukouras *et al.*, 2007), although it has also been recorded at 20 m in sheltered conditions in Scottish Sea lochs. It can be found from Scotland, down to the western Mediterranean, and as far south as the Moroccan coast (Fonseca *et al.*, 2014). Clark & Clark (1967) indicate that *Leptometra celtica* has been found associated with bottom water temperatures of 9.6-14.7°C, and its depth distribution appears to be dependent on temperature. It appears in shallow waters in the northern part of its distribution (i.e. north-west UK, where surface temperatures in the Atlantic Ocean vary between 9-14°C; Huthnance, 2010), and deeper waters in more southerly areas (i.e. south-west UK, Iberian Peninsula, western Mediterranean). NE Atlantic upper bathyal temperatures generally range between 7-10°C (Parry *et al.*, 2015), suggesting that deep-water populations of *Leptometra celtica* are at the tip of their northern distribution

**Sensitivity Assessment.**Upper bathyal water temperatures are generally quite stable (Parry *et al.*, 2015), although the fact that *Leptometra celtica* is distributed from the Faroe Islands to the coast of Morocco, and ranges from a depth of 20 m in sea lochs in Scotland to over 1000 m depth, highlights that this species is tolerant to a range of temperatures. Hiscock *et al.* (2004) suggest that shallow water *Leptometra celtica* populations are at the southern limit of their distribution and may be lost as a result of ocean warming. In contrast to shallow water populations, UK deep-water populations of *Leptometra celtica* are at the northern edge of their distribution, and a 1°C rise in temperature is likely to be beneficial to this species and may even lead to a northward expansion of its upper bathyal population range. Therefore, under all three scenarios (the **middle and high emission and extreme scenarios**), where temperature is expected to increase by 1°C by the end of the century, resistance of this biotope has been assessed as **'High'** and resilience is assessed as **'High'** so that the biotope is considered **'Not sensitive'** to ocean warming at the benchmark level.

Global warming (high)

<mark>High</mark> Q: Low A: Low C: NR



#### Not sensitive

Q: Low A: Low C: Low

Deep waters off the continental shelf (200 – 2500 m) are expected to see a lower temperature rise  $(\approx 1^{\circ}C)$  by the end of this century than shallow water habitats, regardless of scenario (FAO (Fisheries and Aquaculture Organisation), 2019). Leptometra celtica is thought to be found from 46 m to more than 1279 m (Koukouras et al., 2007), although it has also been recorded at 20 m in sheltered conditions in Scottish Sea lochs. It can be found from Scotland, down to the western Mediterranean, and as far south as the Moroccan coast (Fonseca et al., 2014). Clark & Clark (1967) indicate that Leptometra celtica has been found associated with bottom water temperatures of 9.6-14.7°C, and its depth distribution appears to be dependent on temperature. It appears in shallow waters in the northern part of its distribution (i.e. north-west UK, where surface temperatures in the Atlantic Ocean vary between 9-14°C; Huthnance, 2010), and deeper waters in more southerly areas (i.e. south-west UK, Iberian Peninsula, western Mediterranean). NE Atlantic upper bathyal temperatures generally range between 7-10°C (Parry et al., 2015), suggesting that deep-water populations of Leptometra celtica are at the tip of their northern distribution

Sensitivity Assessment. Upper bathyal water temperatures are generally quite stable (Parry et al., 2015), although the fact that Leptometra celtica is distributed from the Faroe Islands to the coast of Morocco, and ranges from a depth of 20 m in sea lochs in Scotland to over 1000 m depth, highlights that this species is tolerant to a range of temperatures. Hiscock et al. (2004) suggest that shallow water Leptometra celtica populations are at the southern limit of their distribution and may be lost as a result of ocean warming. In contrast to shallow water populations, UK deep-water populations of Leptometra celtica are at the northern edge of their distribution, and a 1°C rise in temperature is likely to be beneficial to this species and may even lead to a northward expansion of its upper bathyal population range. Therefore, under all three scenarios (the middle and high emission and extreme scenarios), where temperature is expected to increase by 1°C by the end of the century, resistance of this biotope has been assessed as 'High' and resilience is assessed as 'High' so that the biotope is considered 'Not sensitive' to ocean warming at the benchmark level.

#### Global warming (middle)

High

Q: Low A: Low C: NR

High Q: High A: High C: High

#### Not sensitive

Q: Low A: Low C: Low

Deep waters off the continental shelf (200 – 2500 m) are expected to see a lower temperature rise  $(\approx 1^{\circ}C)$  by the end of this century than shallow water habitats, regardless of scenario (FAO (Fisheries and Aquaculture Organisation), 2019). Leptometra celtica is thought to be found from 46 m to more than 1279 m (Koukouras et al., 2007), although it has also been recorded at 20 m in sheltered conditions in Scottish Sea lochs. It can be found from Scotland, down to the western Mediterranean, and as far south as the Moroccan coast (Fonseca et al., 2014). Clark & Clark (1967) indicate that Leptometra celtica has been found associated with bottom water temperatures of 9.6-14.7°C, and its depth distribution appears to be dependent on temperature. It appears in shallow waters in the northern part of its distribution (i.e. north-west UK, where surface temperatures in the Atlantic Ocean vary between 9-14°C; Huthnance, 2010), and deeper waters in more southerly areas (i.e. south-west UK, Iberian Peninsula, western Mediterranean). NE Atlantic upper bathyal temperatures generally range between 7-10°C (Parry et al., 2015), suggesting that deep-water populations of Leptometra celtica are at the tip of their northern distribution

Sensitivity Assessment. Upper bathyal water temperatures are generally quite stable (Parry et al., 2015), although the fact that Leptometra celtica is distributed from the Faroe Islands to the coast of Morocco, and ranges from a depth of 20 m in sea lochs in Scotland to over 1000 m depth, highlights that this species is tolerant to a range of temperatures. Hiscock *et al.* (2004) suggest that shallow water Leptometra celtica populations are at the southern limit of their distribution and may be lost

as a result of ocean warming. In contrast to shallow water populations, UK deep-water populations of Leptometra celtica are at the northern edge of their distribution, and a 1°C rise in temperature is likely to be beneficial to this species and may even lead to a northward expansion of its upper bathyal population range. Therefore, under all three scenarios (the middle and high emission and extreme scenarios), where temperature is expected to increase by 1°C by the end of the century, resistance of this biotope has been assessed as 'High' and resilience is assessed as 'High' so that the biotope is considered 'Not sensitive' to ocean warming at the benchmark level.

Marine heatwaves (high) 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

Marine heatwaves caused by increased air-sea flux of heat are only expected to penetrate surface waters (≤ 50 m) (Cerrano et al., 2000, Garrabou et al., 2009; Dan Smale, pers. comm.). Therefore, sensitivity to marine heatwaves is probably 'Not relevant' in this bathyal habitat.

Marine heatwaves	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
(middle)	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Marine heatwaves caused by increased air-sea flux of heat are only expected to penetrate surface waters (≤ 50 m) (Cerrano et al., 2000, Garrabou et al., 2009; Dan Smale, pers. comm.). Therefore, sensitivity to marine heatwaves is probably 'Not relevant' in this bathyal habitat.

Ocean acidification	High	High	Not sensitive
(high)	Q: Low A: NR C: NR	Q: High A: High C: High	Q: Low A: Low C: Low

Increasing levels of CO<sub>2</sub> in the atmosphere have led to the average pH of surface waters dropping from 8.25 in the 1700s to 8.14 in the 1990s (Jacobson, 2005). By the end of this century, pH is predicted to decrease by a further 0.15 – 0.35 units depending on the emission scenario used. Crinoids represent the most ancient class of living echinoderms (Smith, 1997), dating back 500 million years ago when atmospheric CO<sub>2</sub> levels were much higher than levels predicted for the end of this century (Guensburg & Sprinkle, 2001). In general, it is thought that calcifying invertebrates will be more sensitive to ocean acidification than non-calcifying invertebrates, which appear to have a more mixed response (Hofmann et al., 2010), although echinoderms on the whole generally appear to be tolerant to a 0.4 unit decrease in pH (Dupont et al., 2010). Widdicombe & Spicer (2008) suggested that the effects of  $pCO_2$  and hypercapnia was likely be species specific rather than predictable by phylogeny or habitat, although early life history stages in invertebrates are known to be more susceptible to ocean acidification than adult stages (Hofmann et al., 2010), and this has been shown to be the case for echinoderms (Dupont et al., 2010).

Sensitivity Assessment. Echinoderms, in general, appear to be robust to a pH decrease of up to 0.4 units, and Leptometra celtica can be found at depths of up to 1279 m, where pH can be up to 0.2 pH units lower than surface waters (Convention of Biological Diversity 2014), which suggests that this species has some tolerance to a decrease in pH. Hence, for both the middle and high emission scenarios, the resistance of this biotope has been assessed as 'High' and resilience is assessed as 'High' so that the biotope is considered 'Not sensitive' to ocean acidification at the benchmark level. Confidence is 'medium' for the middle emission scenario, as its large bathymetric range suggests that this species will be likely to tolerate a 0.2 unit pH decrease, but confidence in the assessment for the high emission scenario is 'low' due to lack of evidence.

Ocean acidification	
(middle)	

<mark>High</mark>	
Q: Medium A: Low C: Lo	w

<mark>High</mark> Q: High A: High C: High

<mark>Not sensitive</mark> Q: Medium A: Low C: Low

Increasing levels of  $CO_2$  in the atmosphere have led to the average pH of surface waters dropping from 8.25 in the 1700s to 8.14 in the 1990s (Jacobson, 2005). By the end of this century, pH is predicted to decrease by a further 0.15 - 0.35 units depending on the emission scenario used. Crinoids represent the most ancient class of living echinoderms (Smith, 1997), dating back 500 million years ago when atmospheric  $CO_2$  levels were much higher than levels predicted for the end of this century (Guensburg & Sprinkle, 2001). In general, it is thought that calcifying invertebrates will be more sensitive to ocean acidification than non-calcifying invertebrates, which appear to have a more mixed response (Hofmann *et al.*, 2010), although echinoderms on the whole generally appear to be tolerant to a 0.4 unit decrease in pH (Dupont *et al.*, 2010). Widdicombe & Spicer (2008) suggested that the effects of pCO<sub>2</sub> and hypercapnia was likely be species specific rather than predictable by phylogeny or habitat, although early life history stages in invertebrates are known to be more susceptible to ocean acidification than adult stages (Hofmann *et al.*, 2010), and this has been shown to be the case for echinoderms (Dupont *et al.*, 2010).

**Sensitivity Assessment.** Echinoderms, in general, appear to be robust to a pH decrease of up to 0.4 units, and *Leptometra celtica* can be found at depths of up to 1279 m, where pH can be up to 0.2 pH units lower than surface waters (Convention of Biological Diversity 2014), which suggests that this species has some tolerance to a decrease in pH. Hence, for both the **middle** and **high emission scenarios**, the resistance of this biotope has been assessed as 'High' and resilience is assessed as 'High' so that the biotope is considered '**Not sensitive**' to ocean acidification at the benchmark level. Confidence is 'medium' for the middle emission scenario, as its large bathymetric range suggests that this species will be likely to tolerate a 0.2 unit pH decrease, but confidence in the assessment for the high emission scenario is 'low' due to lack of evidence.

Sea level rise (extreme)	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

At a depth of 200 – 600 m, these biotopes will not be affected by sea-level rise. Therefore sensitivity to this climate change pressure is probably **'Not relevant'** in this bathyal habitat.

Sea level rise (high)

Not relevant (NR) Q: NR A: NR C: NR **Not relevant (NR)** Q: <u>NR</u> A: <u>NR</u> C: <u>NR</u>

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

At a depth of 200 – 600 m, these biotopes will not be affected by sea-level rise. Therefore sensitivity to this climate change pressure is probably **'Not relevant'** in this bathyal habitat.

Sea level rise (middle)

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

At a depth of 200 – 600 m, these biotopes will not be affected by sea-level rise. Therefore sensitivity to this climate change pressure is probably **'Not relevant'** in this bathyal habitat.

## 🏦 Hydrological Pressures

#### Resistance

Medium

#### **Temperature** increase (local)

Q: Medium A: Low C: High

Q: High A: High C: High

#### Sensitivity

Medium Q: Medium A: Low C: High

Changes in abiotic variables such as temperature can affect echinoderms in a range of ways, from decreased production to complete mortality (Tokioka, 1963, 1966 in Lawrence, 1995). Abrupt temperature changes are thought to induce spawning in laboratory specimens of Antedon bifida (Dimelow, 1958, in Holland, 1991). Leptometra celtica is found at depths from 40 m to more than 200 m on the edge of the continental shelf to the west of the British Isles, at 20 m in Scottish sea lochs (Southward & Campbell, 2006) and as far south as the Moroccan coast (Fonseca *et al.*, 2013). The species, therefore, appears to occur in shallower waters in the northern part of its distribution (i.e. north-west UK, where surface temperatures in the Atlantic Ocean vary between 9-14°C; Huthnance, 2010), and deeper in more southerly areas (i.e. south-west UK where surface temperatures in the Atlantic Ocean vary between 10-18°C; Huthnance, 2010). Clark & Clark (1967) further indicate that Leptometra celtica has been found associated with bottom water temperatures of 9.61 - 14.70°C.

Therefore, if the biotope occurs in an area corresponding to the lower limit or middle of its temperature range, as given by Clark and Clark (1967), then it is probably able to tolerate a longterm increase in temperature of 2°C. However, if the biotope occurs at the upper limit of its temperature range, then it probably won't be able to tolerate an increase in temperature of 2°C. Even at the lowest limit of its temperature range, Leptometra celtica is unlikely to tolerate a shortterm increase in temperature of 5°C.

**Sensitivity assessment**. Due to the range of bottom water temperatures that *Leptometra celtica* is associated with, resistance is assessed as 'Medium', resilience is assessed as 'Medium', and overall sensitivity is assessed as 'Medium'.

**Temperature decrease** (local)

Medium Q: High A: Low C: High Medium

Q: High A: High C: High

Medium

Q: High A: Low C: High

Changes in abiotic variables such as temperature can affect echinoderms in a range of ways, from decreased production to complete mortality (Tokioka, 1963 and 1966, in Lawrence, 1995). Abrupt temperature changes are thought to induce spawning in laboratory specimens of Antedon bifida (Dimelow, 1958, in Holland, 1991). Leptometra celtica is found at depths of 40 m to more than 200 m on the edge of the continental shelf to the west of the British Isles, at 20 m in Scottish sea lochs (Southward & Campbell, 2006) and as far south as the Moroccan coast (Fonseca et al., 2013). The species, therefore, appears to occur in shallower waters in the northern part of its distribution (i.e. north-west UK, where surface temperatures in the Atlantic Ocean vary between 9-14°C; Huthnance, 2010), and deeper in more southerly areas (i.e. south-west UK where surface temperatures in the Atlantic Ocean vary between 10-18°C; Huthnance, 2010). Clark & Clark (1967) further indicate that Leptometra celtica has been found associated with bottom water temperatures of 9.61 – 14.70°C.

Therefore, if the biotope occurs in an area corresponding to the upper limit or middle of its temperature range, as given by Clark and Clark (1967), then it is probably able to tolerate a longterm decrease in temperature of 2°C. However, if the biotope occurs at the lower limit of its temperature range, then it probably won't be able to tolerate a decrease in temperature of 2°C. Even at the upper limit of its temperature range, *Leptometra celtica* is unlikely to tolerate a shortterm decrease in temperature of 5°C.

Sensitivity assessment. Due to the range of bottom water temperatures that Leptometra celtica is associated with, resistance is assessed as 'Medium', resilience is assessed as 'Medium', and overall sensitivity is assessed as 'Medium'.

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

The depth at which Leptometra celtica assemblages are found, combined with the distance from shore and the low potential for brine or freshwater discharge, means changes in salinity are unlikely. However, Fonseca et al. (2011) reported an assemblage of Leptometra celtica in 500 m off the southern coast of Portugal, where it is exposed to a westward-flowing vein of higher-salinity Mediterranean water. However, the authors did not give salinity values or state how much they varied. Bozec et al. (2011) discussed variability in Mediterranean outflow water over decades and mentioned multi-decadal variations in the flow pathway. This combination of location and variability suggest that Leptometra celtica might be subjected to variations in salinity in some areas but it is not clear how much variation is involved and over what lengths of time (e.g. within vs. over several generations). Therefore, as specific evidence is limited on its effect, this pressure is assessed as 'No Evidence'.

#### Salinity decrease (local)

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

The depth at which Leptometra celtica assemblages are found, combined with the distance from shore and the low potential for brine or freshwater discharge, means changes in salinity are unlikely. However, Fonseca et al. (2013) reported an assemblage of Leptometra celtica in 500 m off the southern coast of Portugal, where it is exposed to a westward-flowing vein of higher-salinity Mediterranean water. However, the authors did not give salinity values or state how much they varied. Bozec et al. (2011) discussed variability in Mediterranean outflow water over decades and mentioned multi-decadal variations in the flow pathway. This combination of location and variability suggest that Leptometra celtica might be subjected to variations in salinity in some areas, but it is not clear how much variation is involved and over what lengths of time (e.g. within vs. over several generations). Therefore, as specific evidence is limited on its effect, this pressure is assessed as 'No Evidence'.

Water flow (tidal current) changes (local)

High

Q: Medium A: Medium C: High

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

Q: Medium A: Medium C: High

Crinoids are dependent on water movement to allow them to feed via suspension feeding (Birkeland, 1988). Although semi-cryptic (rheophobic) species orient their arms in postures that take advantage of multi-directional water movement, those that live completely exposed (rheophilic), such as Leptometra celtica, arrange their arms in various planar, conical, or parabolic postures in response to laminar, near-bottom flow (e.g. La Touche, 1978; Macurda and Meyer, 1974; Meyer & Macurda Jr, 1980). Figure 3 in Fonseca et al. (2013) shows a group of Leptometra celtica with arms arranged in a monoplanar fan in response to likely unidirectional near-bottom flow. Crinoids modify arm postures in response to flow that is either too weak or too strong for feeding. It is unclear whether Leptometra celtica can rely on gravitational settling of particles for

feeding, however.

The settlement of *Leptometra celtica* individuals is also facilitated by specific hydrodynamics, i.e., bottom currents that create a turbulent environment (Fonseca *et al.*, 2013). Barbaglio et al. (2012) reported that pre-settlement larvae of *Antedon mediterranea* slowed and moved to the bottom, indicating the importance of these specific hydrodynamics.

*Leptometra celtica* assemblages occur at the shelf edge and in the heads of canyons, as these are areas associated with fast currents, providing a favourable habitat for suspension feeding organisms (Parry *et al.*, 2015). Flow within canyons can be caused by wind-driven shelf-break or slope currents, leading to upwelling or downwelling flows within the canyon, with the strongest effects at the canyon rim (Allen and Durrieu de Madron, 2009). The specific velocity limits for *Leptometra celtica* are unknown, however.

Modifications in the intensity of currents (e.g., those caused by climate change) could seriously impact the structure and functioning of canyon communities (Fernadez-Arcaya *et al.*, 2017). It could also have important implications for nutrient supply to the deep-ocean ecosystem (Fernadez-Arcaya *et al.*, 2017). However, changes in water flow at the pressure benchmark are unlikely to result in such major implications to *Leptometra celtica* assemblages. It may be worth noting though, that for the shallow, reef-dwelling, 10-armed feather star *Oligometra serripinna*, particle capture rate peaked at a current speed of 6.4 cm sec<sup>-1</sup> (close to the mean ambient speed) and declined at higher tested velocities (9.5 and 13.3 cm/sec) (Leonard *et al.*, 1988).

**Sensitivity assessment.** *Leptometra celtica* assemblages occur at the shelf edge and in the heads of canyons with fast currents (JNCC, 2015) and the species appears to have developed behaviours (e.g., crouching) adapted to a change in the current regime. Therefore, resistance is assessed as '**High**'. Although it has not been observed, *Leptometra celtica* is probably able to recolonise after an episode of larval recruitment, or through adult immigration, however, the habitat preference for larvae and adults are likely to be different. This mobility of *Leptometra celtica*, therefore, acts as a means of colonization of optimal habitats for post-larvae, so resilience is assessed as '**High**'. The biotopes are therefore considered '**Not sensitive**' at the benchmark level.

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

Leptometra celtica assemblages are deep-sea biotopes, relevant to the Atlantic upper-bathyal or mid-bathyal zones, at depths of 200-600 m or 600-1300 m, respectively. Therefore, the biotopes will not be affected by changes in the emergence regime, and the assessment at the pressure benchmark is '**Not relevant**'.

Wave exposure changes	Not relevant (NR)	Not relevant (NR)	Not relevant (NR)
(local)	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

*Leptometra celtica* assemblages are deep-sea biotopes, relevant to the Atlantic upper-bathyal or mid-bathyal zones, at depths of 200 –600 m or 600 –1300 m, respectively. As such, they occur at depths at which even the wave action generated by storm conditions is unlikely to penetrate. Therefore, the assessment for the biotopes at the pressure benchmark is '**Not relevant**'.

#### A Chemical Pressures

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

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

No information on the effects of heavy metals on *Leptometra celtica* was found, and little is known about the effects of heavy metals on echinoderms in general. Bryan (1984) reported that early work had shown that echinoderm larvae were sensitive to heavy metals contamination. Migliaccio *et al.* (2014) reported that exposure of larvae from the Mediterranean shallow-water sea urchin *Paracentrotus lividis* to increased levels of cadmium and manganese caused abnormal larval development and skeletal malformations.

Potential impacts from the disposal of waste from the oil and gas sector (including drill cuttings, drilling mud and produced water) can include increased metal abundance (Cordes *et al.*, 2016). Increased concentrations of harmful metals (e.g., barium) have been identified as causing community-level changes in megafaunal assemblages (Cordes *et al.*, 2016). However, no specific evidence was recorded for *Leptometra celtica* or echinoderms.

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

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

Although there is no information available on the effect of hydrocarbons on *Leptometra celtica*, mass mortality of echinoderms has followed oil spills. Organisms must be exposed to the oil for an effect to occur, so exposure will have an influence (Lawrence, 1995). Crude oil from the *Torrey Canyon* in 1967 off Land's End, Cornwall, and the detergent used to disperse it, caused mass mortality of echinoderms. Repopulation of one species, the sea potato *Echinocardium cordatum*, did not occur until two years later. The high sensitivity of *Echinocardium cordatum* was also seen in another soil off Brittany in 1978 and the discharge of oil-contaminated drill cuttings in the Dutch sector of the North Sea (Lawrence, 1995).

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. Certain anthropogenic chemicals are known as endocrine disrupter (ED) contaminants. These can cause dysfunctions in steroid hormone production/metabolism and activities, as well as inducing significant effects on reproductive competence, development and growth (Carnevali, 2005). These compounds can be bioaccumulated by organisms and include polychlorinated biphenyls (PCBs), nonylphenols and organotins (Barbaglio *et al.*, 2006; Carnevali, 2005). Echinoderms are susceptible to bioaccumulation of such dissolved aquatic pollutants through primary uptake across external epithelia or secondary update from food (Smith *et al.* 1981, Tremolada *et al.* 2004 in Barbaglio, *et al.*, 2006).

Sugni *et al.* (2010) exposed *Antedon mediterranea* to five different endocrine disrupters: triphenyltin (TPT), fenarimol (FEN), methyltestosterone (MET), p,p<sup>-</sup>-DDE (DDE), and cyproterone acetate (CPA), and found that TPT was the most effective in altering both reproductive and regenerative parameters, even at very low concentrations.

For Antedon mediterranea, Barbaglio et al. (2006) tested the effects of Fenarimol, a halogenated pesticide, particularly a fungicide, as well as TPT-Cl, an organotin compound used extensively in agriculture and in antifouling paints. This study showed that both compounds strongly affect skeletal development, as shown by both external and internal anatomical malformations, as well as regenerative potential.

Some experiments have reproduced common conditions of exposure to environmental contaminants, with concentrations comparable to those of moderately polluted coastal zones. These showed that prolonged exposure to such compounds significantly affects the regenerative mechanisms (regeneration times, overall growth, general morphology and histological and cellular patterns; Barbaglio *et al.*, 2006; Carnevali, 2005). If *Leptometra celtica* is exposed to these compounds, it is likely to be similarly affected through their interference with fundamental physiological processes, including growth, development and reproductive competence (Sugni *et al.*, 2007).

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

Tierney *et al.* (2017) found that radiocarbon (<sup>14</sup>C) was transported from the Sellafield nuclear site as far as the Firth of Lorn, Scotland (~260 km from Sellafield), and recorded ecosystem uptake via <sup>14</sup>C enrichment in marine organisms. Although <sup>14</sup>C activity did diminish with distance from Sellafield following dilution in Atlantic water, <sup>14</sup>C enrichment was a result of uptake by phytoplankton during photosynthesis, which was transferred through the benthic food web as enriched particulate organic material. The Firth of Lorn mud basins support dense beds of *Leptometra celtica* (Tierney *et al.*, 2017). Although this species was not sampled in the study, other suspension feeders (sea pens) were found to be enriched with <sup>14</sup>C (Tierney *et al.*, 2017). However, the study was undertaken in a different region and depth than the deep-sea *Leptometra celtica* assemblage biotopes, notably with different currents. As such, the evidence is considered insufficient for an assessment of the effects of radionuclide contamination on the biotopes. This pressure-feature combination is assessed as '**No Evidence**'.

Introduction of other
substances

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

This pressure is '**Not assessed**', and no evidence was available on the effects of 'introduction of other substances' on *Leptometra celtica*.

**De-oxygenation** 

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

*Leptometra celtica* assemblages occur in deep-water and the cold, open ocean waters that bathe the shelf margin and slope are typically well oxygenated (Hill, 2008). This may indicate that the species prefers such conditions. However, echinoderm oxygen consumption rates are typically lower than

those found in representatives of other marine invertebrate phyla, such as crustaceans (Lawrence & Lane, 1982, in Hughes *et al.*, 2011; Webster, 1975). *Leptometra celtica* may thus survive exposure to lower dissolved oxygen concentrations than other invertebrates, especially more active forms. Oxygen consumption varies depending on other environmental conditions influencing the metabolic rate. However, Hughes *et al.* (2011) found no change in echinoderm respiration rate with depth.

**Sensitivity assessment**. *Leptometra celtica* assemblages occur in well-oxygenated areas and are likely to have low oxygen consumption rates. Resistance is assessed as '**High**' and resilience is assessed as '**High**', therefore *Leptometra celtica* assemblage biotopes are considered to be '**Not sensitive**' at the benchmark level.

#### Nutrient enrichment

Not relevant (NR) Q: NR A: NR C: NR Not relevant (NR) Q: NR A: NR C: NR <mark>Not sensitive</mark> Q: NR A: NR C: NR

Intermittent mixing events may generate increased ammonium and nitrate concentrations at shelf break areas (Colloca *et al.*, 2004), where the biotopes are known to occur. Colloca *et al.* (2004) stated that nutrient input at the shelf break due to water turbulence and shelf-break upwelling (Pinazo *et al.*, 1996, in Colloca *et al.*, 2004) could be involved in structuring the benthic and demersal assemblages, including high concentrations of crinoids. Nutrient enrichment is also associated with upwelled water and results in high pelagic productivity (Joint *et al.*, 2002; Serrano *et al.*, 2008; Tenore *et al.*, 1995). It is likely that *Leptometra celtica* would benefit from the additional detritus for filter-feeding due to this productivity increase.

Nevertheless, by definition, the biotopes are considered '**Not sensitive**' at the pressure benchmark, which assumes compliance with good status as defined by the WFD.

 Organic enrichment
 High
 High
 Not sensitive

 Q: Medium A: Medium C: Medium
 Q: High A: High C: High
 Q: Medium A: Medium C: Medium

Colloca *et al.* (2004) stated that an increase in organic matter transportation at the shelf break due to water turbulence and shelf break upwelling (Pinazo *et al.*, 1996, in Colloca *et al.*, 2004) could be involved in structuring the benthic and demersal assemblages, including high concentrations of crinoids. Organic enrichment is positively correlated with mud (Serrano *et al.*, 2008), so a change in substratum may occur over time. There are records of *Leptometra celtica* living deep sandy-muds in Scotland (SNH, 2013). *Leptometra celtica* has been reported as occurring on sediment at depths of 40-200 m (Baxter *et al.*, 2011). However, abundant *Leptometra celtica* was recorded on 'mixed muddy sediments with a surface scatter of stones and shells', and Ferguson *et al.* (2018) (see also associated images of these biotopes) include a photograph of *Leptometra celtica* apparently clinging to dead shells or pebbles on an unconsolidated sediment substratum, at 265 m depth (Davies *et al.*, 2008). The other images associated with these biotopes (from MESH cruise 01-07-01; Davies *et al.*, 2008) show *Leptometra celtica* clinging to the seabed, which either consists of a sediment or a hard-bottom with a thin sediment veneer. Serrano *et al.* (2008) found *Leptometra celtica* associated with fine and very fine sands that were poorer in organic matter. Muddy substrata may, therefore, be suitable for *Leptometra celtica*, however, it may benefit from the presence of stones or shells.

Bo *et al.* (2010) concluded that upwelling conditions re-suspend organic particles but can also increase phytoplankton biomass in the euphotic layer, which subsequently sinks to the seafloor as organic detritus, favouring suspension-feeding organisms such as crinoids. This depends on the

amount and rate of sinking however, as phytodetritus may blanket the seafloor (see 'smothering and siltation changes' pressure).

**Sensitivity assessment**. *Leptometra celtica* requires organic matter in suspension to filter feed (Fonseca *et al.*, 2013). Therefore, the species would likely benefit from any organic enrichment. Please note that although *Leptometra celtica* is unlikely to be affected if the organic matter causes a change to mud substratum, the biotope would be lost and/or reclassified. Resistance for the organic enrichment pressure is assessed as '**High**', resilience as '**High**', and the *Leptometra celtica* assemblages are considered '**Not sensitive**' at the benchmark level.

#### A Physical Pressures

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

All marine habitats and benthic species are considered to have no resistance to this pressure and to be unable to recover from a permanent loss of available habitat.

**Sensitivity assessment.** Resistance is assessed as '**None**', resilience is assessed as '**Very low**' and sensitivity is considered to be '**High**'.

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

Crinoids are suspension feeders and can be found on a wide variety of substrata, depending on their attachment strategy. Some deep-sea stalked crinoids root in sediment (e.g., Bathycrinus species; Eléaume et al., 2012), and some deep-sea feather stars with long, slender cirri that are not distally hooked or prehensile (e.g., Atelecrinus species; Messing, 2013) can rest on hard or sediment substrata. Leptometra celtica has been reported as occurring on bedrock, gravel, shell, or sediment at depths of 40-200 m (Baxter et al., 2011). Ferguson et al. (2018) (see also associated images of these biotopes) include a photograph of Leptometra celtica apparently clinging to dead shells or pebbles on an unconsolidated sediment substratum, at 265 m depth (Davies et al., 2008). The other images associated with these biotopes (from MESH cruise 01-07-01; Davies et al., 2008) show Leptometra celtica clinging to the seabed, which either consists of sediment or a hard-bottom with a thin sediment veneer. Howson et al. (2006) reported Leptometra celtica on hard substrata such as bedrock in shallow waters. No information is available to suggest that Leptometra celtica attaches to artificial hard substrata such as oil rigs. Oliveira et al. (2015) observed that a discarded fishing net stretched over soft bottom provided a fixation point for a large concentration of Leptometra cf. *celtica*. However, for the 'physical change (to another seabed type)' pressure to occur), the original substratum would be lost/removed, which would result in the removal of living species and likely lead to a change in biotope (i.e. loss of the biotope in that area).

**Sensitivity assessment**. If the sediment that characterizes the biotopes was replaced with rock substratum, this would represent a fundamental change to the physical character of the biotopes. Although evidence shows that *Leptometra celtica* can occur on a range of substrata, this change in biotope would cause a reclassification of the biotope (i.e., loss of the biotope). Resistance is, therefore, assessed as '**None**', resilience as '**Very low**', and sensitivity is assessed as '**High**'.

Physical change (to another sediment type)



Q: High A: High C: High





Q: High A: High C: High

Sediment type is a key factor structuring the biological assemblage present in a biotope. A change in one Folk class for Leptometra celtica assemblages on coarse sediment could mean a change to 'mixed' or 'sand and muddy sand' substratum. For assemblages on sand, a change on one Folk class could mean a change to 'mixed', 'coarse' or 'mud and sandy mud'. There are records of abundant Leptometra celtica living on 'mixed muddy sediments with a surface scatter of stones and shells', and on deep sandy-muds in Scotland (SNH, 2013). Leptometra celtica has been reported as occurring on bedrock, gravel, shell, or sediment at depths of 40-200 m (Baxter et al., 2011). Ferguson et al. (2018) (see also associated images of these biotopes) include a photograph of Leptometra celtica apparently clinging to dead shells or pebbles on an unconsolidated sediment substratum, at 265 m depth (Davies et al., 2008). The other images associated with these biotopes (from MESH cruise 01-07-01; Davies et al., 2008) show Leptometra celtica clinging to the seabed, which either consists of sediment or a hard-bottom with a thin sediment veneer. The substrata 'mixed', 'coarse', 'sand and muddy sand' or 'mud and sandy mud' would, therefore, all be suitable for Leptometra celtica, but any associated species are likely to differ. As such, and due to the change in sediment type, it would likely result in a change to a different biotope.

Sensitivity assessment. A change in Folk class from 'coarse' sediment to 'mixed' or 'sand and muddy sand' would probably not affect the characterizing species (Leptometra celtica) which appears to have habitat preferences that would fall within this range. Equally, a change in Folk class from 'sand' to 'mixed', 'coarse' or 'mud and sandy mud' is unlikely to affect the characterizing species. However, this change in substratum may represent a fundamental change in the character of the biotopes and a change in the abundance of the associated species. This would result in the loss and/or reclassification of the biotopes. Resistance is, therefore, assessed as 'None', resilience as 'Very low' and the biotopes are considered to have 'High' sensitivity to a change in seabed type (by one Folk class).

Habitat structure changes - removal of substratum (extraction) Q: Low A: NR C: NR

None

Medium

Medium

Q: Medium A: Medium C: High

Q: Low A: Low C: Low

As Leptometra celtica assemblages are characterized by species with very limited mobility, removal of the substratum at the benchmark pressure would cause destruction of the biotope within the affected area. Assuming adequate fixation substratum remains (Fonseca et al., 2013), recovery could occur from the regeneration of surviving individuals (Przibram, 1901, cited in Holland, 1991), new individuals moving into the area, and through larval recruitment. However, Leptometra celtica is likely to have low fecundity and low connectivity (Gallego et al., 2013), meaning the recruitment of new individuals following disturbance is likely to be more limited.

Sensitivity assessment. The resistance of Leptometra celtica assemblages to the removal of substratum is assessed as 'None', resilience as 'Medium' and overall sensitivity to the pressure is assessed as 'Medium'.

Abrasion/disturbance of the surface of the substratum or seabed

```
None
```

Q: Medium A: Medium C: High



Q: Medium A: Medium C: High



Q: Medium A: Medium C: High

https://www.marlin.ac.uk/habitats/detail/1186

Studies within La Fonera Canyon in the NW Mediterranean Sea showed that trawling gear passing near and along the canyon flanks down to 800 m depth significantly impacted the seafloor (Puig *et al.*, 2012 in Fernadez-Arcaya *et al.*, 2017). This could, therefore, have an impact on the associated communities.

Cranmer *et al.* (1984) found that specimens of crinoids (identified either as *Leptometra celtica* or *Antedon bifida*) were badly damaged when collected in trawl samples, with their cirri often missing. Despite crinoids being able to regenerate lost or damaged arms, or a new animal from the larger part if bisected (Przibram, 1901, cited in Holland, 1991), the cirri are used to attach to substratum (Rowley, 2007). Therefore, without these, the individuals will have reduced survival potential. Cook *et al.* (2013) noted a significant decline in abundance of *Antedon bifida* one year after a trawling event on a protected reef. During trawl surveys, Colloca *et al.* (2004) observed that about 300 kg of crinoids, or about 200,000 individuals, could easily be collected in one hour of trawling. Clark & Clark (1967) noted that arm length in this species reaches at least 16.5 cm, which creates a span of over 30 cm, so it is unlikely that adult individuals could pass through the mesh of a fishing net.

The impact of otter trawling on beds of the congeneric species Leptometra phalangium has been documented for the eastern Mediterranean. Smith et al. (2000) examined an area affected by trawling on the north coast of Greece at approx. 200 m depth. Aggregations of Leptometra phalangium, a dominant species in the control area, were observed on either side of the trawling lane. However, the rare individuals seen in the trawl lane were solitary and found raised on the bank of trawl-door plough marks. Leptometra phalangium and other echinoderms were strongly reduced in numbers in trawled areas, along with a decrease in the richness, abundance and biomass of benthic species (Smith et al., 2000). Similarly, Smith et al. (2007) found that the distribution of Leptometra phalangium was significantly negatively correlated with trawling impact. Mangano et al. (2013) examined trawling impacts in the southern Tyrrhenian Sea and showed that Leptometra phalangium was only found in areas where fishing activity was the least intensive. Furthermore, the crinoid bed of Leptometra celtica found by Fonseca et al. (2013) at around 500 m depth on the Portuguese south coast corresponded to an area thought not to be trawled by crustacean trawlers due to the substratum. Surrounding trawled areas displayed far fewer epibenthic taxa in comparison with the non-towed areas where crinoids occurred (Fonseca et al., 2013). They also noted that the crinoid bed was located in an "enclave of gravelly sand surrounded by muddy sediments" (p. 223), which were the habitat of the commercially trawled lobster, Nephrops norvegicus.

Removal of significant numbers of crinoid specimens is likely to have a large impact on the biotope's structure and function. *Leptometra celtica* is able to crawl or swim (SNH pers. comm., in Mazik *et al.*, 2015; M. Eleaume, 2019, pers. comm., 5 May 2019) and may exhibit this behaviour if subject to disturbance. However, it is unknown how far or quickly they move. This behaviour may allow them to repopulate damaged areas, if a viable population exists nearby, through either larval settlement or swimming adults. Clark *et al.* (2019) speculated that feather stars might be early recolonizers on seamounts following abatement of long-term bottom trawling but also noted that such individuals might be remnants missed by trawling rather than (or as well as) recruits. Unstalked crinoids have also been observed recolonizing scours left behind by drifting icebergs in Antarctica (Gutt *et al.*, 1996).

**Sensitivity assessment**. Surface abrasion would remove, damage or kill most of the population of *Leptometra celtica*, so resistance is assessed as '**None**'. Recovery could occur through larval settlement or adult immigrants, so resilience is assessed as '**Medium**'. Overall sensitivity to the

Penetration or

Medium

pressure is assessed as 'Medium'.



disturbance of the substratum subsurface Q: Medium A: Med

Q: Medium A: Medium C: High Q: Medium A: Medium C: High

Medium

Q: Medium A: Medium C: High

Penetration and or disturbance of the substratum would result in similar, if not identical effects as the 'abrasion' pressure (see above).

**Sensitivity assessment**. *Leptometra celtica* lives on the surface of the seabed. However, any impacts to the sub-surface would inevitably affect the seabed surface. Most of the population, therefore, would likely be killed, damaged or removed by the pressure, causing loss of the biotope, and recovery would be reliant upon larval settlement or adult immigration. Resistance is assessed as '**None**', resilience as '**Medium**' and overall sensitivity to the pressure is assessed as '**Medium**'.

Changes in suspended	<mark>High</mark>	<mark>High</mark>	Not sensitive
solids (water clarity)	Q: Medium A: High C: NR	Q: High A: High C: High	Q: Medium A: High C: High

*Leptometra celtica* is a suspension feeder (Flammang, 1995) and requires suspended particles carried by near-bottom currents to feed. The species occurs on the edge of the continental shelf (e.g. at 200 m depth; Howell, 2010). These environments are characterized by high concentrations of suspended material rising from the shelf-break (Lavaleye *et al.*, 2002), indicating a preference for a certain level of suspended material. As with *Leptometra phalangium*, *Leptometra celtica* lives in direct contact with mobile sandy-gravel substrata in turbid areas where strong currents deliver particles for suspension feeding (Colloca *et al.*, 2004; Davies *et al.*, 2014).

La Touche & West (1980) found that 17% of the gut contents of *Antedon bifida* were inorganic particles, which was consistent throughout the year and for all locations studied. An increase in turbidity, reducing light availability, may reduce primary production by phytoplankton in the water column and thus influence food availability. However, particulate food supplies are also likely to be derived from distant sources, so the long-term impact is not likely to be significant. A large fraction of *Antedon bifida* stomach contents (ca. 65%) may consist of detritus, which is considered an important source of nutrition (La Touche & West, 1980). This indicates that the species isn't solely reliant upon suspended particles. However, Meyer (1982) reported large variations in faecal composition among different individuals of a single reef-dwelling crinoid, *Anneissia* (formerly *Comanthus*) *bennetti* sampled at the same place during a single dive (e.g., 9-57% for sediment grains; 5.5-17% for diatoms).

Several groups of shallow-water feather stars include light-sensitive species that are cryptic during the day and crawl to feeding perches at dusk (e.g., Meyer & Macurda Jr, 1980). Antedon *mediterranea* is one of these shade-loving (sciaphilic) species, which means it may be positively impacted by light reduction in its environment. Antedon bifida is found in shallow areas, under floating pontoons in ports for example (i.e., protected from direct light). From observations of *Antedon bifida* individuals maintained in tanks, individuals will move during night time rather than day time (M. Eleaume, pers. comm., 5 May 2019). Therefore, Antedon bifida may also be shade-loving (sciaphilic) as well. Antedon petasus is mostly found in waters deeper than 90 m (below the euphotic zone) and sometimes co-occurs with Leptometra celtica in the Bay of Biscay (M. Eleaume, pers. comm., 5 May 2019), suggesting a shade-loving (sciaphilic) behaviour as well.

**Sensitivity assessment.** *Leptometra celtica* assemblages occur around shelf edges areas characterised by high concentrations of suspended material (Lavaleye *et al.*, 2002). The characterizing species requires suspended material for feeding but is likely to be shade-loving (sciaphilic), which means it may be positively impacted by light reduction in its environment. As such, *Leptometra celtica* can probably tolerate an increase in suspended sediment at the benchmark level of change in one rank on the WFD scale for one year (i.e., from 10 to 100 mg/l). Resistance is, therefore, assessed as '**High**', resilience as '**High**' and the biotopes are considered '**Not sensitive**' at the benchmark level.

 Smothering and siltation
 High

 rate changes (light)
 Q: Medium A: Medium C: High

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

Burial by sediment is the main cause of mass mortality reported for fossil echinoderms. This can be caused in modern seas by events ranging from tectonically related turbidity flows (Garfield *et al.*, 1994), to severe storms (Sanchez-Vidal *et al.*, 2012), or to siltation from dredging or ocean mining (Lawrence, 1995). In addition, increases in oil and gas exploration to deeper offshore waters (including in the UK) could lead to a discharge of drilling waste, which consists primarily of dense particulate solids that settle rapidly and accumulate in sediments down-current from the platform (Fernadez-Arcaya *et al.*, 2017).

Blanchard (2004) examined trawling impacts on the Bay of Biscay coast of France at around 100 m depth and noted that suspension feeders such as *Leptometra celtica* are sensitive to particles resuspended by the passage of the trawl. Hill (2008) noted that most of the feeding and respiratory structures of feather stars will become clogged if subjected to smothering by sediment. However, as the arms of *Leptometra celtica* can be up to 16.5 cm in length (Clark & Clark, 1967), the tops of the arms could extend above the sediment (Hill, 2008). Furthermore, adult *Leptometra celtica* has long cirri, typically 3.5-4 cm in length that may be used to raise themselves up above the substratum (M. Eleaume, pers. comm., 5 May 2019). Some comatulid species have also developed behaviours that seem to be directed to compensating for feeding structure clogging. *Pentametrocrinus atlanticus*, a deep-sea solitary and probably gravitational settling feeder, has been observed in Whittard Canyon shaking their arms after an ROV had disturbed the surrounding substratum (M. Eleaume, 2019, pers. comm., 5 May). Similar behaviour (shaking of arms) has been observed from *Antedon bifida* kept in tanks (M. Eleaume, 2019, pers. comm., 5 May).

**Sensitivity assessment**. Although smothering may cause the feeding and respiratory structures of *Leptometra celtica* to become clogged (Hill, 2008), the species may be able to compensate for clogging by shaking their arms. *Leptometra celtica* can also raise up and extend their arms above a 5 cm deposit of fine material, and/or use their cirri to raise themselves up above the substratum, allowing them to filter feed. As such, resistance is assessed as '**High**', resilience as '**High**' and the biotopes are considered '**Not sensitive**' at the benchmark level. Any abrasion effects associated with the removal of this pressure are covered under the specific abrasion pressure.

Smothering and siltationNonerate changes (heavy)Q: Media

Q: Medium A: High C: High

Medium

Q: Medium A: High C: High



Q: Medium A: High C: High

Burial by sediment is the main cause of mass mortality reported for fossil echinoderms. This can be caused in modern seas by events ranging from tectonically generated turbidity flows (Garfield *et al.*, 1994), to severe storms (Sanchez-Vidal *et al.*, 2012), or to siltation from dredging or ocean mining (Lawrence, 1995). In addition, increases in oil and gas exploration to deeper offshore

waters (including in the UK) could lead to a discharge of drilling waste, which consists primarily of dense particulate solids that settle rapidly and accumulate in sediments down-current from the platform (Fernadez-Arcaya *et al.*, 2017).

Blanchard (2004) examined trawling impacts on the Bay of Biscay coast of France at around 100 m depth and noted that suspension feeders such as *Leptometra celtica* are sensitive to particles resuspended by the passage of the trawl. Hill (2008) noted that the feeding and respiratory structures of feather stars will become clogged if subjected to smothering by sediment. The slender arms of *Leptometra celtica* are only up to 16.5 cm

Around a drill site in the Faroe-Shetland Channel, Jones *et al.* (2006) reported a ca 87% reduction in density of another crinoid species, *Heliometra glacialis*, in an area affected by 1.5 m of sediment smothering, compared to an undisturbed reference area. *Heliometra glacialis* and *Leptometra celtica* have a similar physiology and ecology, so a similar sensitivity is assumed. Furthermore, the reduction in suspension feeders in disturbed areas may have also promoted the preferential recolonization by epibenthic deposit feeders. This changes the overall species composition (Jones *et al.*, 2006), resulting in loss of the existing biotope.

Survival of filter/suspension feeders was directly linked to motility in the Faroe-Shetland Channel (Jones *et al.*, 2006), and they were found to increase in abundance with a reduction in smothering disturbance. The impact of disturbance on sessile forms was thought to be directly related to levels of suspended solids and to their ability to clear particles from their feeding and respiratory surfaces (Rogers, 1990, in Jones *et al.*, 2006). Although the mobility of *Leptometra celtica* is limited, their crawling/swimming behaviour (SNH pers. comm., in Mazik *et al.*, 2015; M. Eleaume, pers. comm., 5 May 2019) might, therefore, allow rapid re-colonization of disturbed areas if the pressure is removed.

**Sensitivity assessment**. Deposition of 30 cm of fines may completely smother *Leptometra celtica* assemblages, particularly as their arms (16.5 cm in length; Clark & Clark, 1967) and long cirri (3.5-4 cm) will not be able to extend above the sediment. Resistance is therefore assessed as '**None**'. Recovery could occur from adults moving into the area and from larval recruitment. Therefore, resilience is assessed as '**Medium**', and overall sensitivity is assessed as '**Medium**'. Any abrasion effects associated with the removal of this pressure are covered under the specific abrasion pressure.

#### Litter

#### Medium Q: Medium A: Medium C: Medium

Medium

Q: High A: High C: High

#### Medium

Q: Medium A: Medium C: Medium

In UK waters, the *Leptometra celtica* assemblage biotopes have only been found to date at the SW Canyons (Howell *et al.*, 2010). Canyons act as natural traps, deposits and transport pathways of particles from the shelf to the abyssal plains (Granata *et al.*, 1999; Oliveira *et al.*, 2007; Turchetto *et al.*, 2007 in Oliveira *et al.*, 2015), and the hydrodynamic processes of canyons also enhance the transport of litter (Fernadez-Arcaya *et al.*, 2017). A study comparing the accumulation of marine litter in different deep-sea habitats across Europe showed that litter densities in canyons were higher than in other physiographic settings, such as continental shelves, seamounts, banks, and mounds (Pham *et al.*, 2014 in Fernadez-Arcaya *et al.*, 2017).

The effects of litter on the benthic fauna are little understood. However, impacts such as suffocation and physical damage of sessile fauna (e.g., corals, sponges, crinoids) have been observed (Ramirez-Llodra *et al.*, 2013; Pham *et al.*, 2014; Bergmann *et al.*, 2015 in Fernadez-Arcaya

et al., 2017). Oliveira et al. (2015) studied marine litter in a submarine canyon off SW Portugal and found that coiled up fishing lines were a primary source of entanglements for tridimensional complex or branching fauna, including Leptometra celtica. Echinodermata may become entangled on their own while moving on the seafloor or scavenging for food, but since they are mobile it is plausible that they might be able to escape with only minor distress (Oliveira et al., 2015). In addition, some types of litter may provide suitable substratum for some species. Oliveira et al. (2015) observed a net stretched over a soft bottom that provided a fixation point for a large concentration of Leptometra cf. celtica. Slightly above the seafloor, these filter feeder organisms were apparently in an advantageous position to gather food from the bottom currents.

Sensitivity assessment. Marine litter is likely to cause some entanglement of Leptometra celtica assemblages, however, the species can utilise litter as a fixation substratum (Oliveira et al., 2015). Resistance is assessed as 'Medium', resilience as 'Medium' and overall sensitivity is considered to be 'Medium'.

Electromagnetic changes 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 could be found for the effects of electromagnetic changes on Leptometra celtica. Therefore, this pressure benchmark is assessed as 'No evidence'.

Underwater noise	<mark>High</mark>
changes	Q: Medium A: Low C: High

High Q: High A: High C: High Not sensitive Q: Medium A: Low C: High

Leptometra celtica has no means to detect noise, however, crinoids do respond to changes in water pressure and movement (i.e. vibrations). For example, Morais et al. (2007) noted that Leptometra celtica displayed a 'crouching' behaviour as a reaction to an approaching ROV and Promachocrinus kerguelensis in the Antarctic has been observed reacting to an approaching ROV by 'flying' (M. Eleaume, pers. comm., 5 May 2019). The 'flying' or 'crouching' behaviour they display may be a consequence of vibration (bow waves generated by the approaching ROVs or submersible) or the light associated with the video camera. In other species, such as Atelecrinus helgae or some Democrinus from Whittard Canyon, touching the individuals using the arm of an ROV also induces a 'flying' or 'crouching' reaction (M. Eleaume, pers. comm., 5 May 2019). It is unknown what sort of receptors crinoids have, and whether these receptors are sensitive to vibrations but this cannot be ruled out.

Sensitivity assessment. Observations by Morais et al. (2007) suggest that Leptometra celtica displays a likely avoidance response (i.e. 'crouching' behaviour) to approaching ROVs (vibration), in a similar way to other crinoid species (M. Eleaume, pers. comm., 5 May 2019). As there is no evidence of mortality, and effects are limited to behavioural responses, resistance is assessed as 'High', resilience as 'High' and overall the biotopes are considered to be 'Not sensitive' at the benchmark level.

High

Introduction of light or shading

High

Q: Medium A: Medium C: High

Q: High A: High C: High

Not sensitive

Q: Medium A: Medium C: High

Several groups of shallow-water feather stars include light-sensitive species that are cryptic during the day and crawl to feeding perches at dusk (e.g., Meyer & Macurda Jr, 1980). Antedon *mediterranea* is one of these shade-loving (sciaphilic) species, which means it may be negatively impacted by the introduction of light. *Antedon bifida* is found in shallow areas, under floating pontoons in ports for example (i.e., protected from direct light). From observations of *Antedon bifida* individuals maintained in tanks, individuals will move during night time rather than day time (M. Eleaume, pers. comm., 5 May 2019). Therefore, *Antedon bifida* may also be shade-loving (sciaphilic) as well. *Antedon petasus* is mostly found in waters deeper than 90 m (below the euphotic zone) and sometimes co-occurs with *Leptometra celtica* in the Bay of Biscay (M. Eleaume, 2019, pers. comm., 5 May), suggesting a shade-loving (sciaphilic) behaviour as well.

*Leptometra celtica*, and other crinoids have also been shown to respond to changes in anthropogenic light. Messing (2019, pers. comms., 30 April) observed strong responses (crown rotation, arm waving) in two species of stalked crinoids in response to bright submersible lights at a depth of ~400 m in the Bahamas. Furthermore, Morais *et al.* (2007) noted that *Leptometra celtica* displayed a 'crouching' behaviour as a reaction to an approaching ROV and *Promachocrinus kerguelensis* in the Antarctic has been observed reacting to an approaching ROV by 'flying' (M. Eleaume, 2019, pers. comm., 5 May). The 'flying' or 'crouching' behaviour they display may be a consequence of the light associated with the video camera (or vibration from bow waves generated by the approaching ROVs or submersible). In other species, such as *Atelecrinus helgae* or some *Democrinus* from Whittard Canyon, touching the individuals using the arm of an ROV also induces a 'flying' or 'crouching' reaction (M. Eleaume, pers. comm., 5 May 2019). It is unknown what sort of receptors crinoids have, and whether these receptors are sensitive to light, but this cannot be ruled out.

**Sensitivity assessment.** Although *Leptometra celtica* assemblages occur at considerable depths where little or no incident light penetrates from the surface, and where the movement of surface vessels is not likely to affect the species, evidence shows that they respond to changes in anthropogenic light. Observations by Messing (2019, pers. comms., 30 April), Eleaume (2019, pers. comm., 5 May) and Morais *et al.* (2007) suggest that *Leptometra celtica* and other crinoids display a likely avoidance response (i.e. crown rotation, arm waving, 'crouching' or 'flying' behaviour) to approaching ROVs or submersible (bright lights). As there is no evidence of mortality, and effects are limited to behavioural responses, resistance is assessed as '**High**', resilience as '**High**' and overall the biotopes are considered to be '**Not sensitive**' at the benchmark level.

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

*Leptometra celtica* is thought to have a short pelagic larval duration, and therefore low connectivity (Gallego *et al.*, 2013). As such, the biotopes will not be affected by barriers to species movement. This pressure benchmark is assessed as '**Not relevant**'.

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

*Leptometra celtica* is mainly sessile, despite exhibiting some crawling and swimming behaviour of limited unknown distance (Rowley, 2007; SNH, pers. comm., in Mazik *et al.*, 2015; M. Eleaume, 2019, pers. comm., 5 May). Its larvae are thought to have a short pelagic larval duration, and therefore low connectivity (Gallego *et al.*, 2013). As such, *Leptometra celtica* will not be affected by an increased risk of collision. This pressure benchmark is assessed as '**Not relevant**'.

#### Visual disturbance

High		
Q: Medium	A: Medium	C: High

<mark>High</mark> Q: High A: High C: High Not sensitive Q: Medium A: Medium C: High

Leptometra celtica, and other crinoids do respond to changes in movement and light. Messing (2019, pers. comms., 30 April) observed strong responses (crown rotation, arm waving) in two species of stalked crinoids in response to bright submersible lights at a depth of ~400 m in the Bahamas. Furthermore, Morais *et al.* (2007) noted that *Leptometra celtica* displayed a 'crouching' behaviour as a reaction to an approaching ROV and *Promachocrinus kerguelensis* in the Antarctic has been observed reacting to an approaching ROV by 'flying' (M. Eleaume, 2019, pers. comm., 5 May). The 'flying' or 'crouching' behaviour they display may be a consequence of the light associated with the video camera or vibration (bow waves generated by the approaching ROVs or submersible). In other species, such as *Atelecrinus helgae* or some *Democrinus* from Whittard Canyon, touching the individuals using the arm of an ROV also induces a 'flying' or 'crouching' reaction (M. Eleaume, 2019, pers. comm., 5 May). It is unknown what sort of receptors crinoids have, and whether these receptors are sensitive to light, but this cannot be ruled out.

**Sensitivity assessment.** Observations by Messing (2019, pers. comms., 30 April), Eleaume (2019, pers. comm., 5 May) and Morais *et al.* (2007) suggest that *Leptometra celtica* and other crinoids display a likely avoidance response (i.e. crown rotation, arm waving, 'crouching' or 'flying' behaviour) to approaching ROVs or submersible (bright lights). As there is no evidence of mortality, and effects are limited to behavioural responses, resistance is assessed as '**High**', resilience as '**High**' and overall the biotopes are considered to be '**Not sensitive**' at the benchmark level.

#### Biological Pressures

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

*Leptometra celtica* is not subject to cultivation or translocation so this pressure is considered '**Not** relevant'.

Introduction or spread of	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
species	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence could be found for the effects of 'introduction or spread of non-indigenous' species on *Leptometra celtica*. This pressure benchmark is assessed as '**No evidence**'.

Introduction of microbial	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
pathogens	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

Myzostomida are the most abundant agents to infect Crinoidea (Jangoux, 1987a). *Leptometra celtica* is affected by two myzostome worms: the semi-parasitic *Pulvinomyzostomum pulvinar*, which lives within the digestive tract of its crinoid host (Jangoux, 1987b), and the epibiont *Myzostoma alatum*. Graff (1884) originally identified the host of both as *Leptometra phalangium*, but his

specimens were collected off NW Scotland, outside the range of this species. Clark (1921) listed both species as occurring on both *Leptometra* species, with specimens of *Pulvinomyzostomum pulvinar* from NW Scotland and off Italy, and *Myzostoma alatum* from NW Scotland, Portugal, and the Mediterranean coast of Spain. Jangoux (1987b) also listed Roscoff for the former and noted that its infestation level can reach 10-20%. *Pulvinomyzostomum pulvinar* does not injure its host, but, being located at the anterior part of the digestive tract, it instead diverts the flow of food particles entering the crinoid's mouth (Prenant, 1959, West & West, 1976 in Jangoux, 1987b). Crinoids are noted to be sensitive to external agents (those that attach themselves to the host's external body surface, such as *Myzostoma alatum*), possibly resulting from a weak defensive capacity of their epidermal barrier (Jangoux, 1987a).

Although no diseases associated with crinoids have been reported, echinoderms in other parts of the world have been severely affected by epidemic type diseases, so there is the potential for this to occur. Nevertheless, this pressure only considers microbial pathogens which are spread/introduced by human activities/humans, or are controllable by management, or reported to cause a decline in the affected species population. Myzostomes are therefore not deemed relevant to the pressure, so this pressure is assessed as '**No evidence**'.

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

*Leptometra celtica* is not a commercially or recreationally targeted species so this pressure is '**Not** relevant'.

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

This pressure only assesses the biological effects of the removal of species. For evidence on the effects of the removal itself, please see the physical damage pressures.

Leptometra celtica is a small crinoid (a feather star) that lives on the surface of the seabed, and it raises its arms to feed on suspended particles carried by near-bottom currents. The species is therefore at risk of being removed as by-catch. This is supported by evidence showing that, during trawl surveys, about 300 kg of crinoids, or about 200,000 individuals, could easily be collected in one hour of trawling (Colloca *et al.*, 2004). If a significant proportion of *Leptometra celtica* are removed, the biotope structure (species richness and diversity) will be altered. Evidence for this loss of structure has been recorded by Smith *et al.* (2000), who noted a strong reduction in *Leptometra phalangium* and other echinoderms in trawled areas of the eastern Mediterranean, along with a decrease in the richness, abundance and biomass of benthic species.

The degree of recovery would depend on the ability of *Leptometra celtica* to survive damage (Przibram, 1901, cited in Holland, 1991), immigrate into an area via swimming (Scottish Natural Heritage pers. comm., in Mazik *et al.*, 2015; M. Eleaume, 2019, pers. comm., 5 May), or recolonise through larval recruitment. However, *Leptometra celtica* is likely to have low fecundity, typical of most crinoids (McEdward *et al.*, 1988, in Holland, 1991), and Gallego *et al.* (2013) suggest the species has low connectivity, resulting from a short pelagic larval duration. Although *Leptometra celtica* occurs inshore as well as in the deep-sea offshore, any significant exchange of organisms between these areas is unlikely, meaning that the populations are likely to be distinct (Gallego *et al.*, 2013). Recruitment of new individuals following disturbance will, therefore, be limited to any

viable populations nearby.

**Sensitivity assessment**. Trawl surveys have shown that large quantities of crinoids can be collected during one hour of trawling (Colloca *et al.*, 2004). The removal of a significant proportion of *Leptometra celtica* would alter the biotope structure (species richness and diversity), so resistance is assessed as '**Low**'. Resilience is assessed as '**Medium**', as recovery could occur through larval recruitment and individuals moving into the area. Sensitivity is therefore assessed as '**Medium**'.

## **Bibliography**

Allen, S.E. & Durrieu de Madron, X., 2009. A review of the role of submarine canyons in deep-ocean exchange with the shelf. *Ocean Science*, **5** (4), 607-620. DOI https://doi.org/10.5194/os-5-607-2009

Barbaglio, A., Mozzi, D., Sugni, M., Tremolada, P., Bonasoro, F., Lavado, R., Porte, C. & Carnevali, M.D.C., 2006. Effects of exposure to ED contaminants (TPT-CI and Fenarimol) on crinoid echinoderms: comparative analysis of regenerative development and correlated steroid levels. *Marine Biology*, **149** (1), 65-77. DOI https://doi.org/10.1007/s00227-005-0205-0

Barbaglio, A., Turchi, C., Melone, G., Di Benedetto, C., Martinello, T., Patruno, M., Biggiogero, M., Wilkie, I.C. & Carnevali, M.D.C., 2012. Larval development in the feather star *Antedon mediterranea*. *Invertebrate Reproduction & Development*, **56** (2), 124-137. DOI https://doi.org/10.1080/07924259.2011.578154

Baumiller, T.K., 2008. Crinoid Ecological Morphology. Annual Review of Earth and Planetary Sciences, **36** (1), 221-249. DOI https://doi.org/10.1146/annurev.earth.36.031207.124116

Baumiller, T.K., Mooi, R. & Messing, C.G., 2008. Urchins in the meadow: paleobiological and evolutionary implications of cidaroid predation on crinoids. *Paleobiology*, **34** (1), 22-34. DOI https://doi.org/10.1666/07031.1

Baxter, J.M., Boyd, I.L., Cox, M., Donald, A., Malcolm, S., Miles, H., Miller, B. & Moffat, C.J.M.S., Edinburgh, 2011. Scotland's Marine Atlas: Information for the national marine plan. 191.

Blanchard, F., LeLoc'h, F., Hily, C. & Boucher, J., 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. *Marine Ecology Progress Series*, **280**, 249-260. DOI https://doi.org/10.3354/meps280249

Bo, M., Di CaMillo, C.G., Bertolino, M., Povero, P., Misic, C., Castellano, M., Harriague, A.C., Gasparini, G.P., Borghini, M. & Schroeder, K., 2010. The megabenthic assemblages of the Vercelli seamount (North Tyrrhenian Sea)/le comunità megabentoniche del Vercelli seamount (Mar Tirreno Settentrionale). *Biologia Marina Mediterranea*, **17** (1), 94.

Bowden, D.A., Schiaparelli, S., Clark, M.R. & Rickard, G.J., 2011. A lost world? Archaic crinoid-dominated assemblages on an Antarctic seamount. *Deep Sea Research Part II: Topical Studies in Oceanography*, **58** (1), 119-127. DOI https://doi.org/10.1016/j.dsr2.2010.09.006

Bozec, A., Lozier, M.S., Chassignet, E.P. & Halliwell, G.R., 2011. On the variability of the Mediterranean Outflow Water in the North Atlantic from 1948 to 2006. *Journal of Geophysical Research: Oceans*, **116** (C9). DOI https://doi.org/10.1029/2011JC007191

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

Carnevali, M.D.C., 2005. Regenerative Response and Endocrine Disrupters in Crinoid Echinoderms: An Old Experimental Model, a New Ecotoxicological Test. *Echinodermata: Progress in Molecular and Subcellular Biology*. Springer, Berlin, Heidelberg, pp. 167-200. DOI https://doi.org/10.1007/3-540-27683-1\_8

Cerrano, C., Bavestrello, G., Bianchi, C., Cattaneo-Vietti, R., Bava, S., Morganti, C., Morri, C., Picco, P., Sara, G., Schiaparelli, S., Siccardi, A. & Sponga, F., 2000. A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-western Mediterranean), summer 1999. *Ecology Letters*, **3** (4), 284-293. DOI https://doi.org/10.1046/j.1461-0248.2000.00152.x

Clark, A.H. & Clark, A.M., 1967. A Monograph of the Existing Crinoids, vol. 1. The Comatulids, pt. 5: Suborders Oligophreta (Concluded) and Macrophreata. *Bulletin of the United States National Museum*, **82** (pt 5), 1-860. Available from https://repository.si.edu/handle/10088/21747

Clark, A.H., 1921. A monograph of the existing crinoids, vol. 1. The comatulids, pt. 2: [General]. Bulletin of the United States National Museum, 82, 1-795. DOI https://doi.org/10.5479/si.03629236.82.2

Clark, M.R., Bowden, D.A., Rowden, A.A. & Stewart, R., 2019. Little Evidence of Benthic Community Resilience to Bottom Trawling on Seamounts After 15 Years. *Frontiers in Marine Science*, **6**. DOI https://doi.org/10.3389/fmars.2019.00063

Colloca, F., Carpentieri, P., Balestri, E. & Ardizzone, G.D., 2004. A critical habitat for Mediterranean fish resources: shelf-break areas with *Leptometra phalangium* (Echinodermata: Crinoidea). *Marine Biology*, **145** (6), 1129-1142. DOI https://doi.org/10.1007/s00227-004-1405-8

CBD (Convention on Biological Diversity), 2014. An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. *Secretariat of the Convention on Biological Diversity, Montreal*, ISBN 92-9225-527-4, 99 pp.

Cook, R., Fariñas-Franco, J. M., Gell, F. R., Holt, R. H., Holt, T., Lindenbaum, C., Porter, J.S., Seed, R., Skates, L.R., Stringell, T.B. & Sanderson, W.G., 2013. The substantial first impact of bottom fishing on rare biodiversity hotspots: a dilemma for evidence-based conservation. *PloS One*, **8** (8), e69904. DOI https://doi.org/10.1371/journal.pone.0069904

Cordes, E.E., Jones, D.O.B., Schlacher, T.A., Amon, D.J., Bernardino, A.F., Brooke, S., Carney, R., DeLeo, D.M., Dunlop, K.M., Escobar-Briones, E.G., Gates, A.R., Génio, L., Gobin, J., Henry, L.-A., Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N.C., Metaxas, A., Pfeifer, S., Sink, K., Sweetman, A.K. & Witte, U., 2016. Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies. *Frontiers in Environmental Science*, **4**. DOI https://doi.org/10.3389/fenvs.2016.00058

Cranmer, G.J., Dyer, M.F. & Fry, P.D., 1984. Further results from headline camera surveys in the North Sea. *Journal of the Marine Biological Association of the United Kingdom*, **64** (2), 335-342. DOI https://doi.org/10.1017/S0025315400030034

Dimech, M., Camilleri, M., Gristina, M., Kaiser, M.J. & Schembri, P.J., 2005. Commercial and non-target species of deep-water trawled muddy habitats on the Maltese continental shelf. *Xjenza*, **10**, 18-23. Available from http://staff.um.edu.mt/jgri1/xjenza/articles/10/index.html

Dupont, S., Ortega-Martínez, O. & Thorndyke, M., 2010. Impact of near-future ocean acidification on echinoderms. *Ecotoxicology*, **19** (3), 449-462. DOI https://doi.org/10.1007/s10646-010-0463-6

Ferguson, M., Last, E. & Robson, L., 2018. Deep-Sea Life - Issue 12. INDEEP Available from http://www.indeep-project.org/indeep/sites/indeep/files/documents/DSL12\_Dec\_2018\_small.pdf

FAO (Fisheries and Aquaculture Organisation), 2019. Deep-ocean climate change impacts on habitat, fish and fisheries. FAO Fisheries and Aquaculture Technical Paper, FAO (Fisheries and Aquaculture Organisation), Rome, No. 638., 186 pp

Fonseca, P., Abrantes, F., Aguilar, R., Campos, A., Cunha, M., Ferreira, D., Fonseca, T.P., García, S., Henriques, V., Machado, M., Mechó, A., Relvas, P., Rodrigues, C.F., Salgueiro, E., Vieira, R., Weetman, A. & Castro, M., 2014. A deep-water crinoid *Leptometra celtica* bed off the Portuguese south coast. *Marine Biodiversity*, **44** (2), 223-228. DOI https://doi.org/10.1007/s12526-013-0191-2

Gallego, A., Gibb, F.M., Tulett, D. & Wright, P.J., 2013. Scottish Marine and Freshwater Science: Connectivity of Benthic Priority Marine Species within the Scottish MPA Network. Scottish Marine and Freshwater Science, vol 4(2), Marine Scotland, Aberdeen, 51pp. pp. Available from

https://www.gov.scot/publications/scottish-marine-freshwater-science-volume-4-number-2-connectivity-benthic/

Garfield, N., Rago, T.A., Schnebele, K.J. & Collins, C.A., 1994. Evidence of a turbidity current in Monterey Submarine Canyon associated with the 1989 Loma Prieta earthquake. *Continental Shelf Research*, **14** (6), 673-686. DOI <a href="https://doi.org/10.1016/0278-4343(94)90112-0">https://doi.org/10.1016/0278-4343(94)90112-0</a>

Garrabou, J., Coma, R., Bensoussan, N., Bally, M., Chevaldonné, P., Cigliano, M., Díaz, D., Harmelin, J.-G., Gambi, M.C. & Kersting, D., 2009. Mass mortality in Northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. *Global Change Biology*, **15** (5), 1090-1103.

Gofas, S., Salas, C., Rueda, J.L., Canoura, J., Farias, C. & Gil, J., 2014. Mollusca from a species-rich deep-water Leptometra community in the Alboran Sea. *Scientia Marina*, **78** (4), 537-553. DOI https://doi.org/10.3989/scimar.04097.27A

Guensburg, T. & Sprinkle, J., 2001. Earliest crinoids: New evidence for the origin of the dominant Paleozoic echinoderms. *Geology*, **29** (2), 131-134. DOI 2.0.CO" target="\_blank">https://doi.org/10.1130/0091-7613(2001)029<0131>2.0.CO

Gutt, J., Starmans, A. & Dieckmann, G., 1996. Impact of iceberg scouring on polar benthic habitats. *Marine Ecology Progress Series*, **137**, 311-316. DOI https://doi.org/10.3354/meps137311

Haig, J.A., Gillanders, B.M. & Rouse, G.W., 2012. Live fast, die young: the life cycle of the brooding feather star Aporometra wilsoni (Echinodermata: Crinoidea). Invertebrate Biology, **131** (3), 235-243. DOI https://doi.org/10.1111/j.1744-7410.2012.00270.x

Hill, J., 2008. Antedon bifida. Rosy feather-star. Marine Life Information Network: Biology and Sensitivity Key Information Subprogramme [On-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 25/01/18] Available from: https://www.marlin.ac.uk/species/detail/1521

Hiscock, K., Southward, A., Tittley, I. & Hawkins, S., 2004. Effects of changing temperature on benthic marine life in Britain and Ireland. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **14** (4), 333-362.

Hofmann, G.E., Barry, J.P., Edmunds, P.J., Gates, R.D., Hutchins, D.A., Klinger, T. & Sewell, M.A., 2010. The Effect of Ocean Acidification on Calcifying Organisms in Marine Ecosystems: An Organism-to-Ecosystem Perspective. *Annual Review of Ecology, Evolution, and Systematics*, **41**, 127-147. DOI https://doi.org/10.1146/annurev.ecolsys.110308.120227

Howell, K.L., 2010. A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. *Biological Conservation*, **143** (5), 1041-1056. DOI https://doi.org/10.1016/j.biocon.2010.02.001

Howell, K.L., Davies, J.S. & Narayanaswamy, B.E., 2010. Identifying deep-sea megafaunal epibenthic assemblages for use in habitat mapping and marine protected area network design. *Journal of the Marine Biological Association of the United Kingdom*, **90** (01), 33. DOI https://doi.org/10.1017/S0025315409991299

Howson, C.M., Mercer, T. & Moore, J.J., 2006. Site Condition Monitoring: survey of rocky reefs in the Firth of Lorn marine Special Area of Conservation. Scottish Natural Heritage, Inverness, Scotland, 316 pp. Available from http://www.snh.org.uk/pdfs/publications/commissioned\_reports/F05AC701.pdf

Hughes, S.J.M., Ruhl, H.A., Hawkins, L.E., Hauton, C., Boorman, B. & Billett, D.S.M., 2011. Deep-sea echinoderm oxygen consumption rates and an interclass comparison of metabolic rates in Asteroidea, Crinoidea, Echinoidea, Holothuroidea and Ophiuroidea. *Journal of Experimental Biology*, **214** (15), 2512-2521. DOI https://doi.org/10.1242/jeb.055954

Huthnance, J., 2010. Temperature and salinity, in: Charting the Progress 2: Ocean processes feeder report, section 3.2. (eds. Buckley, P., et al.): UKMMAS, Defra, London.

Huthnance, J., 2010. Temperature and salinity, in: Charting the Progress 2: Ocean processes feeder report, section 3.2. (eds. Buckley, P., et al.): UKMMAS, Defra, London.

Jacobson, M.Z., 2005. Studying ocean acidification with conservative, stable numerical schemes for nonequilibrium air-ocean exchange and ocean equilibrium chemistry. **110** (D7). DOI https://doi.org/10.1029/2004jd005220

Jangoux, M., 1987b. Diseases of Echinodermata. IV Structural abnormalities and general considerations on biotic diseases. *Diseases of Aquatic Organisms*, **3**, 221-229. DOI https://doi.org/10.3354/dao003221

Jangoux, M., 1987a. Diseases of Echinodermata. III Agents metazoans (Annelida to Pisces). Diseases of Aquatic Organisms, 3, 59-83.

#### DOI https://doi.org/10.3354/dao003059

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

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

Joint, I., Groom, S.B., Wollast, R., Chou, L., Tilstone, G.H., Figueiras, F.G., Loijens, M. & Smyth, T.J., 2002. The response of phytoplankton production to periodic upwelling and relaxation events at the Iberian shelf break: estimates by the 14C method and by satellite remote sensing. *Journal of Marine Systems*, **32** (1), 219-238. DOI https://doi.org/10.1016/S0924-7963(02)00037-4

Jones, D.O.B., Hudson, I.R. & Bett, B.J., 2006. Effects of physical disturbance on the cold-water megafaunal communities of the Faroe–Shetland Channel. *Marine Ecology Progress Series*, **319**, 43-54.

Koukouras, A., Sinis, A.I., Bobori, D., Kazantzidis, S. & Kitsos, M.S., 2007. The echinoderm (Deuterostomia) fauna of the Aegean Sea, and comparison with those of the neighbouring seas. *Journal of Biological Research*, **7**, 67-92.

La Touche, R. & West, A., 1980. Observations on the food of *Antedon bifida* (Echinodermata: Crinoidea). *Marine Biology*, **60** (1), 39-46.

La Touche, R.W., 1978. The feeding behaviour and autecology of the shallow-water featherstar Antedon bifida (Pennant). Journal of the Marine Biological Association of the United Kingdom, **58**, 877-890.

Lahaye, M.-C. & Jangoux, M., 1987. The skeleton of the stalked stages of the comatulid crinoid Antedon bifida (Echinodermata). Zoomorphology, **107** (1), 58-65. DOI https://doi.org/10.1007/BF00312130

Lavaleye, M.S.S., Duineveld, G.C.A., Berghuis, E.M., Kok, A. & Witbaard, R., 2002. A comparison between the megafauna communities on the N.W. Iberian and Celtic continental margins—effects of coastal upwelling? *Progress in Oceanography*, **52** (2), 459-476. DOI https://doi.org/10.1016/S0079-6611(02)00019-8

Lawrence, J.M., 1996. Mass mortality of echinoderms from abiotic factors. In *Echinoderm Studies Vol. 5* (ed. M. Jangoux & J.M. Lawrence), pp. 103-137. Rotterdam: A.A. Balkema.

Leonard, A.B., Strickler, J.R. & Holland, N.D., 1988. Effects of current speed on filtration during suspension feeding in *Oligometra serripinna* (Echinodermata: Crinoidea). *Marine Biology*, **97** (1), 111-125. DOI https://doi.org/10.1007/BF00391251

Macurda, D.B. & Meyer, D.L., 1974. Feeding Posture of Modern Stalked Crinoids. *Nature*, **247** (5440), 394. DOI https://doi.org/10.1038/247394a0

Mangano, M., Kaiser, M., Porporato, E. & Spanò, N., 2013. Evidence of trawl disturbance on mega-epibenthic communities in the Southern Tyrrhenian Sea. *Marine Ecology Progress Series*, **475**, 101-117. DOI https://doi.org/10.3354/meps10115

Mazik, K., Strong, J., Little, S., Bhatia, N., Mander, L., Barnard, S. & Elliott, M., 2015. A review of the recovery potential and influencing factors of relevance to the management of habitats and species within Marine Protected Areas around Scotland. Scottish Natural Heritage Commissioned Report No. 771. Scottish Natural Heritage, Inverness, 135 pp. Available from https://www.nature.scot/snh-commissioned-report-771-review-recovery-potential-and-influencing-factors-relevance-manage ment

McEdward, L.R., Carson, S.F. & Chia, F.-S., 1988. Energetic Content of Eggs, Larvae, and Juveniles of *Florometra serratissima* and the Implications for the Evolution of Crinoid Life Histories. *International Journal of Invertebrate Reproduction and Development*, **13** (1), 9-21. DOI https://doi.org/10.1080/01688170.1988.10510338

Messing, C.G., 1984. Brooding and paedomorphosis in the deep-water feather star *Comatilia iridometriformis* (Echinodermata: Crinoidea). *Marine Biology*, **80** (1), 83-91. DOI https://doi.org/10.1007/BF00393131

Messing, C.G., 2013. A revision of the genus Atelecrinus PH Carpenter (Echinodermata: Crinoidea). Zootaxa, **3681** (1), 1-43. DOI https://doi.org/10.11646/zootaxa.3681.1.1

Meyer, D.L. & Lawrence, J.M., 1982. Food composition and feeding behavior of sympatric species of comatulid crinoids from the Palau Islands (western Pacific). In Lawrence, J.M. ed., *Echinoderms: Proceedings of the International Conference, Tampa Bay*, pp. 43-49. AA Balkema, Rotterdam.

Meyer, D.L. & Macurda Jr, D.B., 1980. Ecology and distribution of the shallow-water crinoids of Palau and Guam. *Micronesica*, **16** (1), 59-99.

Migliaccio, O., Castellano, I., Romano, G. & Palumbo, A., 2014. Stress response to cadmium and manganese in *Paracentrotus lividus* developing embryos is mediated by nitric oxide. *Aquatic Toxicology*, **156**, 125-134.

Morais, P., Borges, T.C., Carnall, V., Terrinha, P., Cooper, C. & Cooper, R., 2007. Trawl-induced bottom disturbances off the south coast of Portugal: direct observations by the 'Delta'manned-submersible on the Submarine Canyon of Portimão. *Marine Ecology*, **28** (s1), 112-122. DOI https://doi.org/10.1111/j.1439-0485.2007.00175.x

Oliveira, F., Monteiro, P., Bentes, L., Henriques, N.S., Aguilar, R. & Gonçalves, J.M.S., 2015. Marine litter in the upper São Vicente submarine canyon (SW Portugal): Abundance, distribution, composition and fauna interactions. *Marine Pollution Bulletin*, **97** (1-2), 401-407. DOI https://doi.org/10.1016/j.marpolbul.2015.05.060

Parry, M.E.V., Howell, K.L., Narayanaswamy, B.E., Bett, B.J., Jones, D.O.B., Hughes, D.J., Piechaud, N., Nickell, T.D., Ellwood, H., Askew, N., Jenkins, C. & Manca, E., 2015. *A Deep-sea section for the Marine Habitat Classification of Britain and Ireland*. JNCC report 530. ISSN 0963 8901 In: JNCC (2015) The Marine Habitat Classification for Britain and Ireland Version 15.03. [Date accessed]. Available from: https://mhc.jncc.gov.uk/

Pertossi, R.M., Brogger, M.I., Penchaszadeh, P.E. & Martinez, M.I., 2019. Reproduction and developmental stages in the crinoid *Isometra vivipara* Mortensen, 1917 from the southwestern Atlantic. *Polar Biology*, **42** (4), 807-816. DOI https://doi.org/10.1007/s00300-019-02477-5

Sanchez-Vidal, A., Canals, M., Calafat, A.M., Lastras, G., Pedrosa-Pàmies, R., Menéndez, M., Medina, R., Company, J.B., Hereu, B., Romero, J. & Alcoverro, T., 2012. Impacts on the Deep-Sea Ecosystem by a Severe Coastal Storm. *PLOS ONE*, **7** (1), e30395. DOI https://doi.org/10.1371/journal.pone.0030395

Serrano, A., Preciado, I., Abad, E., Sánchez, F., Parra, S. & Frutos, I., 2008. Spatial distribution patterns of demersal and epibenthic communities on the Galician continental shelf (NW Spain). *Journal of Marine Systems*, **72** (1-4), 87-100. DOI https://doi.org/10.1016/j.jmarsys.2007.05.012

Smith, A.B., 1997. Echinoderm Larvae and Phylogeny. *Annual Review of Ecology and Systematics*, **28** (1), 219-241. DOI https://doi.org/10.1146/annurev.ecolsys.28.1.219

Smith, C., Papadopoulou, K.N. & Diliberto, S., 2000. Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. *ICES Journal of Marine Science*, **57** (5), 1340-1351. DOI https://doi.org/10.1006/jmsc.2000.0927

Smith, C.J., Banks, A.C. & Papadopoulou, K.N., 2007. Improving the quantitative estimation of trawling impacts from sidescansonar and underwater-video imagery. *ICES Journal of Marine Science*, **64** (9), 1692-1701. DOI https://doi.org/10.1093/icesjms/fsm165

SNH (Scottish Natural Heritage), 2013. Scottish MPA Project Assessment against the MPA selection guidelines. North-West Sea Lochs and Summer Isles Possible Nature Conservation MPA. Scottish Natural Heritage, Inverness, 26 pp. Available from https://www.nature.scot/sites/default/files/2017-11/Marine Protected Area - Detailed Assessment Against the MPA Selection Guidelines - North-west sea lochs and Summer Isles\_0.pdf

Southward, E.C. & Campbell, A.C., 2006. *Echinoderms*. The Linnean Society of London. Avon: The Bath Press. [Synopses of the British Fauna No. 56.]

Sugni, M., Mozzi, D., Barbaglio, A., Bonasoro, F. & Carnevali, M.D.C., 2007. Endocrine disrupting compounds and echinoderms: new ecotoxicological sentinels for the marine ecosystem. *Ecotoxicology*, **16**(1), 95-108. DOI https://doi.org/10.1007/s10646-006-0119-8

Sugni, M., Tremolada, P., Porte, C., Barbaglio, A., Bonasoro, F. & Carnevali, M.D.C., 2010. Chemical fate and biological effects of several endocrine disrupters compounds in two echinoderm species. *Ecotoxicology*, **19** (3), 538-554. DOI https://doi.org/10.1007/s10646-009-0439-6

Tenore, K.R., Alonso-Noval, M., Alvarez-Ossorio, M., Atkinson, L.P., Cabanas, J.M., Cal, R.M., Campos, H.J., Castillejo, F., Chesney, E.J., Gonzalez, N., Hanson, R.B., McClain, C.R., Miranda, A., Roman, M.R., Sanchez, J., Santiago, G., Valdes, L., Varela, M. & Yoder, J., 1995. Fisheries and oceanography off Galicia, NW Spain: Mesoscale spatial and temporal changes in physical processes and resultant patterns of biological productivity. *Journal of Geophysical Research*, **100** (C6), 10943. DOI https://doi.org/10.1029/95JC00529

Tierney, K.M., Muir, G.K.P., Cook, G.T., MacKinnon, G., Howe, J.A., Heymans, J.J., Hughes, D.J. & Xu, S., 2017. "Ecosystem uptake and transfer of Sellafield-derived radiocarbon (<sup>14</sup>C) part 2: The West of Scotland." *Marine Pollution Bulletin*, **115** (1-2): 57-66. DOI https://doi.org/10.1016/j.marpolbul.2016.11.014

Tokioka, T., 1963. Supposed effects of the cold weather of the winter 1962-63 upon the intertidal fauna in the vicinity of Seto. *Publications of the Seto Marine Biological Library*, **11** (2), 415-424. DOI https://doi.org/10.5134/175332

Tokioka, T., 1966. Recovery of the *Echinometra* population in the intertidal zone in the vicinity of Seto, with a preliminary note on the mass mortality of some sea urchins in the summer season. *Publications of the Seto Marine Biological Libray*, **14** (1), 7-16. DOI https://doi.org/10.5134/175426

Von Graff, L., 1884. Report on the Myzostomida collected during the voyage of HMS Challenger during the years 1873-1876. *Report on the Scientific Results of the Voyage of H.M.S. Challenger during the years* 1873-76, *Zoology*, **10**, 1-216.

Webster, S.K., 1975. Oxygen consumption in echinoderms from several geographical locations, with particular reference to the Echinoidea. *The Biological Bulletin*, **148**(1), 157-164. DOI https://doi.org/10.2307/1540656

Widdicombe, S. & Spicer, J.I., 2008. Predicting the impact of ocean acidification on benthic biodiversity: What can animal physiology tell us? *Journal of Experimental Marine Biology and Ecology*, **366** (1), 187-197. DOI https://doi.org/10.1016/j.jembe.2008.07.024