Icelandic cyprine (*Arctica islandica*)

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

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Arctica islandica **on a black background.**
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See online review for
distribution map

Distribution data supplied by the Ocean
Biogeographic Information System (OBIS). To
interrogate UK data visit the NBN Atlas.

Researched by	Dr Harvey Tyler-Walters & Marisa Sabatini	**Refereed by**	This information is not refereed.
Authority	(Linnaeus, 1767)		
Other common names	Ocean quahog	**Synonyms**	*Cyprina islandica* Linnaeus, 1767

Summary

🏷️ Description

Arctica islandica has a heavy, thick, oval to rounded shell up to 13 cm in length. The shell is sculptured with numerous fine concentric lines and the beaks are anterior. It has a thick glossy periostracum that is brown in smaller individuals, becoming greenish-brown to black in larger specimens. The periostracum peels away on dead shells, revealing a white to pale brown shell beneath.

📍 Recorded distribution in Britain and Ireland

The Icelandic cyprine is found around all British and Irish coasts and offshore e.g. in the North Sea.

📍 Global distribution

Recorded from Iceland, the Faeroe Islands, Onega Bay in the White Sea to the Bay of Biscay in the north-east Atlantic, including the Kattegat and western Baltic, and from Labrador to North Carolina in the west Atlantic.

🖼 Habitat

Arctica islandica is found at extreme low water level but predominately on sublittoral firm sediments including level offshore areas, buried (or part buried) in sand and muddy sand that ranges from fine to coarse grains.

↓ Depth range
4-482 m

🔍 Identifying features

- Large up to 13 cm long.
- Shell heavy, thick oval to rounded in shape.
- Periostracum thick and glossy.
- Periostracum brown in smaller individuals and greenish brown to black in larger individuals.
- Dead shells white to pale brown shell.

🏛 Additional information

Arctica islandica is the last surviving species of the family Arcticidae that dates back to the Jurassic and reached its highest diversity in the Cretaceous ca 135-65 million years ago (Morton, 2011).

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Biology review

☰ Taxonomy

Phylum	Mollusca	Snails, slugs, mussels, cockles, clams & squid
Order	Venerida	Cockles, hatchet shells, coin shells, venus shells, otter shells, wedge shells, razor shells and tellins
Family	Arcticidae	
Genus	Arctica	
Authority	(Linnaeus, 1767)	
Recent Synonyms	Cyprina islandica Linnaeus, 1767	

⚘ Biology

Typical abundance	See additional information
Male size range	8 - 13 cm
Male size at maturity	Varies (see text)
Female size range	8 - 13 cm
Female size at maturity	Varies (see text)
Growth form	Bivalved
Growth rate	See additional information
Body flexibility	None (less than 10 degrees)
Mobility	Burrower
Characteristic feeding method	Active suspension feeder, Surface deposit feeder
Diet/food source	Detritivore, Planktotroph
Typically feeds on	Phytoplankton, suspended sediment, detritus
Sociability	Not relevant
Environmental position	Infaunal
Dependency	None.
Supports	Host The nemertean worm *Malacobdella grossa* was recorded living commensally in the mantle cavity of *Arctica islandica* (Lauckner, 1983).
Is the species harmful?	No

🏛 Biology information

Growth

The growth rate of *Arctica islandica* is rapid in juveniles but very slow and indeterminate in adults. Individual growth rates are highly variable between different regions in the North Atlantic, within sites, between seasons and daily, depending on temperature, salinity, hydrography and food supply (see reviews by Cargnelli *et al.*, 1999a and Schone, 2013). Annual growth bands in the shell are used to determine growth rate and the age of specimens (Thompson *et al.*, 1980a; Butler *et al.*, 2013; Schone, 2013). *Arctica islandica* is the longest lived unitary (non-colonial) species known; the oldest recorded specimen being 507 years old (Butler *et al.*, 2013). The longevity of the specimens has allowed numerous authors to construct 'master chronologies' over tens or hundreds of years

to study changes in climate and environmental change (see Schone, 2013 for review).

Maximum growth occurs between three and seven years of age and growth slows down after 15 to 20 years (Thompson *et al.*, 1980b; Cargnelli *et al.*, 1999; Thorarinsdottir *et al.*, 2005). For example, Lutz *et al.* (1982) found that juveniles varied between 1.0 and 3.9 mm, 7.5 days after metamorphosis. And Kraus *et al.* (1989; 1992) reported a growth rate of 18.5 mm/yr in the first two years, and 7.3 mm/yr in the third year, in laboratory conditions. In Iceland, growth was rapid in the first 20 years to ca 7 cm in shell length, and then slows (Thorarinsdottir & Jacobson, 2005). Kennish *et al.* (1992) recorded that 9.2-19.9 mm shell length specimens averaged 10-22 mm/yr in the field. Growth rates may be reduced at high densities (Cargnelli *et al.*, 1999a). *Arctica islandica* exhibits considerable geographical variation in growth rates. In Whitsand Bay, (UK) individuals grew on average 0 -1.5 mm/yr, whereas off the coast of Long Island, (U.S.A) individuals grew 0.56 mm/yr. in 1970 and 11.7 mm/yr. in 1980; and specimens from New Jersey grew an average of 1 mm in 1.6 years (Kennish *et al.*, 1994; cited in Cargnelli *et al.*, 1999). In the North Sea, Witbaard *et al.* (1999) recorded that growth rate ranged from 0.2 to 1 mm/yr but the shells from the Fladen Ground, and the White Sea had the lowest growth rates, while the highest rates were found in Isafjord (north-west Iceland) and the Monkey Bank (central North Sea). In Belfast Lough, Ridway *et al.* (2012) recorded rapid growth until about 20 years of age, and a decline in rate until about 80 years of age, followed by low indeterminate growth, and an overall growth rate of 0.03 mm/yr. In the Meckelenburg Bight (Baltic), Zettler et al. (2001) reported rapid growth in the first five years, similar to populations in the Kaettegat, but slower growth in later years, and suggested that low salinity may result in lower growth rates. Begum *et al.* (2010) also recorded low growth rates but also reduced lifespan in the Kattegat (ca 58 yrs) and especially the White Sea (44 yrs) and Kiel Bay (40 yrs) compared with the North Sea (e.g. 125 yrs in the German Bight) associated with the reduced salinity. Individuals of similar size may vary greatly in age. For example, individuals ranging in age from about 50 - 179 years showed little discernible difference in mean length (Ropes & Murawski, 1983).

Daily, seasonal and annual growth, as revealed by growth rings and isotope analysis (^{18}O and ^{14}C), vary with temperature (inc. sea surface temperature (SST)), salinity, turbidity, food availability, sea-level pressure and oceanographic currents such as the North Atlantic Oscillation (NAO) and Atlantic Mutlidecadal Oscillation (AMO) (see Schone, 2013 for detailed review). For example, *Arctica islandica* from the shallow North Sea exhibited very low growth between September and November, and a growth season between December and August (Schone, 2013). Master chronologies in the North Icelandic Shelf looking at climate oscillations have shown 43-year and ca 205-year cycles relating to the AMO and de Vries cycles (Butler *et al.*, 2013; Schone, 2013), while ca decadal variation in shell growth over a 155-year composite chronology in the Fladen Grounds suggested the presence of a strong NAO(Schone, 2013). In addition, anthropogenic changes and disturbance also affects growth rates For example, low synchronicity in growth record from the German Bight was attributed to tidal and wind movements, changes in salinity due to riverine input, temperature shifts and turbidity (Schone, 2013). A chronology covering 1843 to 2007 from Lyne of Lorne, Scotland, revealed a severe reduction in growth between the mid 1940s and late 1980s. The authors suggested that slower growth was due to change in land-use and marine aquaculture in that period and result changes in eutrophication and plankton dynamics (Stott *et al.*, 2010; Schone, 2013).

Abundance
Abundance varies between regions and between sites. For example, in the south-east North Sea, the average density of adults >10 mm in length was 7 specimens per 100/m^2. The highest abundances of spat and adults were recorded in the central regions of the North Sea with 21

individuals >10 mm per 100/m^2 (Witbaard & Bergman, 2003). The northern North Sea (Fladen Grounds) was dominated by juveniles with 28,600 individuals per 100/m^2 (Witbaard & Bergman, 2003). In Kiel Bay, Baltic Sea, recorded abundances were 50 / m^2 but no size was recorded (Rees & Dare, 1993). In the Mecklenburg Bight (Baltic) Zettler *et al.* (2001) recorded an average density of 91 individuals/ m^2 but a maximum of 571 individuals/ m^2. In Belfast Lough, *Arctica islandica* is restricted to a single site with a density of 4.5 individuals/ m^2 (Ridgeway *et al.*, 2012).

Biomass / Production

In major areas of the north-west Atlantic the standing stock was (expressed as wet meat weight) over 119,000 t, an average of 10 g/ m^2, with a maximum (over 19,000 t) of 16 g/ m^2 (Murawski & Serchuk, 1989; cited in Rees & Dare, 1993). The total live shell weight /flesh weight ratio was not stated but was presumed to be 2:1 or 3:1. In Kiel Bay, the annual production was estimated to be 15 g ash free dry weight (AFDW) / m and the biomass was estimated to be 44.4 g AFDW /m^2 (Rees & Dare, 1993). Zettler *et al.* (2001) reported a mean biomass of 15 g/m^2 with a maximum of 120 g/m^2. Off Iceland, the small commercial quahog fishery landed 15000t of meat between 2005-2008 (Thorarinsdottir *et al.*, 2010). In the western Atlantic, the quahog fishery landed over 21,600 mt in 1996 and 3% decrease on 1995 (Cargnelli *et al.*, 1999a) and has an annual catch of ca 4.5 million bushels (Cargnelli *et al.*, 1999a; Powell & Mann, 2005) and, in 2012, landed 15.83 millions kg on 'meats' (Hennen, 2015).

Life style

Arctica islandica lives buried vertically in the top few centimetres of the sediment (soft sands and muddy sands) with is inhalant and exhalent siphons at the surface (Taylor, 1976; Morton, 2011). Morton (2011) noted that *Arctica islandica* remains motionless when feeding and does not open and close its valves even slightly during feeding or respiration. However, it alternates between periods at the surface and several centimetres in the sediment where is respires anaerobically. Like many other bivalves it is able to respire aerobically and anaerobically. Taylor (1976) noted that it could stay below the surface for episodes of between one and seven days, normally, although a single specimen remained buried for 24 days before returning to the surface. This behaviour was observed in laboratory specimens and specimens transplanted into the sediment in Port Erin Bay, Isle of Man. However, no rhythm was found to this behaviour, as it varied between and within specimens. The heart rate of *Arctica islandica* after long periods of shell closure usually takes over 20 hours to return to normal in Mytilus edulis this is accomplished in a few minutes). This behaviour in *Arctica islandica* was apparently self-induced (Oeschger, 1990) since no stimulus that initiates either burrowing or a return to the surface was identified (Taylor, 1976).

However, Thorarinsdottir *et al.* (2009) noted that *Artcia islandica* burrowed to a depth of 14 cm in the winter months in Iceland. Strahl *et al.* (2011a) noted that *Arctica islandica* burrowing behaviour varied with season. In February 2004 they were found 4-12 cm deep in the sediment but only 0-10 cm in June 2003. Icelandic *Arctica islandica* burrowed more frequently and deeper in winter than German Bight specimens *in situ*, while both populations remained burrowed for one to six days. They noted that in June, when the phytoplankton concentration in Eyjafjordur, North Iceland are 30 times higher than in February, 50% of bivalves are in contact with the sediment surface. Strahl *et al.* (2011a) suggested that burrowing activity was in response to food availability and temperature.

Morton (2011) concluded that *Arctica islandica* was a specialised surface deposit feeder, feeding on the surface film and suspended particles at the sediment surface. Morton (2011) also noted that *Arctica islandica* was characterized by slow, deliberate near undetectable movements (even when handled) and soft exhalant and inhalant streams. Morton (2011) concluded that the motionless,

sedate lifestyle probably predisposed the organism to a long lifespan, and negligible senescence.

🖼 Habitat preferences

Physiographic preferences	Offshore seabed, Open coast
Biological zone preferences	Lower circalittoral, Lower infralittoral, Upper circalittoral, Upper infralittoral
Substratum / habitat preferences	Coarse clean sand, Fine clean sand, Muddy sand, Sandy mud
Tidal strength preferences	No information
Wave exposure preferences	Exposed, Extremely exposed, Moderately exposed, Very exposed
Salinity preferences	Full (30-40 psu), Variable (18-40 psu)
Depth range	4-482 m
Other preferences	Distribution thought to be limited by an optimal temp to be 6 - 16 °C (see additional information).
Migration Pattern	

Habitat Information

Arctica islandica is distributed within the North Sea north of 53° 30`N and along the southern and eastern borders of its range is limited to depths below 30 m (Witbaard & Bergman, 2003). Similarly, the optimal temperature for adult *Arctica islandica* was estimated to be 6 to 16°C, while the inshore limit of their distribution in the eastern USA was reported to be the 16°C bottom isotherm (Cargnelli *et al.*, 1999a). Nicol (1951; cited in Holmes *et al.*, 2003) stated that *Arctica islandica* occurs at depths ranging from 4-482 m, although it is commonly found between 10-280 m.

℘ Life history

Adult characteristics

Reproductive type	Gonochoristic (dioecious)
Reproductive frequency	Annual protracted
Fecundity (number of eggs)	>1,000,000
Generation time	See additional information
Age at maturity	Varies, see additional information
Season	June - August (peak)
Life span	100+ years

Larval characteristics

Larval/propagule type	Trochophore, Veliger
Larval/juvenile development	Planktotrophic
Duration of larval stage	1-2 months
Larval dispersal potential	Greater than 10 km

Larval settlement period   See additional information

🏛 Life history information

Sexual maturity

Sexual maturity is reached in *Arctica islandica* at a later age than has been reported for other bivalves and age and size at maturity vary widely (Cargnelli *et al.*, 1999a; Thorarinsdottir & Steingrimsson, 2000). The age at sexual maturity in *Arctica islandica* was reported to vary between 5 and 11 years and may be dependent upon growth rate and locality (Thorarinsdóttir, 1999). Off north-west Iceland, the smallest mature male was 3.6 cm in length but the youngest was a 10-year old at 4.9 cm (Thorarinsdottir & Steingrimsson, 2000). The youngest mature female was 4.4 cm in length and 13-years of age (Thorarinsdottir & Steingrimsson, 2000). The mean age of sexual maturity in Nova Scotia was estimated to be 13.1 years for males and 12.5 years for females (Rowell *et al.* 1990; cited in Cargnelli *et al.*, 1999a). The earliest age at maturity was 7 years for both sexes and maturity occurred at a shell length of about 4.9 cm (Cargnelli et al., 1999a). Thompson *et al.* (1980b) reported immature individuals ranging in age from 4 -14 yr., at shell lengths ranging from 2.4 - 4.7 cm from the mid Atlantic Shelf, North America. Thompson *et al.* (1980b) suggested that immature *Arctica islandica* physiologically mimic the reproductive cycle of adults without providing gametes but very little research has been done on annual cycles of reproduction in juveniles.

Hennen (2015) estimated that the generation time of *Arctica islandica* (in USA populations) of ca 83 years, based on a generation time algorithm

Gametogenic cycle

Thorarinsdóttir (2000) examined the gametogenic cycle of *Arctica islandica* from Iceland and suggests that there are five phases in *Arctica islandica*'s gametogenic cycle (Thorarinsdóttir, 2000).

1. Early Active Phase. In females, oogonia appear and are embedded in the alveolar walls, often before the gonads are completely empty of ripe eggs. The shape of the oocytes may be square, triangular, cylindrical or hemispherical. In males, darkly stained spermatogonia are seen in the thickened alveolar walls but no spermatozoa are present.
2. Late Active Phase. In females, oocytes are larger and most are free from the membrane of the follicles. In males, secondary spermatocytes are numerous and the surrounding cytoplasm is irregular in shape and sperm appear in the lumina.
3. Ripe Phase. Follicles are extended and the gonads are full and ripe. In the female gonads, the follicle contains almost exclusively free large ripe eggs. In males, spermatozoa occupy the largest portion of the follicular spaces, while cells of early stages of spermatogenesis are few and confined to the area near the follicular walls. The sperm then form dense masses in the alveoli.
4. Partially Spent Phase. Gametes are discharged. In females, few large ripe oocytes are free in the lumina of some follicles but others are void of ripe oocytes. Oogonia and early oocytes may appear in the contracted and thickened walls. In males, substantially fewer spermatozoa are contained within the centre of the follicles. Most gonads are completely void of sperm.
5. Spent Phase. The follicles contain few undercharged eggs or sperm. Sometimes oocytes and primary spermatogonia begin to develop before the old ones are fully discharged (Thorarinsdóttir, 2000).

Investigations on *Arctica islandica* have shown that the timing and duration of events in the gametic cycle can be highly variable between years, which may reflect both environmental and endogenous factors (Thorarinsdóttir, 2000). In the Bay of Mecklenburg, Baltic, von Oertzen (1972) reported eggs and sperm in specimens between February and December and ripe gametes between March and November.

Spawning
Spawning is protracted. Loosanoff (1953) reported spawning off Rhode Island between late June or early July when water temperatures reach 13.3 °C, although not all individuals reach ripeness at the same time. The majority of individuals completed spawning by early October. The optimum salinity range for the existence and reproduction of *Arctica islandica* was between 31.0 - 32.8 ppt (Loosanoff, 1953). However, the spawning period varies with location. For example, another study reported spawning between May to November off Rhode Island, while spawning was reported to occur between September and November, and sometimes persisting into January off New Jersey, and between July to September off Nova Scotia (see Cargnelli *et al.*, 1999a). In the Bay of Mecklenburg, Baltic, von Oertzen (1972) reported spawning between May and September. Thorarinsdottir (2000) noted that all phases of gametogenesis were present all year round around north-west Iceland, except May and June, and that ripe specimens predominated samples from May until August when spawned individuals predominated until February. Thorarinsdottir (2000) concluded that spawning probably occurred all year but was most intense in June to August in north-west Icelandic waters.

Attempts to ripen specimens or induce spawning of *Arctica islandica* out of season in the laboratory have had no or very limited success (Loosanoff, 1953; Landers, 1976). The average size of a fertilized egg is 75-95 µm (Loosanoff, 1953; Lutz *et al.*, 1982). However, von Oertzen (1972) noted reported an eggs size of 70 µm in Baltic specimens and cited an egg size of 75 µm from the Kattegatt.

Larval development
The fertilized egg hatches into a trochophore larva that develops into a veliger larva. The veliger develops into a pediveliger prior to settlement. The duration of each stage is temperature dependent (Cargnelli *et al.*, 1999a). The minimum time for larval development was reported to be 55 days at 8.5-10°C, 60 days at 10-12°C and 32 days at 13°C and the reported size at metamorphosis varied between 175-200 µm and 240 µm (Cargnelli et al., 1999a). Therefore, the larval settling is likely to occur over several months and dispersal potential is thought to be high.

Sensitivity review

Resilience and recovery rates

Arctica islandica is a long-lived bivalve that takes up to 10 or more years to reach sexual maturity, depending on locality. It spawns over a protracted period but with a peak in late summer and autumn, depending on location. In addition, it has a long-lived, planktonic larvae and the potential for wide dispersal across the Atlantic. However, the length of time in the plankton increases the likelihood of predation. Recruitment in most bivalves is considered to be is sporadic and variable (Olafsson *et al.*, 1994). Recruitment in bivalve molluscs is affected by adult population density, settlement intensity (in some but not all cases), post-settlement and juvenile predation, active and passive transport, bed-load transport or sediment erosion (Olafsson *et al.*, 1994); hence larval and post-settlement mortality. As a result, larval dispersal may not be as effective as it assumed.

Recruitment in *Arctica islandica* is reported to be variable with a steady low level of recruitment interspersed with unpredictable large recruitment events at intervals of one or more decades, depending on location (Hennen, 2015). For example, examination of the dynamics of populations in the mid-Atlantic Bight (Powell & Mann, 2005) demonstrated that recruitment varied across that region. In the area northeast of the Hudson Canyon, the size frequency distribution was dominated by older individuals 6.6-8 cm in length. The abundance in this area had increased ca 40 or more years prior to the study, and received little recruitment since. The area off New Jersey was characterized by large size classes and the absence of significant recruitment over in the last century. The area south of 39°N was unique, with the widespread presence of young recruits, in an area most heavily impacted by the local fishery that included individuals within the lifespan of the regional fishery. Powell & Mann (2005) concluded that recruitment events were rare, occurring only once in 20 or 40 years but noted that this time frame was not rare when compared to an adult lifespan of over 200 years. They also noted that recruitment success was probably dependent on local conditions. Shellfish surveys between 1980 and 1999 in the Georges Bank revealed a population dominated by large individuals (7.5-9 cm in length) in the 1980s but a bimodal distribution of small (<7 cm) and large individuals in the 1990s (Lewis *et al.*, 2001b). Lewis *et al.* (2001b) concluded that annual recruitment was variable in the past 40 years with recent recruitment from individuals spawned in 1981 or 1982 and 1986 or 1987. Further studies in the Mid-Atlantic Bight (from Long Island Sound to Chesapeake Bay mouth) demonstrated a decadal pattern of recruitment with cohorts of individuals corresponding to recruitment during the 1948–1950, 1954–1959, 1972–1980, and 1978–1983 periods (Harding *et al.*, 2008). They also reported that successful recruitment was correlated with above average bottom water temperatures between January and March; recruitment was good in years in which the number of months with water temperatures averaging 6°C to 10°C exceeds the number of months with water temperatures less than 6°C by at least two months (Harding *et al.*, 2008).

In the waters of Iceland, major recruitment events may occur more frequently (Thorarinsdottir & Jacobson, 2005). Some recruitment was noted each year since 2002 (Thorarinsdottir & Jacobson, 2005), although peaks in recruitment occurred at about 20-year intervals (Steingrimsson & Thorarinsdottir, 1995; Thorarinsdottir & Jacobson, 2005). In the Mecklenburg Bight (Baltic), Zettler *et al.* (2001) reported a population dominated by individuals <3 cm in length, and suggested strong recruitment in the previous 10 – 15 years, although the adult lifespan was reduced in this area.

Recruitment varied with location in the North Sea based on observations between 1970 and 2000 (Witbaard & Bergman, 2003). The highest density of individuals was found in the Fladen Ground

(northern North Sea). In 1983, the Fladen Ground was dominated by specimens with a shell height of ca 3.5 cm high that had settled in the 1960s. This cohort of specimens was still identifiable 17 years later (2000) together with new recruits that settled in 1995. Witbaard & Mann (2003) concluded that successful recruitment had only occurred twice in 30 years, with an interval of 25 years in this region. In the Oyster Ground (southern North Sea) the population was dominated by specimens larger than 5 cm but specimens less than 5 cm were rare but also concentrated in the deeper central part of the Oyster Ground, together with relatively high densities of spat and juveniles. Witbaaard & Bergman (2003) suggested that the stratified water column in summer over the Oyster Ground led to the accumulation of larvae in or below the seasonal thermocline, resulting in a high density of spat and juveniles (1-5 cm in shell height). However, spat and juvenile survival did not result in recruitment to the adult population. While the spat were concentrated in the deepest part of the Oyster Ground, the overall spat density was low; ca 5% of that required to maintain the density of juveniles found in the Fladen Grounds (Witbaaard & Bergman, 2003). In addition, the Oyster Ground was subject to a beam trawl fishery. Witbaaard & Bergman (2003) estimated that the overall fishing related mortality of adult *Arctica islandica* would have been enough to decimate the adult population within ca 25 years, as well as damage spat and juveniles, and result in a reduced density of reproductive adults and hence a low fertilization efficiency.

In Belfast Lough, the 41-60 years and 101-120 year classes dominated the population with over 15% of the population aged over 100 years (Ridgway *et al.*, 2012), although their experimental dredge may not have sampled the smaller size classes. However, they concluded that the population experienced almost continuous recruitment in the last century prior to the study with a gap in recruitment at 90-100 years and another at 140-150 years prior to the study (Ridgway *et al.*, 2012).

Relatively few studies of *Arctica islandica* populations have examined recovery. Gilkinson *et al.* (2005, 2015) examined recovery of commercial bivalve populations, including *Arctica islandica* after experimental dredging over a ten-year period (1998-2008) on the Scotia Shelf, Canada. Dredging in 1998 resulted in a 67% reduction in the commercial bivalve biomass (Gilkinson *et al.*, 2005). However, in the 10-year post-dredging period, out of 844 measured bivalves only 11 specimens of the four species studied (one specimen of ocean quahog) were new recruits. Sediment mobility in the area allowed the sediment the to recover, and benthic macrofauna recovery, except the target bivalves, was well underway after two years. The lack of recruitment by the four commercial species was not due to sediment modification. Gilkinson *et al.* (2015) suggested that recovery of the commercial species, including *Arctica islandica*, would take more than 10 years. Hennen (2015) noted that the minimum population density for successful fertilization was unknown, and a population reduced below this minimum level could decrease and fail to recover.

Ragnarsson *et al.* (2015) examined the effects of hydraulic dredging on the benthos of Þistilfjörður Bay, NE Iceland over a five year period. The benthic community was significantly affected by dredging with up to 50% reductions or increases in abundance immediately after dredging. Most taxa recovered their prior abundances within a year. However, *Arctica islandica* experienced a 93% decrease in abundance after dredging and recovered within the dredge tracks to only 7% to 26% of controls within five years. Ragnarsson *et al.* (2005) noted that adult quahogs did not migrate into the affected area from the surrounding sediments. They also reported that larval recruitment occurred within the period of the study but were unable to determine if the recruitment contributed to the recovery. However, they suggested that recovery was due to the growth of small specimens that remained in the dredged tracks. Ragnarsson *et al.* (2015) noted that in north-west Iceland it took ca 50-60 years for *Arctica islandica* to attain a fishable size. They speculated

that 50-100 years was required to for full recovery in abundance and population size distributions and that fishery closure was the required to rebuild stocks.

Recent genetic studies suggest that effective larval dispersal is not as good as assumed and that *Arctica islandica* populations are not panmictic. For example, examination of haplotypes of the mitochondrial cytochrome-*b* (cyt-*b*) revealed differences between the western and eastern Atlantic populations of *Arctica islandica* (Dahlgren *et al.*, 2000). The western Atlantic populations (from Maine to southern Virginia) showed a low diversity of cyt-*b* haplotypes and were genetically very similar, while Icelandic populations were more diverse. The phylogeny suggested that Icelandic population was more closely related to western Atlantic populations than eastern Atlantic populations, while the Faeroese population was intermediate. Dahlgren *et al.* (2000) suggested that the low diversity in the western Atlantic was due to a bottleneck during a climatic optimum (warm waters) during the Holocene (ca 7500 BP). They also suggested that dispersal was most likely from the western Atlantic to eastern Atlantic, and not vice-versa (Dahlgren *et al.*, 2000).

Holmes *et al.* (2003) examined specimens from Nova Scotia, the Fladen Ground and Oyster Ground in the North Sea, and Inner and Outer Gullmarsfjord, Sweden using RAPDs (randomly amplified polymorphic DNA) and shell morphology. They found that each population studied was genetically different for the RAPD markers examined. Although the populations also showed phenotypic, morphological, differences these did not correlate with the genetic markers nor geographic distance between populations. However, their results demonstrated population subdivision and evidence of physical reproductive isolation between the populations studied (Holmes *et al.* 2003).

Resilience assessment. *Arctica islandica* is a long-lived, slow-growing bivalve that takes between ca 5 and ca 15 years to reach maturity depending on location. Hennen (2015) estimated that the generation time of *Arctica islandica* (in USA populations) of ca 83 years, based on a generation time algorithm and noted that the history of commercial fishing for *Arctica islandica* in the USA (since 1943), spanned a period less than a single generation. It has long-lived planktonic larvae but, like most bivalves, larval survival and the survival of spat is low and dependent on numerous environmental factors so that recruitment to the population is sporadic and unpredictable. Studies show that recruitment is continuous at a low level but successful peaks in recruitment occur at intervals in excess of 10 years and can vary between, 10, 20, 30 or even a 100 years, depending on location, although the Baltic population is an exception.   Studies of recovery post-disturbance suggest that the population of *Arctica islandica* in Canada had begun to recover after 10 years. However, Ragnarsson *et al.* (2015) noted that in north-west Iceland it took ca 50-60 years for *Arctica islandica* to attain a fishable size and speculated that 50-100 years was required to for the full recovery in abundance and population size distributions and that fishery closure was the required to rebuild stocks. Therefore, if a population experienced significant mortality (i.e. 'Low' or 'None' resistance) then recovery is likely to take in excess of ten years and maybe in excess of 25 years (e.g. in the North Sea; Witbaard & Bergman, 2003), and a precautionary resilience of '**Very low'** is recorded in UK waters. If the population only suffered some mortality (i.e. 'Medium' resistance) then recovery might be possible from low levels of continuous recruitment, and a resilience of '**Medium**' would be recorded. However, as noted above, recruitment and recovery will depend on numerous environmental factors including the size of the local population, variations in sea temperature, the local hydrography, regional oceanic currents (see growth above) and local reproductive isolation from other populations (see Holmes *et al.*, 2003) and, hence, resilience may vary depending on location.

🚢 Hydrological Pressures

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

An increase in temperature may affect spawning and recruitment levels. Kennish & Lutz (1995; cited in Cargnelli *et al.*, 1999a) attributed low recruitment to adverse environmental factors such as high temperatures. In the North Sea, *Arctica islandica* are restricted to north of 53° 30´ N and have never been reported south of this latitude (Witbaard & Bergman, 2003). This southern limit coincides with a 30 m depth contour, which borders the southern limit of the summer stratified water mass of the Oyster Ground, where bottom water temperatures never exceed 16°C. Larvae here can successfully develop but conditions for development and survival deteriorate along the southern margins of the North Sea (Witbaard & Bergman, 2003). Similarly, the inshore limit of *Arctica islandica* in the eastern USA was reported to be the 16°C bottom isotherm (Cargnelli *et al.*, 1999a). In the mid-Atlantic Bight (from Long Island Sound to Chesapeake Bay mouth), Harding *et al.* (2008) reported that successful recruitment was correlated with above average bottom water temperatures between January and March. Recruitment was good in years in which the number of months with water temperatures averaging 6°C to 10°C exceeds the number of months with water temperatures less than 6°C by at least two months (Harding *et al.*, 2008).

Laboratory studies have shown that larvae and juveniles can survive temperatures as high as 20°C, although larvae tend to grow optimally between 13°C - 15°C (Cargnelli *et al.*, 1999a). Field studies off Massachusetts observed the highest concentrations of larvae between August and September at temperatures of 14 -18°C (Cargnelli *et al.*, 1999a). Merrill *et al.* (1969) reported a lethal temperature of 13-16°C and that adults died in a few days at 21°C in the laboratory. It was stated that it was difficult to keep adult specimens alive long enough to transport them to market in the summer months in the USA, which suggested a low tolerance of high temperatures. It was also suggested that an intolerance of high temperatures might explain their absence from shallow waters in the southern extent of its range (Merrill *et al.*, 1969; Cargnelli *et al.*, 1999a).

Hiebenthal *et al.* (2012) exposed *Arctica islandica* collected from the Kiel Bight to temperatures of 4, 10 and 16°C a salinities of 15, 20 and 25. They noted that shell growth was highest at 4°C and salinity 35, but still high at 10 and 16°C at salinity 25. The condition index of *Arctica islandica* was not affected by salinity but decreased with increasing temperature, while mortality was not correlated with temperature but decreased with increasing salinity. However, at full salinity (35) shell growth increased from 4 to 10°C but reduced on increase to 16°C (Hiebenthal *et al.*, 2012). Begum *et al.* (2010) also noted that low salinity and low temperature were particularly stressful conditions for Arctica islandica, based on population in Kiel Bay, Kattegat, and the White Sea.

Basova *et al.* (2012) suggested that the long lifespan of *Arctica islandica* in the North Atlantic was explained partly by low metabolic rate and high ability to repair damage (metabolic). However, shorter lifespans were associated with raised metabolic rate due to higher temperatures and low and fluctuating salinity so that Baltic populations exhibited the lowest life spans of the populations studied.

Sensitivity assessment. Overall the larvae and spat (juveniles) appear to be able to tolerate up to 20°C while 16°C is the upper limit of tolerance for adults, and the 16°C isotherm is considered to limit their distribution. A short-term increase in temperature, e.g. 5°C for a month, may not cause mortality and *Arctica islandica* can burrow into the sediment to escape short-term temperature increases at the sediment surface. However, a prolonged increase e.g. 2°C for a year is likely to result in mortality, especially in the summer months and where the population is at its southern

limit (e.g. Belfast Lough; Ridgway *et al.*, 2012 or the southern North Sea; Witbaard & Mann, 2003) or in relatively shallow inshore waters (Witbaard & Mann, 2003). Therefore, a resistance **'Medium'** is suggested at the benchmark level.   Hence, resilience is probably **'Medium'** and sensitivity is assessed as **'Medium'**.

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

Arctica islandica is a temperate, boreal cold water species. Cargnelli *et al.* (1999a) reported that juveniles could grow at temperatures as low as 1°C, while other estimates suggested an optimal temperature range for adults of 6 -16°C. Begum *et al.* (2010) suggested that low temperature is particularly stressful when combined with low salinity (see salinity below) based on the unusual growth pattern observed in the White Sea.   It is likely to be tolerant of lower temperatures than it experiences around the British Isles since it also occurs as far north as the Faeroes, Iceland and the White Sea. However, Thorarinsdottir *et al.* (2009) noted that *Arctica islandica* burrowed to a depth of 14 cm in the winter months in Iceland. Strahl *et al.* (2011a) noted that *Arctica islandica* burrowing behaviour varied with season. In February 2004 they were found 4-12 cm deep in the sediment but only 0-10 cm in June 2003. Icelandic *Arctica islandica* burrowed more frequently and deeper in winter than German Bight specimens *in situ*, while both populations remained burrowed for one to six days. They noted that in June, when the phytoplankton concentration in Eyjafjordur, North Iceland are 30 times higher than in February, 50% of bivalves are in contact with the sediment surface. Strahl *et al.* (2011a) suggested that burrowing activity was in response to food availability and temperature. Crisp (1964) noted a few dead specimens but no abnormal mortality in the North Sea after the severe winter of 1962/63. Therefore, a resistance of **'High'** is suggested. Hence, resilience is assessed as **'High'** and this species is probably **'Not sensitive'** at the benchmark level.

Salinity increase (local)	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

An increase in salinity at the benchmark level would result in a salinity of >40 psu, and as hypersaline water is likely to sink to the seabed, shallow water populations of *Arctica islandica* species may be affected by hypersaline effluents. Ruso *et al.* (2007) reported that changes in the community structure of soft sediment communities due to desalinization plant effluent in Alicante, Spain. In particular, in close vicinity to the effluent, where the salinity reached 39 psu, the community of polychaetes, crustaceans and molluscs was lost and replaced by one dominated by nematodes. Roberts *et al.* (2010b) suggested that hypersaline effluent dispersed quickly (within 10s of metres of the outfall) but was more of a concern at the seabed and in areas of low energy where widespread alternations in the community of soft sediments were observed. In several studies, echinoderms and ascidians were amongst the most sensitive groups examined (Roberts *et al.*, 2010b).

Sensitivity assessment. An increase in salinity from full to >40 psu is probably detrimental to the *Arctica islandica* over a period of a year (the benchmark). However, no direct no direct evidence of the effects of hypersaline conditions or effluent on the species was found. Therefore, **'No evidence'** was recorded.

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

Larval *Arctica islandica* were collected at mean salinities of 32.4 ppt in the USA, while juveniles

were grown successfully at salinities ranging from 32 - 34 ppt in the laboratory. Adults are usually found at full salinities but were kept in the laboratory at 22 ppt for several weeks (Oeschager & Storey, 1993; Cargnelli *et al.*, 1999a). Zettler *et al.* (2001) reported that *Arctica islandica* inhabited an area in Mecklenburg Bight where the bottom water salinity ranged from 12.5 to 22 psu but also that the population was dominated by small adults with a maximum recorded age of 70 years, and a slower growth rate than in the Kattegat. Zettler *et al.* (2001) reported a large population of *Arctica islandica* in the Mecklenburg Bight with a maximum density of 571/m^2 and an area of 5200 km^2.

Hiebenthal *et al.* (2012) exposed *Arctica islandica* collected from the Kiel Bight to temperatures of 4, 10 and 16°C at salinities of 15, 20 and 25. They noted that shell growth was highest at 4°C and salinity 35, but still high at 10 and 16°C at salinity 25. The condition index of *Arctica islandica* was not affected by salinity but decreased with increasing temperature, while mortality was not correlated with temperature but decreased with increasing salinity. However, at full salinity (35) shell growth increased from 4 to 10°C but reduced on increase to 16°C (Hiebenthal *et al.*, 2012).

Begum *et al.* (2010) noted that low salinity and low temperature were particularly stressful conditions for *Arctica islandica*, based on population in Kiel Bay, Kattegat, and the White Sea. They also noted a reduction in overall lifespan with decreasing salinity. For example, the maximum age they recorded in the German Bight was 125 years but only 58 years in the Kattegat. But the maximum age in low salinities sites of the White Sea and Kiel Bay was less than 50 years (Begum *et al.*, 2010).

Sensitivity assessment. *Arctica islandica* is generally found in full salinity but can occur in lower salinity, although its growth rate and life expectancy are reduced. Hiebenthal *et al.* (2012) noted that mortality increased with decreasing salinity in the laboratory and suggested that Baltic populations of *Arctica islandica* may experience severe stress under a climate change scenario of increased temperature and desalination in the Baltic region. However, Zettler *et al.* (2001) reported a large population. Therefore, a change in salinity from 'Full' to 'Reduced' (18-30) is likely to result in additional stress to the population but may not result directly in an increase in mortality of the population in UK waters. Therefore, a resistance of **'High'** is suggested to reflect a decrease in lifespan. Hence, resilience is **'High'** and sensitivity is recorded as **'Not sensitive'** at the benchmark level. However, populations in reduced salinity exposed to low salinities, especially in combination with low temperatures (Begum *et al.*, 2010; Hiebenthal *et al.*, 2012) may suffer mortality due to a further reduction in salinity.

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

Arctica islandica is recorded from sandy muds to coarse sands and hence a range of water flow regimes. Recruitment and growth are influenced by the local hydrography (e.g. thermal inversions and gyres in the North Sea, Witbaard & Mann, 2003) and regional currents (e.g the North Atlantic Oscillation, and Atlantic Multidecadal Oscillation (AMO) (see Schone, 2013) that entrain larvae or alter food supply as plankton or detritus. However, little information on the water flow preferences was found.

In shallow waters, *Arctica islandica* populations may be vulnerable to severe storm events. For example, small numbers were washed ashore in Red Wharf Bay after a severe storm (Rees *et al.*, 1977; Rees & Dare, 1993). In Iceland, a heavy storm (winds >20 m/s) in April 2006 caused large waves and currents in Lonafjordur, where a dense population of *Arctica islandica* occurred between

9 and 30 m. As a result, large numbers of *Arctica islandica* were washed to shallow waters (7-9m) on hard substrata where they rapidly fell prey to wolffish, starfish and other invertebrate predators. Nevertheless, extensive deep water populations are unlikely to be vulnerable to storms (Rees & dare, 1993; OSPAR, 2009c)

However, a change in water flow of 0.1-0.2 m/s is probably of limited effect given the species preference for a range of sediment types. Therefore, a resistance of **'High'** is suggested, with a **r**esilience of **'High'** so that the biotope is probably **'Not sensitive'** at the benchmark level.

Emergence regime changes	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

Changes in emergence are **Not Relevant** to this species, which are restricted to fully subtidal conditions. The pressure benchmark is relevant only to species found in the littoral and shallow sublittoral fringe.

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

Arctica islandica is recorded from open coasts and exposed, extremely exposed, moderately exposed, and very exposed wave conditions but in sandy muds to coarse sands, sheltered from wave action, primarily due to depth. In shallow waters, *Arctica islandica* populations may be vulnerable to severe storm events. For example, small numbers were washed ashore in Red Wharf Bay after a severe storm (Rees *et al.*, 1977; Rees & Dare, 1993). In Iceland, a heavy storm (winds >20 m/s) in April 2006 caused large waves and currents in Lonafjordur, where a dense population of *Arctica islandica* occurred between 9 and 30 m. As a result, large numbers of *Arctica islandica* were washed to shallow waters (7-9m) on hard substrata where they rapidly fell prey to wolffish, starfish and other invertebrate predators. Nevertheless, extensive deep water populations are unlikely to be vulnerable to storms (Rees & Dare, 1993; OSPAR, 2009c). However, a 3-5% change in significant wave height is unlikely to any significant effect on the population even in shallow waters. Therefore, a resistance of **'High'** is suggested, with a **r**esilience of **'High'** so that the species is probably **'Not sensitive'** at the benchmark level.

⚗ Chemical Pressures

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

This pressure is **Not assessed.**

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

This pressure is **Not assessed.**

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

This pressure is **Not assessed**.

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

No evidence was found

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

This pressure is **Not assessed**.

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

Arctica islandica was reported to be resistant to severe hypoxia (Theede *et al.*, 1969, Diaz & Rosenberg, 1995). Kiel Bay (Baltic Sea) has seen significant declining trends in deep water oxygen concentration since the 1950's. In 1981 salinities of 20 - 26 psu and temperatures of 10-14°C were recorded. Anoxia and hydrogen sulphide were widespread below the halocline at a depth of >20 m (Rosenberg & Loo, 1988). The anoxic event lasted several weeks and during that time, 30,000 t of macrofauna died over 750 km. However, *Arctica islandica* was amongst the few surviving species. Another area that has recorded severe hypoxic events was in the Kattegat (Sweden). The worst year recorded was 1988, when approximately 30,000 km of the bottom water was hypoxic. Oxygen concentrations recorded were 3.1 ml/l (4.34 mg/l) in June, 1.0 ml/l in August, 0.9 ml/l (1.26 mg/l) in September, and *Arctica islandica* was amongst the surviving species. However, in an anoxic episode off New Jersey (USA), up to 13.3% of the *Arctica islandica* population died in shallow waters, while in deeper water the population was not affected (Ropes *et al.*, 1979; Cargnelli *et al.*, 1999a). Zettler *et al.* (2001) also reported that a long period of oxygen depletion in the Mecklenburg Bight (Baltic) resulted in the loss of the *Arctica islandica* population, although the density had increased in some areas by the early 1990s.

Arctica islandica can respire anaerobically when burrowed below the surface for ca seven days (but exceptionally for up to 25 days) (Taylor, 1976; Strahl *et al.*, 2011a) and when exposed to anoxia with or without hydrogen sulphide (Oeschger, 1990; Oeschger & Storey, 1993; Cargnelli *et al.*, 1999a). Oeschger & Storey (1993) also noted that *Arctica islandica* can still burrow under anoxic conditions and in the presence of hydrogen sulphide. However, Strahl *et al.* (2011b) noted that anaerobiosis was switched on only at anoxia and that respiration remained aerobic down to oxygen levels of 2 kPa (ca 0.88 mg/l).

Ropes *et al.* (1979) reported a critical oxygen tension for *Arctica islandica* of 5-7 kPa (2.2-3.1 mg/l). Theede *et al.* (1969) and Theede (1973) investigated the tolerance of *Arctica islandica* to hypoxia and hydrogen sulphide. The LT50 (50% mortality) occurred in *Arctica islandica* around 55 days into the experiment at an oxygen concentration of <0.15 ml/l (0.21 mg/l) (at 10°C and pH 8.2 - 8.45) and the LT50 occurred after around 33-42 days with the addition of hydrogen sulphide (Theede *et al.*, 1969; Theede, 1973). Environmental factors such as temperature can affect a species resistance to hypoxic conditions. With decreasing temperature below 10°C, the cellular resistance of *Arctica islandica* increases more than in species such as *Mytilus edulis* (Theede, 1973).

While the adults are reported to be highly resistant of low oxygen concentration, juveniles and larvae may be more sensitive (Zettler *et al.*, 2001). Zettler *et al.* (2001) suggested that oxygen

depletion in the deeper parts of the Lubeck Bay, Mecklenburg Bight (due to the pycnocline) prevented the successful recruitment of juveniles and the high biomass in that area was restricted to low numbers of adults. Successful recruitment was restricted to favourable years.

Sensitivity assessment. *Arctica islandica* is regarded as highly tolerant of severe hypoxia, and anoxia even in the presence of hydrogen sulphide. Populations of the species have been reported to survive hypoxic and anoxic events lasting several weeks but succumb to events lasting for long periods (e.g. in the Baltic). However, adults are likely to survive exposure to <2mg/l oxygen for a week. Juveniles may be more sensitive but recruitment is only likely to be interrupted if hypoxia occurred at the same time as peak recruitment, and the long-term population dynamics is only likely to be affected if hypoxia occurs on a regular basis; as in the Mecklenburg Bight example (Zettler *et al.*, 2001). Therefore, a resistance of **'High'** is suggested. Hence, resilience is recorded as **'High'** and the species is considered **'Not sensitive'** at the benchmark level.

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

No specific information regarding the effects of nutrients on *Arctica islandica* was found. Increased nutrients are likely to enhance algal and phytoplankton growth, increase organic material deposits, enhance bacterial growth and, hence, food supply. However, increased levels of nutrients may also result in eutrophication, algal blooms and a reduction in oxygen concentrations. Off the west coast of Kattegat (Sweden), Rosenberg & Loo (1988) reported mass mortalities of the bivalves *Mya arenaria* and *Cerastoderma edule* following a eutrophication event, although no direct causal link was established. However, the abundance of *Arctica islandica* remained very high despite falls in other bivalve populations. Also, low synchronicity in growth records from the German Bight was attributed to tidal and wind movements, changes in salinity due to riverine input, temperature shifts and turbidity (Schone, 2013).

Borja *et al.* (2000) suggested that *Arctica islandica* was "tolerant of excess organic matter enrichment" (AMBI, Group III) while Gittenberger & van Loon (2011) suggested it was "indifferent to enrichment, always present in low densities with non-significant variations with time" (AMBI, Group II).

Sensitivity assessment. *Arctica islandica* is a suspension feeder and/or surface deposit feeder, found in a range of sediment types and resistant to severe hypoxia. Therefore, it may well be resistant to the adverse effects of eutrophication. In addition, as the benchmark levels comply with WFD criteria for good status, resistance is **'High'**, resilience is **'High'** and the species is **'Not sensitive'** at the benchmark level.

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

No specific information regarding the effects organic enrichment on *Arctica islandica* was found. Organic enrichment will increase organic material deposits, enhance bacterial growth and, hence, food supply but also result in eutrophication and a reduction in oxygen concentrations. Off the west coast of Kattegat (Sweden), Rosenberg & Loo (1988) reported mass mortalities of the bivalves *Mya arenaria* and *Cerastoderma edule* following a eutrophication event, although no direct causal link was established. However, the abundance of *Arctica islandica* remained very high despite falls in other bivalve populations. Also, low synchronicity in growth records from the German Bight was attributed to tidal and wind movements, changes in salinity due to riverine

input, temperature shifts and turbidity (Schone, 2013).

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Sensitivity assessment. *Arctica islandica* is a suspension feeder and/or surface deposit feeder, found in a range of sediment types and resistant to severe hypoxia. Therefore, it may well be resistant to the adverse effects of organic enrichment and probably has a resistance of **'High'**. Hence, resilience is **'High'** and the species is **'Not sensitive'** at the benchmark level, albeit at low confidence.

🅰 Physical Pressures

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

All marine habitats and benthic species are considered to have '**No resistance'** to this pressure and to be unable to recover from a permanent loss of habitat. Sensitivity within the direct spatial footprint of this pressure is, therefore '**High'**. Although no specific evidence is described confidence in the resistance assessment is '**High**', due to the incontrovertible nature of this pressure.

	Resistance	Resilience	Sensitivity
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

A change to natural or artificial hard substratum would remove the sedimentary habitat required by the species. Based on the loss of suitable habitat, resistance to this pressure is assessed as '**None'**. Resilience is assessed as '**Very low'** as the pressure benchmark refers to a permanent change. Biotope sensitivity is, therefore '**High**'.

	Resistance	Resilience	Sensitivity
Physical change (to another sediment type)	Low Q: Low A: NR C: NR	Very Low Q: High A: High C: High	High Q: Low A: Low C: Low

Arctica islandica is recorded from sandy muds, muddy sands, and fine to coarse sands (Rees & Dare, 1993; Cargnelli *et al.*, 1999a). A change in one Folk class (based on Long, 2006) to fine muds or to mixed sediments dominated by gravel would place the species outside its preferred habitat. Muds and gravels may impair burrowing, and muds may impair filter feeding. As a result, the population is likely to suffer mortality. Therefore, a precautionary resistance of '**Low**' is suggested but with low confidence. As the pressure represents a permanent change, resilience is assessed as '**Very low**' and sensitivity recorded as '**High'.**

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

The removal of substratum to a depth of 30 cm will remove the substratum occupied by the

species together with the individuals present and any other species in the assemblage, in the impact footprint. Resistance is, therefore, assessed as **'None'.** Where suitable substratum remains, resilience is probably **'Very low'.** Sensitivity is, therefore, assessed as **'High'**. Although no specific evidence is described confidence in this assessment is 'High', due to the incontrovertible nature of this pressure.

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

Arctica islandica lives at the surface of the sediment while feeding but burrows to depths of 14 cm periodically and, in Iceland, over the winter months (Taylor, 1976; Thorarinsdottir *et al.* 2009; Strahl *et al.*, 2011a). It is harvested by hydraulic dredging but is also damaged by bottom trawl fisheries. Therefore, it is exposed to both surface abrasion and penetration of the sediment.

Arctica islandica is fished commercially in the U.S.A. The fishery began in 1943 and has operated continuously since 1967 (Hennen, 2015). Simulations suggest that the fishery operation requires very low fishing mortality rates as rates greater than 0.03 tended to result in fishery closures (Hennen, 2015). He also noted that the length of the commercial fishery was less than the generation time for *Arctica islandica* (ca 83 years). Jacobson & Weinberg (2006) noted that total ocean quahog biomass had decreased since the 1970s but that fishing mortality had remained stable since 1985. The target fishing mortality of 2.8% was not exceeded and hence the stock was not overfished.

It was fished commercially in Iceland between 1995 and 2008 (Ragnarsson *et al.*, 2015). Thorarinsdottir & Jacobson (2005) and Thorarinsdottir *et al.* (2010) noted that *Arctica islandica* was vulnerable to overfishing due to its long lifespan, slow growth, uncertain recruitment, low productivity, and poor estimates of stock biomass and capture efficiency. Ragnarsson *et al.* (2015) examined the effects of hydraulic dredging on the benthos of Þistilfjörður Bay, NE Iceland over a five year period. The benthic community was significantly affected by dredging with up to 50% reductions or increases in abundance immediately after dredging. Most taxa recovered their prior abundances within a year. However, *Arctica islandica* experienced a 93% decrease in abundance after dredging and recovered within the dredge tracks to only 7% to 26% of controls within five years. Ragnarsson *et al.* (2015) noted that in north-west Iceland it took ca 50-60 years for *Arctica islandica* to attain a fishable size. They speculated that 50-100 years was required to for full recovery in abundance and population size distributions. Gilkinson *et al.* (2005, 2015) examined recovery of commercial bivalve populations, including *Arctica islandica* after experimental dredging over a ten-year period (1998-2008) on the Scotia Shelf, Canada. Dredging in 1998 resulted in a 67% reduction in the commercial bivalve biomass (Gilkinson *et al.*, 2005). Gilkinson *et al.* (2015) suggested that recovery of the commercial species, including *Arctica islandica*, would take more than 10 years.

Arctica islandica has a thick, solid and heavy shell but is known to be vulnerable to physical abrasion. Klein & Witbaard (1993) and Witbaard & Klein (1994) examined damaged shells of *Arctica islandica* is the southern North Sea, an area subject to beam trawling. The damage to this species was related to their body size, and larger specimens were more affected than smaller ones (Klein & Witbaard, 1993; Witbaard & Klein, 1994). The number of damaged shells was highest in the southern North Sea, impacted by the beam trawl fishery, compared to mid-west and northern North Sea areas (Witbaard & Klein, 1994). Only 10% of empty shells collected in the southern North Sea were undamaged, compared to 40% in the mid-west North Sea (Witbaard & Klein,

1994). In addition, 80-90% of shell scars were found on the posterior side due to the animal's position in the upper sediment and the transit of the tickler chains along the seabed. Up to 90% of *Arctica islandica* caught by a commercial trawler were severely damaged with an estimated mortality rate ranging from 74% - 90% (Fronds, 1991; cited in Witbaard & Klein, 1994). However, shells were also damaged on board as well as during the fishing process. The number of damaged shells and the number caught increased when tickler chains were used. For example, 74% were damaged with the use of tickler chains whereas only 27% were damaged without their use (Fronds, 1991; cited in Witbaard & Klein, 1994). Witbaard & Klein (1994) also suggested that the age-frequency distribution was skewed by trawling, as juveniles were uncommon and the population was dominated by large adults. OSPAR (2009c) also noted that trends in shell scar frequencies corresponded to fluctuations in the total engine capacity of the Dutch beam trawl fleet. Thorarinsdottir *et al.* (2008) noted that 30-50% of ocean quahog caught in a hydraulic dredge were damaged, as were 11-29% of those left in the dredge track, and concluded that mortality of clams remaining on the track was due to shell damage or predation.

Declines in *Arctica islandica* populations were reported in the North Sea (OSPAR, 2009c). Examination of historic surveys with surveys in 1986 noted that *Arctica islandica* was present in 20-30% of stations in 1986 compared to 45% in 1902-1912 (Rumohr *et al.*, 1998, OSPAR, 2009c) because of its absence from shallow sites (30-50 m) in 1986. A significant decline in abundance between 1972-80 and 1990-1994 was also noted in the southern North Sea (Witbaard, 1997; Witbaard & Bergman, 2003). Improved survey techniques in 2000 revealed higher abundances of *Arctica islandica* in the North Sea than previously recorded but its occurrence in the North Sea had still decreased between the 1900s and 1990s (Witbaard & Bergman, 2003; OSPAR, 2009c). Bergman & van Santbrink (2000) reported direct mortality from a single pass of a beam trawl in *Arctica islandica* of ca 11% but only <0.5% for an otter trawl. Witbaard & Bergman (2003) suggested that this level of mortality (11%) would have been enough to decimate the population of adults in the Oyster Ground (southern North Sea) within 25 years and result in the observed densities of only 10 individuals /100m^2, which were low compared to the Fladen Grounds.

Sensitivity assessment. The above evidence suggests that *Arctica islandica* can be damaged by abrasion due to mobile fishing gear, e.g. beam trawls and otter trawls. Direct mortality can be attributed to mobile gear and to targeted fishing using hydraulic dredges. In addition, the decline in the population of *Arctica islandica* in the southern North Sea may correspond with beam trawling (OSPAR, 2009c). Therefore, a resistance of **'Low'** is suggested. Resilience is probably **'Very low'** so that a sensitivity of **'High'** is suggested.

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

The relevant evidence on the effects of fishing activities is presented above under abrasion. Direct mortality can be attributed to mobile gear and to targeted fishing using hydraulic dredges. In addition, the decline in the population of *Arctica islandica* in the southern North Sea may correspond with beam trawling (OSPAR, 2009c). Therefore, a resistance of **'Low'** is suggested. Resilience is probably **'Very low'** so that a sensitivity of **'High'** is suggested.

Changes in suspended solids (water clarity)	High	High	Not sensitive
	Q: Low A: NR C: NR	Q: High A: High C: High	Q: Low A: Low C: Low

Morton (2011) examined the anatomy of *Arctica islandica* and concluded that it was an unusual,

specialist, deposit feeder with typical large intestine but unusually large ctenidia. Its siphons sit at the sediment-water interface so that it probably feeds off the rich surface film and deposited organic material brought in on the inhalent current since it has an extremely sedentary lifestyle (Morton, 2011). It can also feed on phytoplankton if available. Winter (1969) recorded that *Arctica islandica* (3.3-8.3 mm in length) could filter 0.7-7 litres/hour and 30-280 mg dry weight of algae in 24h, in the laboratory.

Arctica islandica occurs in silty sediments in sheltered to wave exposed conditions, where the surface of the sediment is probably regularly mobilized, and where accretion rates are moderate to high. Therefore, increase in turbidity (suspended sediments) may not adversely affect the species, especially as it can avoid sudden changes by burrowing for several days. Although, no specific evidence was found a resistance of **'High'** is suggested but with Low confidence. Therefore, resilience is assessed as **'High'** and *Arctica islandica* is probably **'Not sensitive'** at the benchmark level.

Smothering and siltation rate changes (light)	High	High	Not sensitive
	Q: High A: High C: Medium	Q: High A: High C: High	Q: High A: High C: Medium

Powilleit *et al.* (2006) examined the effects of experimental spoil disposal in Mecklenburg Bay. They deposited 'till' and 'sand/till' mixtures up to ca 1.5 m deep on existing sediment, although the depth of deposit varies over time. The resident *Arctica islandica* population was 'almost' unaffected, and its population structure was similar two years later with no apparent change in growth rates. Powilliet *et al.* (2009) exposed *Arctica islandica* to smothering in the laboratory. They were exposed to 'till' (median grain size 8 μm) and 'sand/till' mixtures (median grain size 220 μm) to a depth of 10-20 cm and 14-40 cm. *Arctica islandica* was able to burrow to the surface of 32-41 cm of either sediment and regained contact with the surface. *Arctica islandica* reached burrowing velocities of 0.37-3.89 cm/day. Powilleit *et al.* (2009) stated that a considerable number of the test organism were able to burrow to the sediment surface. No clear difference between the depths of sediment tested was noted. However, they also note that the texture of the 'till' posed burrowing difficulties for *Arctica islandica*, and reported 16% and 0% reached the sediment surface in the 'till' and 'sand/till' mixtures respectively after 28 days. In comparison, they noted that in field experiments (Powilliet *et al.*, 2006) after initial deposition, 78% and 26% reached the surface under the 'till' and 'sand/till' mixtures respectively. Side scan sonar revealed that 75% of the initial deposit varied in depth from 0 to 40 cm after two months, while another 25% was >40 cm deep.

Sensitivity assessment. *Arctica islandica* may take many days to reach the surface of sediment in laboratory experiments, although no mortality was seen. However, in field conditions, it was able to reach the surface of sediment and no effect on its growth or population structure was evident (Powilliet *et al.*, 2006; 2009). Therefore, a deposit of 5 cm of fine material is unlikely to have a negative effect and a resistance of **'High'** is suggested. Hence, resilience is **'High'** and **'Not sensitive** at the benchmark level'** is recorded.

Smothering and siltation rate changes (heavy)	High	High	Not sensitive
	Q: High A: High C: Medium	Q: High A: High C: High	Q: High A: High C: Medium

Powilleit *et al.* (2006) examined the effects of experimental spoil disposal in Mecklenburg Bay. They deposited 'till' and 'sand/till' mixtures up to ca 1.5 m deep on existing sediment, although the depth of deposit varies over time. The resident *Arctica islandica* population was 'almost' unaffected, and its population structure was similar two years later with no apparent change in growth rates. Powilliet *et al.* (2009) exposed *Arctica islandica* to smothering in the laboratory. They were exposed

to 'till' (median grain size 8 μm) and 'sand/till' mixtures (median grain size 220 μm) to a depth of 10-20 cm and 14-40 cm. *Arctica islandica* was able to burrow to the surface of 32-41 cm of either sediment and regained contact with the surface. *Arctica islandica,* reached burrowing velocities of 0.37-3.89 cm/day. Powilleit *et al.* (2009) stated that a considerable number of the test organism were able to burrow to the sediment surface. No clear difference between the depths of sediment tested was noted. However, they also note that the texture of the 'till' posed burrowing difficulties for *Arctica islandica* and reported that 16% and 0% reached the sediment surface in the 'till' and 'sand/till' mixtures respectively after 28 days. In comparison, they noted that in field experiments (Powilliet *et al.*, 2006) after initial deposition, 78% and 26% reached the surface under the 'till' and 'sand/till' mixtures respectively. side scan sonar revealed that 75% of the initial deposit varied in depth from 0 to 40 cm after two months, while another 25% was >40 cm deep.

Sensitivity assessment. *Arctica islandica* may take many days to reach the surface of sediment in laboratory experiments, although no mortality was seen. However, in field conditions, it was able to reach the surface of sediment and no effect on its growth or population structure was evident (Powilliet *et al.*, 2006; 2009). Therefore, a deposit of 30 cm of fine material is unlikely to have a negative effect and a resistance of **'High'** is suggested. Hence, resilience is **'High'** and **'Not sensitive at the benchmark level'** is recorded.

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

Not assessed

Electromagnetic changes	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence was found

Underwater noise changes	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

Morton (2011) noted that *Arctica islandica* has a shadow reflex to light, that is, to its interference (e.g. by an approaching predator) and is also very sensitive to vibration. Once retracted it takes a long time for the siphons to be extended again (Morton, 2011). However, no evidence was found to suggest that underwater sound and vibrations caused by passing vessels, construction etc have any effect. Therefore **'Not relevant'** is recorded.

Introduction of light or shading	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

Morton (2011) noted that *Arctica islandica* has a shadow reflex to light, that is, to its interference (e.g. by an approaching predator) and is also very sensitive to vibration. Once retracted it takes a long time for the siphons to be extended again (Morton, 2011). However, artificial light or shading at the sea surface is unlikely to be detected, especially at the depths that most populations live. Therefore 'Not relevant' is recorded.

Barrier to species movement	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

Not relevant - this pressure is considered applicable to mobile species, e.g. fish and marine mammals rather than seabed habitats. Adult *Arctica islandica* are extremely sedentary and unlikely to move across the sediment (Morton, 2011). However, the dispersal of larvae and, hence recruitment, has been shown to be controlled in part by local and regional hydrography, localised gyres and water stratification (thermoclines and pycnoclines) (Holmes *et al.* 2003; Zettler *et al.*, 2001; Witbaard & Mann, 2003; Schone, 2013). Barriers that interfere with larval transport could reduce recruitment or entrain larvae depending on local conditions, although no examples were found. But dispersal is not considered under the pressure definition and benchmark.

Death or injury by collision	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

Not relevant' to seabed habitats. NB. Collision by interaction with bottom towed fishing gears and moorings are addressed under 'surface abrasion'.

Visual disturbance	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

Morton (2011) noted that *Arctica islandica* has a shadow reflex to light, that is, to its interference (e.g. by an approaching predator) and is also very sensitive to vibration. Once retracted it takes a long time for the siphons to be extended again (Morton, 2011). However, the shadow reflex is probably very localised so that visual disturbance by passing vessels or humans at the sea surface is probably **'Not relevant.**

🐾 Biological Pressures

	Resistance	Resilience	Sensitivity
Genetic modification & translocation of indigenous species	No evidence (NEv)	Not relevant (NR)	No evidence (NEv)
	Q: NR A: NR C: NR	Q: NR A: NR C: NR	Q: NR A: NR C: NR

No evidence was found to suggest that *Arctica islandica* was subject to translocation or genetic modification.

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

No evidence was found to suggest that *Arctica islandica* populations were adversely affected by invasive non-indigenous species.

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

The nemertean worm *Malacobdella grossa* was recorded living commensally in the mantle cavity of *Arctica islandica*. Records show that *Malacobdella grossa* was always present in large numbers (Lauckner, 1983). No information on the effects of *Malacobdella grossa* on *Arctica islandica* could be found, however, it could lower the viability of the population. Therefore, a resistance of **'High'** of low has been recorded. Hence, resilience is **'High'** and a sensitivity of **'Not sensitive'** is recorded.

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

Arctica islandica is fished commercially in the U.S.A. The fishery began in 1943 and has operated continuously since 1967 (Hennen, 2015). Simulations suggest that the fishery operation required very low fishing mortality rates as rates greater than 0.03 tended to result in fishery closures (Hennen, 2015). He also noted the length of the commercial fishery, was less than the generation time for *Arctica islandica* (ca 83 years). Jacobson & Weinberg (2006) noted that total ocean quahog biomass had decreased since the 1970s but that fishing mortality had remained stable since 1985. The target fishing mortality of 2.8% was not exceeded and hence the stock was not overfished.

It was fished commercially in Iceland between 1995 and 2008 (Ragnarsson *et al.*, 2015). Thorarinsdottir & Jacobson (2005) and Thorarinsdottir *et al.* (2010) noted that *Arctica islandica* was vulnerable to overfishing due to its long lifespan, slow growth, uncertain recruitment, low productivity, and poor estimates of stock biomass and capture efficiency. Ragnarsson *et al.* (2015) examined the effects of hydraulic dredging on the benthos of Þistilfjörður Bay, NE Iceland over a five year period. The benthic community was significantly affected by dredging with up to 50% reductions or increases in abundance immediately after dredging. Most taxa recovered their prior abundances within a year. However, *Arctica islandica* experienced a 93% decrease in abundance after dredging and recovered within the dredge tracks to only 7% to 26% of controls within five years. Ragnarsson et al. (2015) concluded that hydraulic dredging could have a drastic effect on *Arctica islandica* populations. Ragnarsson *et al.* (2015) noted that in north-west Iceland it took ca 50-60 years for *Arctica islandica* to attain a fishable size. They speculated that 50-100 years was required to for full recovery in abundance and population size distributions and that fishery closure was the required to rebuild stocks. However, they as also noted that small Icelandic fishery probably did not affect the ocean quahog stock size in Icelandic waters. Gilkinson *et al.* (2005, 2015) examined recovery of commercial bivalve populations, including *Arctica islandica* after experimental dredging over a ten-year period (1998-2008) on the Scotia Shelf, Canada. Dredging in 1998 resulted in a 67% reduction in the commercial bivalve biomass (Gilkinson *et al.*, 2005). Gilkinson *et al.* (2015) suggested that recovery of the commercial species, including *Arctica islandica*, would take more than 10 years. Thorarinsdottir *et al.* (2008) also noted that 30-50% of ocean quahog caught in a hydraulic dredge were damaged, as were 11-29% of those left in the dredge track, and concluded that mortality of clams remaining on the track was due to shell damage or predation.

Sensitivity assessment. The life history or *Arctica islandica*, coupled with its longevity means that it is vulnerable to overfishing (Thorarinsdottir & Jacobson, 2005; Thorarinsdottir *et al.*, 2010; Hennen, 2015; Ragnarsson *et al.*, 2015). The evidence suggests that hydraulic dredging can have drastic, if localised, effects on the population and that recovery is prolonged. The U.S.A the fishery may be sustainable due to the low fishing mortality. Therefore, a resistance of **'Low'** is suggested. Resilience is probably **'Very low'** and a sensitivity of **'High'** is recorded.

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

Arctica islandica has a thick, solid and heavy shell but despite this is known to be vulnerable to physical abrasion. Klein & Witbaard (1993) and Witbaard & Klein (1994) examined damaged shells of *Arctica islandica* is the southern North Sea, an area subject to beam trawling. The damage to this species was related to their body size, and larger specimens were more affected than smaller ones (Klein & Witbaard, 1993; Witbaard & Klein, 1994). The number of damaged shells was highest in

the southern North Sea, impacted by the beam trawl fishery, compared to mid-west and northern North Sea areas (Witbaard & Klein, 1994). Only 10% of empty shells collected in the southern North Sea were undamaged, compared to 40% in the mid-west North Sea (Witbaard & Klein, 1994). In addition, 80-90% of shell scars were found on the posterior side due to the animal's position in the upper sediment and the transit of the tickler chains along the seabed. Up to 90% of *Arctica islandica* caught by a commercial trawler were severely damaged with an estimated mortality rate ranging from 74% - 90% (Fronds, 1991; cited in Witbaard & Klein, 1994). However, shells were also damaged on board as well as during the fishing process. The number of damaged shells and the number caught increased when tickler chains were used. For example, 74% were damaged with the use of tickler chains whereas only 27% were damaged without their use (Fronds, 1991; cited in Witbaard & Klein, 1994). Witbaard & Klein (1994) also suggested that the age-frequency distribution was skewed by trawling, as juveniles were uncommon and the population dominated by large adults. OSPAR (2009) also noted that trends in shell scar frequencies corresponded to fluctuations in the total engine capacity of the Dutch beam trawl fleet. Thorarinsdottir *et al.* (2008) also noted that 30-50% of ocean quahog caught in a hydraulic dredge were damaged, as were 11-29% of those left in the dredge track, and concluded that mortality of clams remaining on the track was due to shell damage or predation.

Declines in *Arctica islandica* populations were reported in the North Sea (OSPAR, 2009). Examination of historic surveys with surveys in 1986 noted that *Arctica islandica* was present in 20-30% of stations in 1986 compared to 45% in 1902-1912 (Rumohr *et al.*, 1998, OSPAR, 2009) because of its absence from shallow sites (30-50 m) in 1986. A significant decline in abundance between 1972-80 and 1990-1994 was also noted in the southern North Sea (Witbaard, 1997; Witbaard & Bergman, 2003). Improved survey techniques in 2000 revealed higher abundances of *Arctica islandica* in the North Sea than previously recorded but that its occurrence in the North Sea had decreased between the 1900s and 1990s (Witbaard & Bergman, 2003; OSPAR, 2009). Bergman & van Santbrink (2000) reported direct mortality from a single pass of a beam trawl in *Arctica islandica* of ca 11% but only <0.5% for an otter trawl. Witbaard & Bergman (2003) suggested that this level of mortality (11%) would have been enough to decimate the population of adults in the Oyster Ground (southern North Sea) within 25 years and result in the observed densities of only 10 individuals /100m^2, which were low compared to the Fladen Grounds.

Sensitivity assessment. The above evidence suggests that *Arctica islandica* can be damaged and removed by non-targeted fishing, e.g. beam trawls and otter trawls. In addition, the decline in the population of *Arctica islandica* in the southern North Sea may correspond with beam trawling (OSPAR, 2009). Therefore, a resistance of **'Low'** is suggested. Resilience is probably **'Very low'** so that a sensitivity of **'High'** is suggested.

Importance review

🔨 Policy/legislation

Species of principal importance (Wales)	☑
OSPAR Annex V	☑
Features of Conservation Importance (England & Wales)	☑
Priority Marine Features (Scotland)	☑

★ Status

National (GB) importance	Not rare/scarce	**Global red list (IUCN) category**	-

Ⓝ Non-native

Native	Native		
Origin	-	**Date Arrived**	-

🏛 Importance information

It was estimated that some 40% of annual cod production was dependent on *Arctica islandica* in the period 1970 - 1985 in the Baltic Sea (Brey *et al.*, 1990). It has also been found in the stomach of North Sea cod (Rees & Dare, 1993).

Fisheries

Arctica islandica is commercially fished in the United States and Iceland.

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