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Marine Information Network

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

Fan mussel (*Atrina fragilis*)

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

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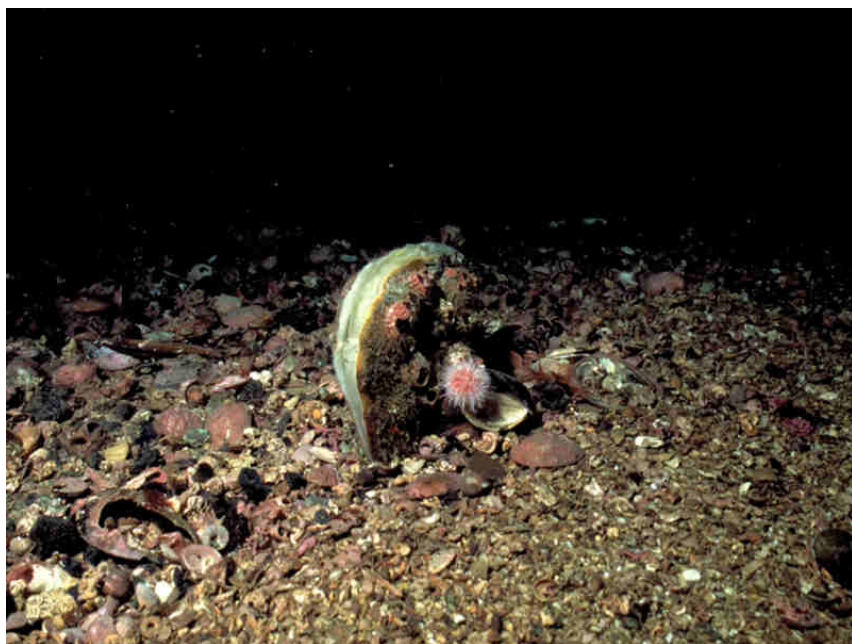
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Adult *Atrina fragilis* embedded in sea bed.

Photographer: Sue Scott

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See online review for
distribution map

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

Researched by	Dr Harvey Tyler-Walters & Catherine Wilding	Refereed by	Dr Dan Minchin
Authority	(Pennant, 1777)		
Other common names	-	Synonyms	<i>Atrina pectinata</i> (Linnaeus, 1767), <i>Pinna fragilis</i> (Pennant, 1777), <i>Pinna pectinata</i> (Linnaeus, 1767)

Summary

🔍 Description

One of Britain's largest and most threatened molluscs. It has a light golden or yellow-brown to dark brown shell reaching 30-48 cm long. The shell is triangular, tapering to a point, thin and brittle, making it very fragile. Fan mussels live with their pointed end embedded in sediment, attached to small stones or shells by abundant fine byssal threads. Between one and two-thirds of the shell is usually buried in the sediment. The posterior (broad) end protrudes from the surface of the sediment and may support growths of sea anemones, barnacles, hydroids and sponges. In the UK, it is often solitary but populations occur as small groups or patches of individuals forming small beds.

📍 Recorded distribution in Britain and Ireland

Recorded from Scotland in deep water around the Shetland Isles and Orkney, and the west coast of Scotland, with scattered records from north-east Scotland, the south coast of England, the Channel Isles, Pembrokeshire in south Wales and Northern Ireland.

Global distribution

Recorded from north Scotland down to Mauritania, including the Iberian Peninsula, and into the Mediterranean.

Habitat

Lives embedded in sublittoral fringe and subtidal muds, sandy muds or gravels.

Depth range

Sublittoral fringe to 600 m

Identifying features

- Large (30-48 cm in length by half that wide), triangular, thin and fragile shell tapering to a point.
- Shell with conspicuous concentric growth and disturbance lines with 8-12 low, smooth, wavy ridges radiating from the beaks (umbones).
- Occasional fluted spines.
- Shell colour light yellow-brown to darker brown or chestnut in colour.
- Inside of shell glossy (partly nacreous) with very dissimilar muscle scars, largest scar in the middle of shell valve.
- Valves gape at the posterior (broad) end.
- Byssus fine and abundant.
- Shell margin smooth but often fragmented at the posterior end.
- Lives with pointed anterior end embedded in muds, sandy mud or gravel, attached to small stones or shell fragments by byssus with between one or two-thirds of the shell below the sediment surface.

Additional information

According to Montagu (1803), the fan mussel was known for its silky byssus from which expensive gloves and stockings were once made. Montagu (1803) also states that shells were historically brought up from trawls off the Eddystone, Plymouth, and also taken by fishermen from Torbay and on the Dorset coast.

Information on the biology of *Atrina fragilis* is limited (Šimunović *et al.*, 2001; Solandt, 2003; Allen, 2011; Fryganiotis *et al.*, 2013; Stirling, 2016; Stirling *et al.*, 2016, 2018). The following review draws on information from other species of *Atrina* and *Pinna* often from outside the UK. Readers should note that *Atrina fragilis* was synonymised with *Atrina pectinata* until recently (Huber & Gofas, 2017). *Atrina pectinata* is now recognized to be restricted to the Indo-Pacific. However, many species of *Atrina* and *Pinna* are 'cryptic', i.e. are difficult to distinguish based on morphology (Yu *et al.*, 2004; Liu *et al.*, 2011; Lemer *et al.*, 2014; Hashimoto *et al.*, 2021). Yu *et al.* (2004) identified four forms of *Atrina pectinata* in Chinese waters based on RAPD markers and external shell morphology and suggested that *Atrina pectinata* could be separated into at least two species. Katsares *et al.* (2008) noted high genetic diversity in mtDNA sequences in *Pinna nobilis* from Greece. An *et al.* (2012) detected no genetic population subdivision in *Atrina pectinata* in Korean populations at 21 microsatellite loci. However, Hashimoto *et al.* (2021) identified six distinct mtDNA lineages in

samples of *Atrina pectinata* from Korea and China, two of which were widespread, but the lineages could not be distinguished using morphology. They also detected significant genetic differentiation between geographically close populations. Conversely, Liu *et al.* (2011) identified five lineages of mtDNA in *Atrina pectinata* along the coast of China and one location in Japan. The lineages corresponded to six morphotypes although hybridization obscured the differences. One lineage was widespread, suggesting good larval connectivity and gene flow. However, the other four occurred in the comparatively small area of the South China Sea, especially Beibu Gulf, which indicated genetic differentiation. Liu *et al.* (2011) suggested that at least five cryptic species of *Atrina pectinata* were present.

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Biology review

☰ Taxonomy

Phylum	Mollusca	Snails, slugs, mussels, cockles, clams & squid
Class	Bivalvia	Clams, cockles, mussels, oysters, and scallops
Order	Ostreida	Oysters, scallops & saddle oysters
Family	Pinnidae	
Genus	<i>Atrina</i>	
Authority	(Pennant, 1777)	
Recent Synonyms	<i>Atrina pectinata</i> (Linnaeus, 1767) <i>Pinna fragilis</i> (Pennant, 1777) <i>Pinna pectinata</i> (Linnaeus, 1767)	

🌿 Biology

Typical abundance	Very low density
Male size range	30-48 cm
Male size at maturity	Unknown
Female size range	30-48 cm
Female size at maturity	Unknown
Growth form	Bivalved
Growth rate	ca 3-4 cm/year
Body flexibility	None (less than 10 degrees)
Mobility	Burrower
Characteristic feeding method	Active suspension feeder
Diet/food source	Planktotroph
Typically feeds on	Phytoplankton
Sociability	Gregarious
Environmental position	Infaunal
Dependency	Independent.
Supports	Host Commensal <i>Pinnotheres pinnotheres</i> (pea crab) and <i>Capulus ungaricus</i> (Hungarian hat shell).
Is the species harmful?	See additional information This species may become toxic due to the accumulation of toxins during blooms of toxic algae.

🏛️ Biology information

Information on the biology of fan mussels (*Atrina* spp. and *Pinna* spp.) is limited, especially regarding reproduction and growth (Chavaz-Villabla *et al.*, 2022). Anon (1999c) suggested that growth is relatively slow (ca 3 -4 cm/year) based on annular growth rings in specimens from Valentia Bay, Ireland. This data suggested that large specimens were at least 10-12 years old (Solandt, 2003). Bulter *et al.* (1993) noted that the growth of *Pinna bicolor* was indeterminate, rapid when small and slow after 2 years of age. For example, the growth rate of *Pinna nobilis* in the Mediterranean was observed to vary between sites, with some populations growing at 9 cm/yr

and others at 6-7 cm/year. Papoutsis & Galinou-Mitsoudi (2010) reported a very low growth rate in *Atrina pectinata* in the Thermaikos Gulf (Greece) with juveniles reaching 4.6 cm at 2-4 months of age and adults reaching 37.5 cm at 32 years of age. [Note that the *Atrina pectinata* of Papoutsis & Galinou-Mitsoudi (2010) are presumably *Atrina fragilis*]. However, Fryganiotis *et al.* (2013) reported that specimens caught in the Thermaikos Gulf) ranged from 7-16 years of age at lengths of 15-34 cm respectively, and calculated an annual growth rate of 2.6 cm/yr. Silina (2012) reported that *Atrina vexillum* in the gulf of Thailand exhibited three size classes, 3.5 years, 4.5 years and <7.5 yr, although one individual was >10.5 years and 43.6 cm in length. Silina (2012) noted that shell growth was fastest in the first years of life and significantly decreased after 5 years of age. Silina also noted that growth rate, size and lifespan varied with location on the Gulf of Thailand, and were greater in the more favourable outer part of the Gulf. Silina (2012) also noted seasonal changes in growth rate, which was very slow in the cold season, probably due to monsoons and the resultant decreased salinity and high suspended sediment loads, and also slower during the peak of reproduction in April (in Thailand). It is likely that growth rates in fan mussel species vary with location, and are dependent on temperature, and food supply. Growth rates in *Atrina zealandica* were reported to be 1-2 cm/year after they reached 20 cm in length (Hewitt & Pilditch, 2004).

The shell margin is easily damaged to produce sharp edges. These edges may cut the feet of bathers (Anon 1999c). However, fan mussels rapidly repair shell damage (Yonge, 1953).

Community interactions

Fan mussel communities have been poorly studied in the UK and information is only available from the Mediterranean, South Australia and the USA. Mollusc shells are often important settlement substrata for sessile organisms, or shelters/nest sites for mobile benthic animals in marine soft sediments (Kuhmann, 1998). The resource availability of shells may affect the population dynamics of these species. For example, *Pinna bicolor* hosts a species rich epifauna (Kay & Keough, 1981; Ward & Young, 1983). In St Joseph Bay, Florida, shells of dead *Atrina rigida*, predated by the horse conch, provide shelter for crabs, fish and octopus and were used as 'nests' by blennies, clingfish, and toadfish (Kuhmann, 1997).

The presence of burrowing bivalves may also alter small-scale flow dynamics, as is the case with *Atrina zealandica* (Nikora *et al.*, 2002). However, *Atrina zealandica* occurs in far greater densities than UK examples of *Atrina fragilis*. Large suspension-feeding bivalves, such as *Atrina*, have been shown to affect benthic-pelagic coupling, increase sediment flux to the seabed, deplete phytoplankton, and change ammonia and oxygen concentrations (Hewitt *et al.*, 2006). Gibbs *et al.* (2005) reported that *Atrina* beds increased nutrient supply to the water column in turbid waters in light and may contribute ca 80% of the nutrient supply for pelagic primary production in Marhurangi Harbour, New Zealand. Hewitt *et al.* (2002) found that the distance between individuals of *Atrina zealandica* affected the associated benthic macrofauna. Hewitt *et al.* (2006) noted that proximity to *Atrina* increased the abundance of small macrofauna that used the sediment-water interface, although the strength of the effect varied between sites. The settlement of biodeposits (faeces and pseudofaeces) from *Atrina zealandica* is likely to have localised effects on benthic community structure (Miller *et al.*, 2002). Pseudofaeces from pen shells resulted in biodeposits that reduced the variability of nematode meiofauna in *Atrina zealandica* beds (Warwick *et al.* 1997). In addition, the *Atrina* beds increase surface roughness and alter water flow across the sediment (Nikora *et al.*, 2002; Norkko *et al.*, 2006). Norkko *et al.* (2006) reported increased macrofaunal abundance and species richness in *Atrina zealandica* beds in low suspended sediment but that increased suspended sediment loads decreased or reversed the effect. However, Cummings *et al.* (1998, 2001) noted that the relationship between *Atrina* beds and macrofaunal

abundance was more complicated and also dependent on sediment characteristics and hydrography rather than the presence of *Atrina* and biodeposits alone. The same effects may be true of *Atrina fragilis* beds, although these effects are likely to be reduced due to far lower densities.



Habitat preferences

Physiographic preferences	Enclosed coast / Embayment, Offshore seabed, Ria / Voe
Biological zone preferences	Lower circalittoral, Lower infralittoral, Sublittoral fringe, Upper circalittoral, Upper infralittoral
Substratum / habitat preferences	Coarse clean sand, Fine clean sand, Gravel / shingle, Mixed, Mud, Muddy gravel, Muddy sand, Sandy mud
Tidal strength preferences	Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Weak < 1 knot (<0.5 m/sec.)
Wave exposure preferences	Sheltered, Very sheltered
Salinity preferences	Full (30-40 psu)
Depth range	Sublittoral fringe to 600 m
Other preferences	No text entered
Migration Pattern	Non-migratory / resident

Habitat Information

Distribution

Specimens occur as solitary individuals or localised patches of small groups of individuals.

Atrina fragilis was recorded in *Zostera* sp. beds in the Isles of Scilly. However, specimens have not been found since the *Zostera* sp. beds were lost (Turk 1982; Turk & Seaward, 1997). This species was more common in scallop areas in the early 1900s. Presumably trawling and dredging of these formerly populated regions is the reason for the decline of this species (Minchin pers. comm.). Dredging of a *Pecten maximus* bed off Glengad Head, Ireland, after 1975, removed many live specimens of *Atrina fragilis* in scallop dredges and the population of fan mussels is thought to have been destroyed by subsequent dredging (Anon 1999c). A single specimen was recorded from Rathlin Island, Northern Ireland in 2007 (Goodwin *et al.*, 2011c).

Solandt (2003) described two 'hotspots' for *Atrina fragilis* in UK waters; in Scotland and south-west coast of Cornwall. Solandt (2003) also noted that in recent years (the 1990s onwards) more records of *Atrina fragilis* were obtained from deep water. For example, records in the Western Approaches of the English Channel were at ca 100 m deep and 50 km offshore. In Scotland, considerable populations were found in the deep tidal waters of The Minch and the Sound of Skye and in the waters between John O'Groats and the Shetland Isles. *Atrina fragilis* was also recorded from Melville Knoll and Haddock Bank sea mounts, at depths of 50 m and 200 m ca 50 miles south-west of the Isles of Scilly (Solandt, 2003). OBIS (checked in July 2022) included records of *Atrina fragilis* from 0-300 m in depth. The largest known area of fan mussels in the UK, in the Sound of Canna, covered an area of at least 170 ha and the densest patches were estimated to be 2-4 /m² where the fan mussels occurred in clumps or scattered individuals at 102 -274 m (Howson *et al.*, 2012).

Nevertheless, the species has declined in abundance in the last 100 years, especially in inshore

waters (Solandt, 2003). It was once regularly caught in trawls in the Celtic Sea with anecdotal records of large individuals and 'decks covered with fragments of their shells' (Solandt, 2003).

Habitat preferences

Stirling *et al.* (2016) used species distribution models, based on existing records, to examine the habitat preferences of *Atrina fragilis* and predict suitable habitat in the waters of the west coast of Scotland. Ground truthing of the model revealed 57 new records of *Atrina fragilis*. Stirling *et al.* (2016) identified depth and habitat complexity (bathymetric ruggedness) as the most important determinants of distribution followed by current speed, and substratum type (percentage of mud and gravel), while aspect had less importance. They reported that the predicted intensity of *Atrina fragilis* increased below 50 m in depth, although the records used (in the model) ranged from 237 m to -7 m with a mean of 161 m. It is also recorded from the Melville Knoll and Haddock Bank sea mounts, at depths of 50 m and 200 m; at 100 m in the Western approaches; and 102-274 m in the Sound of Canna (Solandt, 2003; Howson *et al.*, 2012). Similarly, Šimunović *et al.* (2001) found that *Atrina fragilis* was most abundant at a depth of 25-50 m but was also found at ca 250 m in the Adriatic. OBIS (checked in July 2022) included records of *Atrina fragilis* from 0-300 m in depth. Stirling *et al.* (2016) suggested that the importance of habitat complexity (or ruggedness) was due to the protection from fishing activities provided by natural and artificial obstacles (or ruggedness). Solandt (2003) had previously suggested this connection.

The species is known from weak to moderately strong currents. For example in Knightstown, Valentia Island, the population is exposed to >2 knots (ca >1 m/s) on spring tides (Dan Minchin pers. comm.). Stirling *et al.* (2016) reported that Scottish records occurred in areas with peak currents, during a mean spring tide, of 0.65 m/s on average and a maximum of 1.24 m/s. Stirling *et al.* (2016) suggested that extremely high currents (i.e. > 2-3 m/s) would probably prevent the settlement of spat and the resultant resuspension of sediments would impact adults.

Atrina fragilis is recorded from a variety of sediment types in UK waters (UK Marine Habitat Classification, JNCC 2022; Stirling *et al.*, 2016). In the Mediterranean, dense populations were recorded from sandy bottoms with a mixture of terrigenous ooze (detritus of terrestrial origin) at a depth of 30 - 50 m (Šimunović *et al.*, 2001; Fryganiotis *et al.*, 2013). Stirling *et al.* (2016) reported that *Atrina fragilis* was recorded from 0.6% to 74% mud (with a mean of 32%) and in 0.2%-62% gravel (with a mean of 12%). Their model predicted the highest abundances in the range of 20-60% mud but approx. <20% gravel. Although usually found at full salinities, *Atrina fragilis* may be exposed to reduced or variable salinities for brief periods (Dan Minchin pers. comm.).

Life history

Adult characteristics

Reproductive type	Gonochoristic (dioecious)
Reproductive frequency	Annual protracted
Fecundity (number of eggs)	Insufficient information
Generation time	Insufficient information
Age at maturity	Insufficient information
Season	Insufficient information
Life span	11-20 years

Larval characteristics

Larval/propagule type	Veliger
Larval/juvenile development	Planktotrophic
Duration of larval stage	1-6 months
Larval dispersal potential	Greater than 10 km
Larval settlement period	Insufficient information

Life history information

Atrina fragilis is assumed to be long-lived due to its large size. Butler *et al.* (1993) reported that the related Mediterranean genus *Pinna nobilis* may live up to 18 years. Solandt (2003) suggested that its lifespan was 10-12 years based on growth estimates in the UK. However, populations of *Atrina fragilis* in the Adriatic were composed of individuals ranging between 7 and 16 years, based on growth rings (Fryganiotis *et al.*, 2013) and between 7 and 32 years, based on adductor muscle scars (Papoutsis & Galinou-Mitsoudi, 2010). Silina (2012) reported that *Atrina vexillum* in the gulf of Thailand exhibited three size classes, 3.5 years, 4.5 years and <7.5 yr, although one individual was >10.5 years and 43.6 cm in length.

Spawning in *Atrina* spp varies with species and location worldwide (Chávez-Villalba *et al.*, 2022). *Atrina* spp. are annual episodic or protracted spawners with one or two periods of spawning often associated with temperature and food supply (Chávez-Villalba *et al.*, 2022). Stirling *et al.* (2018) concluded that *Atrina fragilis* in west Scotland exhibited peaks of spawning in summer and winter with low levels of spawning throughout the year. Size at maturity in *Atrina maura* was estimated as 23.3 cm (females) and 22.8 cm (males) in La Pay Bay but both as 14.6 cm in Ojo de Leibre lagoon (Chávez-Villalba *et al.*, 2022). No information on gametogenesis, egg size, maturity or fecundity in *Atrina fragilis* was found.

Dispersion is assumed to be possible over large distances due to the pelagic life history. Hiscock *et al.* (2011) noted that *Atrina fragilis* larvae were found in hauls in the middle of the English Channel, and suggested that their dispersal range was high. Similarly, the specimens of larvae studied by Allen (2011) were recovered from plankton samples taken at a depth of 150-200 m. Stirling *et al.* (2018) examined the growth of *Atrina fragilis* larvae from the waters of west Scotland and compared those to a late 770 µm post-settlement larva from the Isles of Scilly. They suggested a potential pelagic larval duration of four months based on a growth rate of 6 µm/day. However, Stirling *et al.* (2018) noted that bivalve larval development is strongly influenced by temperature and food supply so the prolonged four-month duration may be shorter in warmer, southern areas, especially as *Atrina fragilis* is at its most northern limit in Scotland. For example, Stirling *et al.* (2018) noted that the larval duration of *Atrina zealandica* larvae was reported as one month (Booth, 1979) but 23-47 days for *Atrina pectinata* in aquaculture studies.

Butler *et al.* (1993) mention evidence for genetic population subdivision in *Pinna bicolor* within the Gulf of St Vincent in South Australia, which suggests that effective dispersal is lower than expected. However, molecular studies have revealed a mixture of cryptic species, with widespread and/or diverse mtDNA lineages that suggest that population subdivision and dispersal are dependent on local conditions and vary between regions and species (Yu *et al.*, 2004; Liu *et al.*, 2011; Lemer *et al.*, 2014; Hashimoto *et al.*, 2021).

Fertilization is external and dependent on the proximity of other individuals, and factors including

water movement. When populations of *Pinna* become very sparse, as is the case in the UK, fertilization failure is likely to be significant (Anon, 1999c; Butler *et al.*, 1993). Recruitment is likely to be sporadic due to variable larval survival and irregular, limited dispersal. Dispersal between different patches is likely to be variable (Anon, 1999c).

Sensitivity review

Resilience and recovery rates

Fan mussels (pen shells) (fan mussels) are vulnerable to over-exploitation due to their long life, slow growth, limited reproductive output and sporadic recruitment (Butler *et al.*, 1993). Fan mussels (pen shells) are a commercially important food source but have been over-exploited worldwide, with the exception of Australia and New Zealand where catches are regulated. Over-exploitation combined with habitat loss, disease, trawling and anchoring, and suspended sediments from coastal activities has resulted in a drastic decline in wild populations of *Atrina* and *Pinna* in past decades (Chavez-Villabla *et al.*, 2022).

Rapid shell repair in pinnids suggests high metabolic demand, that may result in reduced gamete production (Anon, 1999c; Butler *et al.*, 1993), consistent with a long-lived species. Stirling *et al.* (2018) suggested that the larval phase had a long pelagic duration of up to four months in west Scotland but noted that the duration may be shorter in more southern or warmer regions. Nevertheless, Stirling *et al.* (2018) noted that while the long larval duration may increase the species' potential for dispersal, it may also increase mortality rates. Fertilization efficiency in patchy populations of low density may also be low as individuals may be too far apart to reproduce (Anon, 1999c; Hiscock *et al.*, 2011). Poor recruitment may result in population subdivision due to a lack of gene flow over distance. Butler *et al.* (1993) mentioned evidence for genetic population subdivision in *Pinna bicolor* within the Gulf of St Vincent in South Australia, which suggested that effective dispersal was lower than expected. However, molecular studies have revealed a mixture of cryptic species, with widespread and/or diverse mtDNA lineages that suggest that population subdivision and dispersal are dependent on local conditions and vary between regions and species (Yu *et al.*, 2004; Liu *et al.*, 2011; Lemer *et al.*, 2014; Hashimoto *et al.*, 2021). Therefore, with the exception of embayments and inlets where larvae may be trapped, effective recruitment of *Atrina fragilis* may be poor and variable in comparison with other bivalve species (Anon, 1999c). However, surviving adults increase the possibility of fertilization and local recruitment. Anon (1999c) suggested that changes in factors that shorten the adult life of this species cannot be compensated for by an immediate reproductive response and recruitment.

In the Adriatic, Šimunović *et al.* (2001) concluded that the resident population of *Atrina fragilis* were self-sustaining in spite of trawl fishing and occasional hypoxic events, based on experimental bottom trawls in 17 cruises of the PIPETA Expedition between 1982 and 1994. These cruises recorded *Atrina fragilis* from 20% of 780 hauls in that period and averaged between ca 1 to ca 5000 individuals per km². In addition, numerous hauls included both juvenile and adult *Atrina fragilis* (Šimunović *et al.*, 2001). Fryganiotis *et al.* (2013) and Papoutsis & Galinou-Mitsoudi (2010) also reported a range of size classes, including juveniles, from the Thermaikos Gulf, Adriatic, which indicated that the populations studied were recruiting. However, Fryganiotis *et al.* (2013) recorded a density of 0.03 to 6.27 individuals/km in the Thermaikos Gulf, in the Adriatic. Furthermore, Fryganiotis *et al.* (2013; Fig 2) reported that the density of fan mussels in trawled areas (ca 0.03 individuals /km) was sparse compared to the areas in which bottom trawling was prohibited for 25 years (ca 5.5 individuals /km). Fryganiotis *et al.* (2013) suggested that 25 years was probably a time period that allows population recovery in this species. The largest known area of fan mussels in the UK, in the Sound of Canna, covered an area of at least 170 ha. The densest patches were estimated to be 2-4 /m² (but ranged to 1-2 m²) where the fan mussels occurred in clumps or scattered individuals (Howson *et al.*, 2012).

Stirling *et al.* (2016) developed species distribution models for *Atrina fragilis* in the waters of west

Scotland. They reported that depth and habitat complexity (ruggedness) were important factors in the suitability of the habitat for *Atrina fragilis*, together with current speed and substratum type (the percentage of mud and gravel). In particular, they suggested that habitat complexity, either natural or artificial, protected the substratum and, hence, adults from the effects of fishing activities. Stirling *et al.* (2016) noted that *Atrina fragilis* was most abundant in the Sound of Canna, which had the highest habitat complexity (ruggedness) in their study. The Sound of Canna is a deep-sided channel deepened by glaciation with a complex benthic profile including glacial moraines and deep water dredge disposal site (Stirling *et al.*, 2016). They also predicted several other suitable sites for *Atrina fragilis* in the waters of Western Scotland (Stirling *et al.*, 2016).

It is possible that areas of habitat complexity provide refugia for *Atrina fragilis* populations from the effects of fishing activities and, together with the depth at which it can occur, it may be under-recorded at present. Nevertheless, the species has declined in abundance in the last 100 years especially in inshore waters (Solandt, 2003). It was once regularly caught in trawls in the Celtic Sea with anecdotal records of large individuals and 'decks covered with fragments of their shells' (Solandt, 2003). The decline in the Mediterranean (Richardson *et al.*, 1999) and its loss from inlets in south-west England (Anon 1999c) suggest that any recovery from disturbance would be slow.

Resilience assessment. The decline of *Atrina fragilis* in UK inshore waters and the Mediterranean over the last hundred years suggests that recovery is slow (Richardson *et al.*, 1999; Solandt, 2003). Their long life, limited reproductive output, low fertilization efficiency in sparse populations, and sporadic recruitment (Butler *et al.*, 1993; Anon, 1999c) are also likely to hamper their ability to recover from disturbance and population mortality. The increased numbers of records from deep waters could suggest that *Atrina fragilis* is under-recorded in offshore areas, which themselves could provide a reservoir for recruitment to the inshore areas but there is no evidence to support this idea. Nevertheless, recruitment to and recovery of populations is likely to be prolonged. The large area of fan mussels in the Sound of Canna may have resulted from a single successful recruitment event. The presence of viable larvae in the Sound of Canna and the single late-stage larva in the Isles of Scilly (Stirling *et al.*, 2018) suggests that reproductively active populations exist in these areas and have the potential to recruit internally and to their surrounding areas. But that larval/juvenile mortality is probably high, and juveniles and adults require areas protected from physical disturbance to survive. Therefore, recovery from any loss of the population (i.e. a reduction in the extent or abundance, resistance is 'Medium' or 'Low') may take up to 25 years where the populations are sparsely distributed (e.g. in the UK). Hence, resilience is assessed as **Low**'. However, where the population is severely reduced in abundance or extent (i.e. resistance is 'None') resilience is assessed as **Very low**'.

Hydrological Pressures

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

No information on temperature tolerance in *Atrina fragilis* was found, although it has been suggested that changes in seawater temperature are likely to affect larval recruitment patterns (Anon., 1999c). *Atrina* spp. are annual episodic or protracted spawners with one or two periods of spawning often associated with temperature and food supply (Chávez-Villalba *et al.*, 2022). Stirling *et al.* (2018) concluded that *Atrina fragilis* in west Scotland exhibited peaks of spawning in summer and winter with low levels of spawning throughout the year. Wang *et al.* (2017) reported

that *Atrina pectinata* in the Bohai Sea, China had a single spawning event; gametogenesis began in October, completed between June and July, and spawning occurred in August when temperatures and food availability were at their highest.

The tropical pen shell *Atrina maura* was found to reach maturity more quickly at higher temperatures, taking only one month (normal maturation at lower temperatures of 20°C takes two months). However, with higher temperatures, oocytes are of poor quality than at cooler temperatures (Rodriguez-Jaramillo, 2001). Similarly, Leyva-Valencia *et al.* (2001) reported that activity, ingestion rates, scope for growth, and growth rates were highest at 29°C in juvenile *Atrina maura* and suggested an optimal temperature of 29°C or higher. No mortality occurred between 19 and 30°C, 10% mortality at 32°C and the authors reported a 96-hour LD₅₀ of 33.2°C. In flume experiments, Arrieche *et al.* (2010) noted that specimens of the tropical *Atrina maura* survived daily fluctuations of 8°C between 13°C and 33°C. OBIS (July 2022) included records of *Atrina fragilis* from sites where sea surface temperature ranged from 5 to 20°C although most records were recorded from 10-15°C.

Subtidal species such as *Atrina fragilis* are likely to exhibit lower temperature tolerance than intertidal species and are not likely to be resistant to rapid temperature change indicated in this benchmark. However, they occur from the Mediterranean to the Shetland Isles and are probably resistant to the range of temperatures that occur within that range.

Therefore, *Atrina fragilis* is probably resistant to a long-term change in temperature of 2°C for a year (see benchmark). But shallow subtidal and sublittoral fringe populations may be adversely affected by short-term changes in temperature of 5°C for a month (see benchmark). Therefore, a resistance of 'Medium' is recorded to represent the loss of the upper shore or shallow populations, albeit with 'Low' confidence. Resilience is probably 'Low' and sensitivity is assessed as 'Medium', albeit with 'Low' confidence.

Temperature decrease (local)

Medium

Q: Low A: NR C: NR

Low

Q: Medium A: Medium C: Medium

Medium

Q: Low A: Low C: Low

No information on temperature tolerance in *Atrina fragilis* was found, although it has been suggested that changes in seawater temperature are likely to affect larval recruitment patterns (Anon., 1999c). No information on temperature tolerance in *Atrina fragilis* was found, although it has been suggested that changes in seawater temperature are likely to affect larval recruitment patterns (Anon., 1999c). *Atrina* spp. are annual episodic or protracted spawners with one or two periods of spawning often associated with temperature and food supply (Chávez-Villalba *et al.*, 2022). Stirling *et al.* (2018) concluded that *Atrina fragilis* in west Scotland exhibited peaks of spawning in summer and winter with low levels of spawning throughout the year. Wang *et al.* (2017) reported that *Atrina pectinata* in the Bohai Sea, China had a single spawning event; gametogenesis began in October, completed between June and July, and spawning occurred in August when temperatures and food availability were at their highest.

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Subtidal species such as *Atrina fragilis* are likely to exhibit lower temperature tolerance than intertidal species and are not likely to be resistant to rapid temperature change indicated in this benchmark. However, they occur from the Mediterranean to the Shetland Isles and are probably resistant to the range of temperatures that occur within that range.

Therefore, *Atrina fragilis* is probably resistant to a long-term change in temperature of 2°C for a year (see benchmark). But shallow subtidal and sublittoral fringe populations may be adversely affected by short-term changes in temperature of 5°C for a month (see benchmark). Therefore, a resistance of '**Medium**' is recorded to represent the loss of the upper shore or shallow populations, albeit with 'Low' confidence. Resilience is probably '**Low**' and sensitivity is assessed as '**Medium**', albeit with 'Low' confidence.

Salinity increase (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

Atrina fragilis occurs subtidally at full salinity but shallow subtidal populations may experience variable salinity. Dan Minchin (pers. comm.) suggested that *Atrina fragilis* may be exposed to reduced or variable salinities for brief periods. A tropical pen shell *Atrina maura*, was found to have a wide range of halotolerance, from 16-50 (Leyva-Valencia *et al.*, 2001). OBIS (July 2022) included records of *Atrina fragilis* from sites where sea surface salinity ranged from 30-35. *Atrina fragilis* is probably not resistant to hypersaline (>40) conditions for a year. However, no information on the effects of hypersaline conditions or effluent on this or related species was found, and no assessment was made.

Salinity decrease (local)

Low

Q: High A: Medium C: Medium

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Medium C: Medium

Atrina fragilis occurs subtidally at full salinity but shallow subtidal populations may experience variable salinity. Dan Minchin (pers. comm.) suggested that *Atrina fragilis* may be exposed to reduced or variable salinities for brief periods. A tropical pen shell *Atrina maura* was found to have a wide range of halotolerance, from 16-50 (Leyva-Valencia *et al.*, 2001). OBIS (July 2022) included records of *Atrina fragilis* from sites where sea surface salinity ranged from 30 to 35.

Kurihara *et al.* (2018) exposed juvenile *Atrina pectinata* (3.2 to 3.6 cm in length) to both rapid and gradual changes in a range of salinities at 12°C and 24°C in the laboratory. They reported that all juveniles survived 83 hours of gradual exposure to ≥ 21.1 ppt at 24°C but all died after exposure ≤ 18.6 ppt for <20 hours (with one exception). At 12°C, all juveniles survived 83 hours of gradual exposure to ≥ 17.2 ppt but all died after <33.6 hours at ≤ 15.1 ppt. Rapid exposure to reduced salinity, by direct transfer of specimens into the required salinities, decreased the survival time. At 24°C, all juveniles (except one) survived rapid exposure to ≥ 17.7 ppt for 140 hours but all died rapid exposure to ≤ 15.9 ppt for 13 to 20 hours. At 12°C, all specimens survived 140 hours at ≥ 23.1 ppt and all died at ≤ 21.3 ppt. Kurihara *et al.* (2018) concluded that salinity tolerance was lower at 24°C than 12°C but that the difference was reduced during rapid changes in salinity. Kurihara *et al.* (2018) also suggested that juveniles were more sensitive to rapid changes in salinity than adults and report a period study that showed that adult *Atrina pectinata* survived rapid

exposure to >15 ppt but died after exposure to <15 ppt for 96 hours at 28°C.

Sensitivity assessment. *Atrina fragilis* may be able to tolerate short periods of exposure to decreases in salinity but is probably not resistant to changes in salinity (e.g. from 'full' to 'reduced') for a year (see benchmark) based on the evidence from *Atrina pectinata*. Therefore, resistance is assessed as 'Low', resilience as 'Low' and sensitivity as 'High'.

Water flow (tidal current) changes (local)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Atrina fragilis is known from weak (<0.5 m/s) to moderately strong currents (0.5-1.5 m/s). For example in Knightstown, Valentia Island, the population is exposed to >2 knots (ca >1 m/s) on spring tides (Dan Minchin pers. comm.). Stirling *et al.* (2016) reported that Scottish records occurred in areas with peak currents, during a mean spring tide, of 0.65 m/s on average and a maximum of 1.24 m/s. Stirling *et al.* (2016) suggested that extremely high currents (i.e. >2-3 m/s) would probably prevent the settlement of spat and the resultant resuspension of sediments would impact adults. Changes in current patterns may affect larval recruitment (Anon., 1999c). Arrieche *et al.* (2010) found that *Atrina maura* grew significantly larger above a flow rate of 7.3 cm/s in flume experiments. Arrieche *et al.* (2011) reported that ingestion rate, absorption rate, and scope for growth were highest at 1.6 cm/s (0.16 m/s) in *Atrina maura* under laboratory conditions. Scope for growth, ingestion and absorption rates were correlated with food supply at 0.8 and 1.6 cm/s and respiratory rate was positively correlated at 2.5 cm/s (0.25 m/s).

However, an increase of 0.1-0.2 m/s for one year (the benchmark) may not be significant. A decrease in flow to 'very weak' or 'negligible' may be detrimental as water flow is important to provide a food supply for suspension feeders, as well as oxygenate the water column, especially in isolated waters. A reduction in food supply may well decrease growth and reproduction in this species, although as the species is long-lived, a change for one year (see benchmark) may not result in mortality. Therefore, a resistance of 'High' is recorded, albeit with 'Low' confidence. Hence, resilience is 'High' and the species is assessed as 'Not sensitive' at the benchmark level.

Emergence regime changes

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

Not relevant (NR)

Q: NR A: NR C: NR

The majority of *Atrina fragilis* populations occur in the subtidal and in deep water and changes in emergence are **Not relevant**. However, *Atrina fragilis* has been recorded from the sublittoral fringe and shallow subtidal. It is possible that a sublittoral fringe population could be exposed to increased emergence, in which case the affected population would probably die.

Wave exposure changes (local)

High

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

Atrina fragilis occurs in sheltered or very sheltered waters (Anon 1999c; Butler *et al.* 1993) and can burrow into the substratum if partly uncovered by wave action or storms (Yonge, 1953). However, a prolonged increase in wave action could remove some individuals from the substratum, which would not then be able to survive to re-establish themselves. Juveniles may be removed from sediment more easily than adults.

García-March *et al.* (2007) reported that a bed of *Pinna nobilis* at 13 m Moraira Bay, in the Spanish Mediterranean suffered 13.6% mortality after a major storm in 2003 (greater than any recorded in

the prior nine years), in which adults were broken or dislodged and died due to injury or exhaustion. The survivors were notably smaller (on average) than the dead specimens. García-March *et al.* (2007) examined the drag force on *Pinna nobilis* shells from this site and a shallow (6 m) site. They reported that the threshold for dislodgment in the deep population was ca 45 Newtons (N), which could be experienced at a water species of 1.25 m/s in large individuals with a relatively large surface area. The shallow area was populated by significantly smaller individuals, orientated with their dorsal-ventral surface in line with water flow, which reduced their mean drag force. García-March *et al.* (2007) suggested that the shallow site regularly experienced wave-mediated flow higher than the deep site, which selected the population for a smaller size (on average) while depth allowed individuals to grow larger. In the extreme storm, the deep site experienced more damage because it exposed the deeper water to higher than normal water speeds while the largest wave experienced during the storm broke before reaching the shallow site.

Nevertheless, a change in significant wave height of 3-5% (the benchmark) is unlikely to be significant, especially as the depth of the population increases. Therefore, resistance is assessed as 'High', resilience as 'High' and this species is probably 'Not sensitive' at the benchmark level.

Chemical Pressures

	Resistance	Resilience	Sensitivity
Transition elements & organo-metal 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

Anon (1999c) suggested that *Atrina fragilis* may be affected by pollutants such as TBT (tri-butyl tin). Reid & Brand (1989) describe kidney gigantism and nephroliths (calcium or iron granules) in *Pinna bicolor*. Their role in removing excess calcium or heavy metals and potential detoxification is unclear. Ward & Young (1983) examined changes in epifauna of *Pinna bicolor* due to heavy metal contamination in Spence Gulf, South Australia. They stated that *Pinna bicolor* was tolerant of high concentrations of heavy metals in sediments near a lead smelter and contained high body loads of heavy metals. The occurrence of populations of this species in heavy metal contaminated sediment suggests that it is 'Not sensitive'. However, the body burden of *Pinna bicolor* was not given and no citation was provided for the information. The studied population may represent a localised adaptation.

Gongora-Gomez *et al.* (2018) reported that *Atrina maura* from an aquaculture farm in Gulf of California accumulated heavy metals in their body tissues but no information on any adverse effects was reported. They reported mean body burdens of ca 0.064 µg/g dwt Hg, ca 485.66 µg/g dwt Zn, 18.15 µg/g dwt Cd and 2.31 µg/g wwt Pb in soft tissues, and ca 0.058 µg/g dwt Hg, 64.83 µg/g dwt Zn, and 1.82 µg/g dwt Cd in muscle.

Anon (1999c) suggested that *Atrina fragilis* may be affected by pollutants such as TBT (Tri-butyl Tin). Inoue *et al.* (2006) identified a range of TBT contamination of 0.009 to 0.095 µg/g wwt in *Atrina pectinata japonica* collected from northern Kyushu, Japan. Inoue *et al.* (2007) reported that exposure of *Atrina pectinata japonica* to 1 µg/l TBT for 72 hours in the laboratory reduced energy metabolism but did not cause mortality during the experiment.

Overall, information on the effects of heavy metal contamination and TBT exposure is limited to sublethal effects and no information on the native *Atrina fragilis* was found. Therefore, the evidence

is probably not sufficient for an assessment.

Hydrocarbon & PAH 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 of the effects of hydrocarbons and PAHs on *Atrina* spp was found.

Synthetic compound 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 of the effects of 'synthetic compounds' on *Atrina* spp was found.

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

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 of the effects of 'other substances' on *Atrina* spp was found.

De-oxygenation

Low

Q: Medium A: Medium C: Medium

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Medium C: Medium

Bivalves are generally resistant to hypoxia and can respire anaerobically. Butler *et al.* (1993) state that *Pinna bicolor* and *Pinna nobilis* remain active at low oxygen concentrations (no value was given) and open their valves widely. Neither species stop pumping or respire anaerobically. Jaklin & Zahtila (1990, cited by Šimunović *et al.*, 2010) reported a mass mortality in the northern Adriatic due to an anoxic event in November 1989. Subsequent diver surveys in January 1990 found many empty shells of *Atrina fragilis* in an area previously populated by 1-2 fan mussels per m² but suggested that 10% of the population survived. Nagasoe *et al.* (2020) examined the effects of hypoxia in juveniles, 1-year-old (mean of 9.4 cm in length) and 2 years old (mean of 14.6 cm in length) *Atrina japonica* for 96 hours (4 days) under laboratory conditions. As the oxygen concentration decreased, most individuals had open exhalent and inhalent siphons at or below 2 mg/l dissolved oxygen (DO) after 12 hours and under continued low oxygen the specimens emerged from the sediment exposing more than half their shell length. Nagasoe *et al.* (2020) reported 96-hour LD₅₀s of 0.84 mg/l DO for one-year-olds and 1.80 mg/l DO for two years olds. they concluded that two years old were more susceptible to hypoxic conditions than one-year-olds probably because of their productive condition since 96.7% of two years olds were ripe in contrast to only 7.6% of one-year-olds. Masato *et al.* (2017) exposed *Atrina lischkeana* from Kyushu, Japan, with an average length of 13.6 cm to <3.0 mg/l DO for 6 hours a day for 30 days. The animals moved upwards in the substratum under low oxygen levels and then downwards in aerobic conditions for 19 days but the response stopped after 20 days. No mortality was observed but the glycogen content of specimens decreased and Masato *et al.* (2017) suggested the specimen were exhausted by their movement relative to the sediment. Masato *et al.* (2017) also noted that prior studies had reported significant mortality of *Atrina lischkeana* exposed to 0.36 mg/l DO for 6 hours/day for 31 days and 50% mortality after exposure to 14.9% oxygen (ca 4.8 mg/l DO) continuously for 72 hours.

Sensitivity assessment. The limited evidence suggests that *Atrina fragilis* is likely to suffer significant mortality in hypoxic conditions (e.g. below 2 mg/l for one week) and severe mortality in anoxic conditions. Therefore, resistance is assessed as '**Low**'. Hence, resilience is probably '**Low**' and sensitivity is assessed as '**High**'.

Nutrient enrichment	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

Pinnids are mainly found in sheltered oligotrophic (low nutrient) waters (Butler *et al.*, 1993), and they filter continuously, presumably an adaptation to low food availability. A small population of *Atrina fragilis* was recorded near a sewage discharge in Dingle Harbour (Dan Minchin pers comm.). An increase in nutrients is likely to increase phytoplankton production in the short term, which may benefit larvae and juveniles. But excessive nutrient enrichment may lead to the development of algal blooms, and hypoxic conditions in the benthos (see deoxygenation above). However, no evidence of the direct or indirect effects of changes in nutrients (e.g. nitrogen or phosphates) on *Atrina* spp. was found.

Organic enrichment	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

Pinnids are mainly found in sheltered oligotrophic (low nutrient) waters (Butler *et al.*, 1993), and they filter continuously, presumably an adaptation to low food availability. A small population of *Atrina fragilis* was recorded near a sewage discharge in Dingle Harbour (Dan Minchin pers comm.). Organic enrichment is likely to result in hypoxic sediment and an increase in opportunistic infauna, together with an increase in suspended sediments and siltation, which may be detrimental. However, *Atrina fragilis* is recorded from detritic bottoms with terrigenous ooze in the Adriatic (Fryganiotis *et al.*, 2013). Overall, the evidence was not adequate and no sensitivity assessment was made.

A Physical Pressures

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

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

Physical change (to another seabed type)	None Q: High A: High C: High	Very Low Q: High A: High C: High	High Q: High A: High C: High
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A change from sediment to hard rock substratum would result in loss of the habitat for this species. Therefore, resistance is assessed as '**None**'. The change is defined as permanent so that resilience is assessed as '**Very low**' and sensitivity is assessed as '**High**'. Although no specific evidence is described, confidence in this assessment is 'High' due to the incontrovertible nature of this pressure.

Physical change (to another sediment type)**High**

Q: Low A: NR C: NR

High

Q: High A: High C: High

Not sensitive

Q: Low A: Low C: Low

The Pinnidae live embedded in soft substrata but with enough underlying gravel to provide attachment for their byssus threads (Yonge, 1953). *Atrina fragilis* has been recorded from a variety of sediment types e.g. muddy sands to clean sands, often mixed with gravels and shell (see habitat preferences above). For example, Fryganiotis *et al.* (2013) stated that this species was characteristic of 'detritic' bottoms, sandy bottoms and terrigenous ooze sediments, while Šimunović *et al.* (2001) reported that it was most abundant on sand-silt-clay sediments and clayey 'relict' sand. Howson *et al.* (2012) reported that the fan mussel bed in the sound of Canna occurred on mixed muddy sand with cobble, gravel, shell debris and occasional boulders but that one station with dense *Atrina fragilis* occurred on rippled sand with burrows. Furthermore, Stirling *et al.* (2016) reported that *Atrina fragilis* was recorded from 0.6% to 74% mud (with a mean of 32%) and 0.2%-62% gravel (with a mean of 12%) in the waters of west Scotland. Their model predicted the highest abundances in the range of 20-60% mud but approx. <20% gravel. In addition, this biotope is recorded from mud and mixed sediments (JNCC, 2022). Therefore, the characteristic *Atrina fragilis* is probably resistant to a change in one Folk class (see benchmark), and resistance is assessed as 'High'. Hence, resilience is 'High' and the species is assessed as 'Not sensitive' at the benchmark level.

Habitat structure changes - removal of substratum (extraction)**None**

Q: Low A: NR C: NR

Very Low

Q: Medium A: Medium C: Medium

High

Q: Low A: Low C: Low

Atrina fragilis lives buried in sediment, with about one-third to one-half of its shell length above the sediment surface, which, in adults, can be up to 10 -15 cm above the sediment surface. However, the removal of sediment to a depth of 30 cm is likely to remove the entire population of fan mussels in the affected area. Therefore, a resistance of 'None' is recorded. Resilience is probably 'Very low' so sensitivity is assessed as 'High'.

Abrasion/disturbance of the surface of the substratum or seabed**Low**

Q: High A: Medium C: Medium

Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Medium C: Medium

Atrina fragilis has a fragile shell, damaged easily by anchor impact, or trampling by bathers or fish predation. It is probably adapted to such damage as the mantle and tentacles can be withdrawn into the remainder of the shell, and the damaged edge of the shell can repair quickly, e.g. at ca 1 cm /day in *Pinna carnea* (Yonge, 1953; Solandt, 2003). *Atrina* can burrow vertically but cannot 'right' itself if removed from the sediment and laid on its side (Yonge, 1953). Specimens removed from the sediment by a passing trawl, mooring chain etc. are unlikely to be able to reburrow.

Scallop dredging and demersal trawling have been implicated in the decline in populations of this species (Anon, 1999c; Hall-spencer *et al.*, 1999; Solandt, 2003; Šimunović *et al.*, 2001; Fryganiotis *et al.*, 2013). Solandt (2003) noted anecdotal records where 'considerable fragments of *Atrina* shells were collected by scallop trawlers', and large individuals caught in the Celtic Sea in the 1970s with 'decks covered with the broken fragments of this species'. Solandt (2003) also reported anecdotal records from the diving community of considerable numbers of *Atrina fragilis* found in areas where scallop trawlers and dredgers cannot set gear. Rapido trawling for scallops (a form of beam trawl) in the Gulf of Venice resulted in the removal of organisms from the top 2 cm of sediment and an 87% reduction in *Atrina fragilis* abundance in the trawl tracks. Some specimens

were speared on the trawl teeth and pulled from the sediment (Hall-Spencer *et al.*, 1999). Anon (1999c) suggested that the destruction of a population of *Atrina fragilis* off Glengad Head, Ireland after 1975 was caused by scallop dredging. In the Adriatic queen scallop (*Aequipecten opercularis*) trawl fishery, *Atrina fragilis* incurred more damage as a result of the fishing and sorting process than any other species of bycatch (Pranovi *et al.*, 2001). In the Adriatic, Fryganiotis *et al.* (2013; Fig 2) reported that the density of fan mussels in trawled areas (ca 0.03 individuals /km) was sparse compared to the areas in which bottom trawling was prohibited for 25 years (ca 5.5 individuals /km). Furthermore, Stirling *et al.* (2016) used species distribution models, based on existing records, to examine the habitat preferences of *Atrina fragilis* and predict suitable habitat in the waters of the west coast of Scotland. Stirling *et al.* (2016) identified depth and habitat complexity (bathymetric ruggedness) as the most important determinants of distribution followed by current speed, and substratum type (percentage of mud and gravel), while aspect had less importance. In particular, they suggested that habitat complexity, either natural or artificial, protected the substratum and, hence, adults from the effects of fishing activities. Stirling *et al.* (2016) noted that *Atrina fragilis* was most abundant in the Sound of Canna, which had the highest habitat complexity (ruggedness) in their study. The Sound of Canna is a deep-sided channel deepened by glaciation with a complex benthic profile including glacial moraines and deep water dredge disposal site (Stirling *et al.*, 2016).

Sensitivity assessment. The above evidence suggests that *Atrina fragilis* can survive low levels of abrasion e.g. trampling in the shallow sublittoral and possibly pots and creels that damage the exposed shell. However, any passing chains or fishing gear that could remove individuals, or objects placed on the substratum temporarily (e.g. legs of jack-up barges) are likely to cause mortality. Therefore, a resistance of 'Low' is suggested. Resilience is probably 'Low' and sensitivity is assessed as 'High'.

Penetration or disturbance of the substratum subsurface

None

Q: High A: Medium C: Medium

Very Low

Q: Medium A: Medium C: Medium

High

Q: Medium A: Medium C: Medium

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Scallop dredging and demersal trawling have been implicated in the decline in populations of this species (Anon, 1999c; Hall-spencer *et al.*, 1999; Solandt, 2003; Šimunović *et al.*, 2001; Fryganiotis *et al.*, 2013). Solandt (2003) noted anecdotal records where 'considerable fragments of *Atrina* shells were collected by scallop trawlers', and large individuals caught in the Celtic Sea in the 1970s with 'decks covered with the broken fragments of this species'. Solandt (2003) also reported anecdotal records from the diving community of considerable numbers of *Atrina fragilis* found in areas where scallop trawlers and dredgers cannot set gear. Rapido trawling for scallops (a form of beam trawl) in the Gulf of Venice resulted in the removal of organisms from the top 2 cm of sediment and an 87% reduction in *Atrina fragilis* abundance in the trawl tracks. Some specimens were speared on the trawl teeth and pulled from the sediment (Hall-Spencer *et al.* 1999). Anon (1999c) suggested that the destruction of a population of *Atrina fragilis* off Glengad Head, Ireland after 1975 was caused by scallop dredging. In the Adriatic queen scallop (*Aequipecten opercularis*) trawl fishery, *Atrina fragilis* incurred more damage as a result of the fishing and sorting process than

any other species of bycatch (Pranovi *et al.*, 2001). In the Adriatic, Fryganiotis *et al.* (2013; Fig 2) reported that the density of fan mussels in trawled areas (ca 0.03 individuals /km) was sparse compared to the areas in which bottom trawling was prohibited for 25 years (ca 5.5 individuals /km). Furthermore, Stirling *et al.* (2016) used species distribution models, based on existing records, to examine the habitat preferences of *Atrina fragilis* and predict suitable habitat in the waters of the west coast of Scotland. Stirling *et al.* (2016) identified depth and habitat complexity (bathymetric ruggedness) as the most important determinants of distribution followed by current speed, and substratum type (percentage of mud and gravel), while aspect had less importance. In particular, they suggested that habitat complexity, either natural or artificial, protected the substratum and, hence, adults from the effects of fishing activities. Stirling *et al.* (2016) noted that *Atrina fragilis* was most abundant in the Sound of Canna, which had the highest habitat complexity (ruggedness) in their study. The Sound of Canna is a deep-sided channel deepened by glaciation with a complex benthic profile including glacial moraines and deep water dredge disposal site (Stirling *et al.*, 2016).

Sensitivity assessment. The above evidence suggests that *Atrina fragilis* can survive low levels of abrasion. However, penetrative gear such as beam trawls, Rapido trawls and scallop dredges are likely to cause severe mortality. Therefore, a resistance of '**None**' is suggested. Resilience is probably '**Very low**' and sensitivity is assessed as '**High**'.

Changes in suspended solids (water clarity)

Medium

Q: High A: Medium C: Medium

Low

Q: Medium A: Medium C: Medium

Medium

Q: Medium A: Medium C: Medium

Pinnids are adapted to a sedimentary lifestyle and possess a unique ciliated waste canal for the removal of sediment from the mantle cavity (Yonge 1953). However, increased siltation will require increased metabolic demand on filtration and a likely decrease in growth and reproductive capacity. *Pinna bicolor* and *Pinna nobilis* occur in sheltered areas of low turbidity. However, juveniles settle in the boundary layer and grow rapidly to escape the high levels of sediment and it is likely that Pinnids are tolerant of suspended sediment. The absence of *Pinna* sp. from areas of severe sediment disturbance (Bulter *et al.* 1993) suggests that the populations in areas of high sediment availability will be adversely affected by increased siltation.

Thrush *et al.* (1999) demonstrated a decrease in the biochemical condition in *Atrina zealandica* with increasing sediment load in the Mahurangi Estuary, New Zealand. Ellis *et al.* (2002) examined the effects of the addition of sediment in laboratory experiments, at a range of turbidity treatments that represented the range of values (23-512 mg/l) experienced in the Mahurangi Estuary, where the normal background turbidity ranged from 12-90 mg/l but were much higher in storm associated resuspension of sediment or runoff from forestry. The initial addition of suspended sediment increased clearance rates, in the same way, that increased seston (phytoplankton) was found to increase filtration rates (Ellis *et al.*, 2002; Safi *et al.*, 2007). Clearance rates increased with increasing suspended sediment until a threshold of ca 120 FTU (Formazin Turbidity Unit) at which clearance rates declined (Ellis *et al.*, 2002). Clearance rates continued to decrease over the duration of the experiment (12 days) in all of the sediment addition treatments. Negative effects on the condition of *Atrina zealandica* became apparent after only three days of exposure to increased suspended sediment levels, compared to controls with 'no' sediment added (Ellis *et al.*, 2002). In transplantation experiments, Ellis *et al.* (2002) found that *Atrina* transplanted to the area closest to the mouth of the estuary (lower suspended sediment flux) improved in condition over the three months of the experiment. But *Atrina* transplanted to upper estuary sites (with high suspended sediment flux, equivalent to 108 g dry weight of sediment per month in sediment traps) lost condition. No *Atrina* occurred naturally at this upper estuary site, which may represent the

upper limit of its tolerance of suspended sediment. *Atrina* also lost condition at intermediate sites (e.g. at 49 g dry weight of sediment per month) (Ellis *et al.*, 2002). It may be that *Atrina zelandica* found in areas with naturally high sediment loading are adapted to cope better with increases in suspended sediment than those from areas with lower background sediment concentrations. Nonetheless, very large increases in suspended sediment are still likely to be detrimental to *Atrina zelandica* (Hewitt & Pilditch, 2004). Hewitt & Pilditch (2004) examined the response of feeding in *Atrina zelandica* to 0-500 mg/l for ca one day. *Atrina* was able to reject filtered particles (75-100%) but maintain high organic absorption efficiencies. However, they identified site-specific differences in response that they suggested were due to prior history of exposure to suspended sediments at each site (Hewitt & Pilditch, 2004). Arrieche *et al.* (2010) noted that juvenile *Atrina maura* withstood high seston levels of ca 900 mg/l for 10 consecutive days in their flume experiments.

Sensitivity assessment. *Atrina* sp. are probably well adapted to a sedimentary habitat and the occasional resuspension of sediment due to storms, as they are able to cleanse themselves quickly. Short-term (i.e. 3 day) increases in suspended sediment, similar to that created by storms and storm runoff, are likely to result in a loss of condition but not mortality. However, an increase in turbidity from, for example, 'clear' to 'intermediate' (100-300 mg/l) or turbid (>300 mg/l) for a period of a year (see benchmark) may be detrimental. Therefore, a resistance of '**Medium**' is recorded. Resilience is probably '**Low**' and sensitivity is assessed as '**Medium**'.

Smothering and siltation rate changes (light)

Medium

Q: Low A: NR C: NR

Low

Q: Medium A: Medium C: Medium

Medium

Q: Low A: Low C: Low

Atrina fragilis cannot burrow upwards through sediment (Yonge, 1953). However, one-third to one-half of the animal can protrude above the surface which, in adults, can be up to 10-15 cm above the sediment surface. Therefore, adult specimens may not be affected by smothering by 5 cm of fine sediment (see benchmark). Pinnids are adapted to a sedimentary lifestyle and exhibit a powerful exhalent current and a unique ciliated waste canal to remove sediment from the mantle cavity, as would be expected from occasional smothering due to storms (Yonge, 1953). Clearance of sediment from the mantle constitutes a metabolic cost that may reduce their reproductive ability (Butler *et al.*, 1993). Individuals are likely to cleanse themselves relatively quickly. However, small juveniles may be smothered and resistance is assessed as '**Medium**'. Resilience is probably '**Low**' and sensitivity is assessed as '**Medium**'.

Smothering and siltation rate changes (heavy)

None

Q: Low A: NR C: NR

Very Low

Q: Medium A: Medium C: Medium

High

Q: Low A: Low C: Low

Atrina fragilis cannot burrow upwards through sediment (Yonge, 1953). One-third to one-half of the animal can protrude above the surface which, in adults, can be up to 10-15 cm above the sediment surface. Therefore, adult and juvenile specimens are likely to be smothered by 30 cm of fine sediment (see benchmark), which is likely to remain in sheltered conditions. Therefore, resistance is assessed as '**None**'. Resilience is probably '**Very low**' and sensitivity is assessed as '**High**'.

Litter

Not Assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

Not assessed (NA)

Q: NR A: NR C: NR

Not assessed

Electromagnetic changes	No evidence (NEv)	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

Not relevant. *Atrina fragilis* probably reacts to localised vibration but is unlikely to react to the noise from passing vessels etc.

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

Not relevant. *Atrina fragilis* is a suspension feeder, feeding on phytoplankton. Artificial light or localised shading is unlikely to alter phytoplankton productivity to any significant level, especially in deep waters and/or where currents supply food to the fan mussel.

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. Physical and hydrographic barriers may limit the dispersal of larval stages or propagules. However, the dispersal of larval stages or propagules 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' above.

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

Not relevant. *Atrina fragilis* probably reacts to localised shading but is unlikely to react to the visual disturbance from passing vessels etc.

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

Liu *et al.* (2011) identified five lineages of mtDNA in *Atrina pectinata* along the coast of China and one location in Japan. The lineages corresponded to six morphotypes although intraspecific

hybridization between lineages obscured the differences. However, no evidence of translocation, breeding or hybridization with other species was found.

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

Crepidula sp. may have had some impact on near-shore populations of *Atrina fragilis* on the south coast of England (Dan Minchin pers comm.). But no further evidence was found.

Introduction of microbial pathogens	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

The Pinnids are parasitized by the pea crab (Pinnotheridae) (Yonge 1953). Butler *et al.* (1993) state that *Pinna bicolor* and *Pinna nobilis* harbour macroscopic commensals or parasites of unknown effect, although an unidentified parasitic microbe has been recorded as causing castration of *Pinna nobilis*. Any parasite is likely to reduce the condition of the host but no information on mortality rates (if any) was found.

Maeno *et al.* (2006) examined specimens of *Atrina pectinata* after the mass mortality (60-90%) of the pen shell in the fishing grounds of Ariake Bay, Japan between 2003 and 2004. The authors concluded that novel virus-like particles found in the kidney and gill tissues of moribund specimens were the probable cause of mortality. Subsequent, experimental infection of *Atrina lischkeana* in the laboratory and the field (Ariake Bay, Japan) resulted in necrosis of kidney, gill and mantle tissue and 20% mortality in the laboratory but 80-100% mortality of infected specimens in the field Maeno *et al.* (2012; abstract only). Therefore, the authors concluded that the virus-like particles were the causal agent.

Sensitivity assessment. The evidence from Japan suggests that *Atrina* is sensitive to the disease documented. However, no evidence of the disease outside Japan was found. Hence, an assessment of 'No evidence' is given for UK populations until further evidence is found.

Removal of target species	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

In Spain, pinnids may be collected for consumption, used as bait, or for use as souvenirs. In the Bay of Naples, the byssus threads were historically used for making glues. In the Pacific, declines in production have occurred as a result of exploitation in other species of pen shell (Cardoza-Velasco & Maeda-Martinez, 1997). However, *Atrina fragilis* is not targeted by any commercial fishery in the UK.

Removal of non-target species	None	Very Low	High
	Q: High A: Medium C: Medium	Q: Medium A: Medium C: Medium	Q: Medium A: Medium C: Medium

Scallop dredging and demersal trawling have been implicated in the decline in populations of *Atrina fragilis* and other pinnids (Anon, 1999c; Hall-spencer *et al.*, 1999; Solandt, 2003; Šimunović *et al.*, 2001; Fryganiotis *et al.*, 2013; Chavaz-Villabla *et al.*, 2022). In the UK, *Atrina fragilis* was more common in scallop beds in the early 1900s than at present. Presumably trawling and dredging of these formerly populated regions is the reason for the decline of this species (Minchin pers. comm.). Dredging of a *Pecten maximus* bed off Glengad Head, Ireland, after 1975, removed many

live specimens of *Atrina fragilis* in scallop dredges and the population of fan mussels is thought to have been destroyed by subsequent dredging (Anon 1999c). Solandt (2003) noted anecdotal records where 'considerable fragments of *Atrina* shells were collected by scallop trawlers', and large individuals caught in the Celtic Sea in the 1970s with 'decks covered with the broken fragments of this species'. Solandt (2003) also reported anecdotal records from the diving community of considerable numbers of *Atrina fragilis* found in areas where scallop trawlers and dredgers cannot set gear.

In the Adriatic queen scallop (*Aequipecten opercularis*) trawl fishery, *Atrina fragilis* incurred more damage as a result of the fishing and sorting process than any other species of bycatch (Pranovi *et al.*, 2001). In the Adriatic, Fryganiotis *et al.* (2013; Fig 2) reported that the density of fan mussels in trawled areas (ca 0.03 individuals/km) was sparse compared to the areas in which bottom trawling was prohibited for 25 years (ca 5.5 individuals/km). Rapido trawling (a form of beam trawl) for scallops in the Gulf of Venice resulted in the removal of organisms from the top 2 cm of sediment and an 87% reduction in *Atrina fragilis* abundance in the trawl tracks. Some specimens were speared on the trawl teeth and pulled from the sediment (Hall-Spencer *et al.*, 1999). Pinnids in the Mediterranean are associated with seagrass beds, the removal of which has been linked to the decline in pinnid populations (Richardson *et al.*, 1999).

Sensitivity assessment. The above evidence suggests that *Atrina fragilis* is vulnerable to demersal fisheries. Therefore, a resistance of '**None**' is suggested. Resilience is probably '**Very low**' and sensitivity is assessed as '**High**'.

Importance review

Policy/legislation

Wildlife & Countryside Act	Schedule 5, section 9
UK Biodiversity Action Plan Priority	<input checked="" type="checkbox"/>
Species of principal importance (England)	<input checked="" type="checkbox"/>
Species of principal importance (Wales)	<input checked="" type="checkbox"/>
Northern Ireland Priority Species	<input checked="" type="checkbox"/>
Scottish Biodiversity List	<input checked="" type="checkbox"/>
Features of Conservation Importance (England & Wales)	<input checked="" type="checkbox"/>
Priority Marine Features (Scotland)	<input checked="" type="checkbox"/>

★ Status

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

Native	Native		
Origin	-	Date Arrived	-

Importance information

The legendary 'cloth of gold' was made from the long fine byssus threads of pinnids (Osing, 1968, Turk, 1982). Curiously, in past times, although seldom captured, many fishermen considered *Atrina fragilis* unclean, and returned it directly to the sea because the byssus was so similar to human hair that it was thought that they had consumed drowned sailors (Dan Minchin, pers comm.). Mediterranean *Pinna nobilis* may be taken for bait, consumption and for the curio trade. The byssus of pinnids was collected in Bay of Naples for making glues (Dan Minchin pers comm.). The community structure of UK fan mussel beds is poorly studied.

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