# Common mussel (*Mytilus edulis*)

MarLIN – Marine Life Information Network
Biology and Sensitivity Key Information Review

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

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**Clump of mussels.**
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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 | **Refereed by** | Prof. R. Seed |
| **Authority** | Linnaeus, 1758 | | |
| **Other common names** | - | **Synonyms** | - |

# Summary

## Description

The shell is inequilateral and roughly triangular in outline, however, shell shape varies considerably with environmental conditions. Shell smooth with a sculpturing of concentric lines but no radiating ribs. The ligament is inconspicuous. The shell colour varies, usually purple or blue but sometimes brown. Length varies, specimens usually ranging from 5 -10 cm although some populations never attain more than 2-3 cm, and the largest specimens may reach 15 -20 cm. *Mytilus edulis* may be confused with the Mediterranean mussel *Mytilus galloprovincialis*.

## Recorded distribution in Britain and Ireland

Very common all around the coast of the British Isles, with large commercial beds in the Wash, Morecambe Bay, Conway Bay and the estuaries of south-west England, north Wales, and west Scotland.

## Global distribution

Occurs from the White Sea, south to southern France in the N.E. Atlantic. In the W. Atlantic it extends from the Canadian Maritimes south to North Carolina. It occurs on the coasts of Chile, Argentina, the Falkland Islands and the Kerguelen Isles.

## Habitat

Occurs from the high intertidal to the shallow subtidal attached by fibrous byssus threads to suitable substrata. Found on the rocky shores of open coasts attached to the rock surface and in crevices, and on rocks and piers in sheltered harbours and estuaries, often occurring as dense masses.

## Depth range

Intertidal to ca. 5m.

## Identifying features

- Shell solid, equivalve, inequilateral and approximately triangular in outline.
- Shell smooth with a sculpturing of concentric lines but no radiating ribs.
- Shell purple, blue or sometimes brown in colour.
- Periostracum darker than shell, almost black, dark brown or olive in colour.
- Shell interior pearl-white with a purple or dark blue border.
- Posterior adductor scar large but anterior adductor scar much reduced.
- Pallial line wide.
- Beaks are anterior, terminal, and rounded with straight umbones but not turned downward.
- Hinge lacking teeth or chondrophore but with 3-12 small crenulations below the umbones.
- Ligament runs from the beaks to the high point of the shell but is inconspicuous.
- Edge of mantle whitish yellow or brown.
- External ligament inconspicuous, running more than half the length of the shell from the umbones.

## Additional information

*Mytilus edulis* and *Mytilus galloprovincialis* often occur in the same location in the northern range of *Mytilus galloprovincialis*. As they both show great variation in shell shape due to environmental conditions (Seed, 1968, 1992), they are often difficult to distinguish. In addition, they may hybridize. However, in *Mytilus galloprovincialis*:

- the umbones turn down, giving the basal line of the shell a concave appearance;
- the valves are higher and less angular;
- the mantle edges are darker, becoming blue or purple, and
- *Mytilus galloprovincialis* tends to grow larger (Tebble, 1976).

**Note** no single morphological characteristic can be used to separate *Mytilus* species (Gosling, 1992c; Seed, 1992, 1995). Recent evidence suggests that there are only three lineages of the genus, *Mytilus edulis*, *Mytilus galloprovincialis* and *Mytilus trossulus*, although some authorities suggest that all of the smooth shelled mussels belong to the same species (for discussion see Seed, 1992).

## Listed by

## Further information sources

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# Biology review

## Taxonomy

| | | |
|---|---|---|
| **Phylum** | Mollusca | Snails, slugs, mussels, cockles, clams & squid |
| **Class** | Bivalvia | Clams, cockles, mussels, oysters, and scallops |
| **Order** | Mytilida | Mussels & crenellas |
| **Family** | Mytilidae | |
| **Genus** | Mytilus | |
| **Authority** | Linnaeus, 1758 | |
| **Recent Synonyms** | - | |

## Biology

| | |
|---|---|
| **Typical abundance** | Moderate density |
| **Male size range** | |
| **Male size at maturity** | |
| **Female size range** | Medium(11-20 cm) |
| **Female size at maturity** | |
| **Growth form** | Bivalved |
| **Growth rate** | See additional text. |
| **Body flexibility** | None (less than 10 degrees) |
| **Mobility** | |
| **Characteristic feeding method** | Active suspension feeder |
| **Diet/food source** | |
| **Typically feeds on** | Bacteria, phytoplankton, detritus, and dissolved organic matter (DOM). |
| **Sociability** | |
| **Environmental position** | Epilithic |
| **Dependency** | Independent. |
| **Supports** | Host<br>several parasites and commensals, see additional information and Bower (1992) and Bower & McGladdery (1996) for review. |
| **Is the species harmful?** | No<br>Edible (but see 'public health' under additional information). |

## Biology information

*Mytilus edulis* is one of the most extensively studied marine organisms. Therefore, this review is based on comprehensive reviews by Gosling (ed.) (1992a), Bayne, (1976b), Newell (1989), and Holt *et al.* (1998). Where appropriate the original source references in these reviews are given.

*Mytilus edulis* is gregarious, and at high densities forms dense beds of one or more (up to 5 or 6) layers, with individuals bound together by byssus threads. Young mussels colonize spaces within the bed increasing the spatial complexity, and the bed provides numerous niches for other organisms (see importance). Overcrowding results in mortality as underlying mussels are starved or suffocated by the accumulation of silt, faeces and pseudofaeces, especially in rapidly growing populations (Richardson & Seed, 1990). Death of underlying individuals may detach the mussel bed from the substratum, leaving the bed vulnerable to tidal scour and wave action (Seed & Suchanek, 1992).

**Growth rates**
Growth rates in *Mytilus* spp. are highly variable. Part of this variation is explained by genotype and multilocus heterozygosity (Gosling, 1992b) but the majority of variation is probably environmentally determined. The following factors affect growth rates in *Mytilus* spp. Several factors may work together, depending on location and environmental conditions (Seed & Suchanek, 1992) or the presence of contaminants (see sensitivity, e.g. Thompson *et al*., 2000):

- temperature;
- salinity;
- food availability;
- tidal exposure;
- intraspecific competition for space and food, and
- parasitism.

For example, in optimal conditions *Mytilus edulis* can grow to 60 -80mm in length within 2 years but in the high intertidal growth is significantly lower, and mussels may take 15 -20 years to reach 20 -30mm in length (Seed & Suchanek, 1992). Bayne *et al.* (1976) demonstrated that between 10-20 °C water temperature had little effect on scope for growth. Latitudinal variation in temperature influences shell structure in *Mytilus* species (Carter & Seed, 1998).

**Predation and mortality**
Several factors contribute to mortality and the dynamics of *Mytilus edulis* populations, including temperature, desiccation, storms and wave action, siltation and biodeposits, intra- and interspecific competition, and predation. But predation is the single most important source of mortality.
Many predators target specific sizes of mussels and, therefore, influence population size structure. The vulnerability of mussels decreases as they grow, since they can grow larger than their predators preferred size. *Mytilus* sp. may be preyed upon by neogastropods such as *Nucella lapillus*, starfish such as *Asterias rubens*, the sea urchin *Strongylocentrotus droebachiensis*, crabs such as *Carcinus maenas* and *Cancer pagurus*, fish such as *Platichthys flesus* (plaice), *Pleuronectes platessa* (flounder) and *Limanda limanda* (dab), and birds such as oystercatcher, eider, scooter, sandpiper, knot, turnstone, gulls and crows (Seed & Suchanek, 1992; Seed, 1993). Important predators are listed below.

1. Dogwhelks (*Nucella lapillus*) feed on mussels on the mid to lower rocky shore primarily in spring and summer, and are capable of removing 0.1-0.6 mussels/ whelk/ day. Dogwhelk predation is curtailed by periods of strong wave action or desiccation. *Mytilus edulis* can defend itself from predatory gastropods, several mussels working together to immobilise the gastropod with byssus threads (Seed & Suchanek, 1992).
2. Flounders were found to be important predators in Morecambe Bay and Liverpool Docks, as were plaice and dabs in Morecambe Bay (Dare, 1976; Holt *et al*., 1998).
3. *Asterias rubens* usually feeds at low densities in the lower shore or sublittoral in northern Europe preferring large, up to 70mm, mussels. *Asterias rubens* may periodically, and

unpredictably, rise dramatically in number forming swarms in the lower and middle shore, denuding the extensive areas of *Mytilus* sp. (Seed, 1969). For example, Dare (1976; 1982b) recorded a swarm of *Asterias rubens* in Morecambe Bay consisting of 450 starfish /m$^2$ that covered up to 2.25ha and consumed 4000 tonnes of first year mussels.

4. Crab predation is most intense on the lower shore and sublittoral, with crabs selecting mussels up to around 70mm. Small mussels are especially vulnerable since they can be crushed by all sizes of crabs. Vulnerability to crab predation decreases with increasing mussel size (Seed & Suchanek, 1992).
5. Oystercatchers and eider duck consume large numbers of mussels, primarily over winter. Raffaelli *et al.* (1990) recorded the removal of 4500 mussels /m$^2$ (within the preferred size of 10-25mm) within 60 days by a flock of 500 eider in the Ythan estuary. Eider remove mussels in clumps, which they shake to remove the target mussel. This results in additional mortality for those mussels removed from suitable substratum in the clump and leaves bare patches in the mussel beds, which may increase the risk of the loss of further mussels by water movement. Eider may, therefore, significantly affect the structure of the mussel bed (Seed & Suchanek, 1992; Holt *et al.*, 1998). Mussels are often the primary food for oystercatchers on sedimentary shores and mussel density may limit oystercatcher numbers in certain areas (Craeymeersch *et al.*, 1986). In enclosure experiments clumps of mussels only established in protected enclosures, suggesting that bird predation significantly reduced juvenile recruitment (Marsh, 1986).
6. Bird predation has a significant effect on mussel productivity (Holt *et al.*, 1998). For example, in the Ythan estuary, bird predation (eider, oystercatcher and herring gull) accounted for 72% of the annual *Mytilus edulis* production (Raffaelli *et al.*, 1990), and in the Wadden Sea, oystercatchers consumed 40% of the annual mussel production (Meire & Ervynck, 1986; Holt *et al.*, 1998).

**Epifauna and epiflora**
Fouling organisms, e.g. barnacles and seaweeds, may also increase mussel mortality by increasing weight and drag, resulting in an increased risk of removal by wave action and tidal scour. Fouling organisms may also restrict feeding currents and lower the fitness of individual mussels. However, *Mytilus edulis* is able to sweep its prehensile foot over the dorsal part of the shell (Thiesen, 1972, Seed & Suchanek, 1992). Fouling by ascidians may be a problem in rope-cultured mussels (Seed & Suchanek, 1992).

**Diseases and parasites**
The polychaete *Polydora ciliata* may burrow into the shell of *Mytilus edulis*, which weakens the shell leaving individuals more susceptible to predation by birds and shore crabs resulting in significant mortality, especially in mussels >6 cm (Holt *et al.*, 1998).
Bower (1992), concluded that, although most parasites did not cause significant mortality, several species of parasite found in mussels could also infect and cause mortality in other shellfish. This suggested that mussel populations may be reservoirs of disease for other shellfish (see sensitivity or reviews by Bower, 1992; Bower & McGladdery, 1996).

**Public heath**
*Mytilus edulis* is a filter feeding organism, which collects algae, detritus and organic material for food but also filters out other contaminants in the process. Shumway (1992) noted that mussels are likely to serve as vectors for any water-borne disease or contaminant. Mussels have been reported to accumulate faecal and pathogenic bacteria and viruses, and toxins from toxic algal blooms (see Shumway, 1992 for review). Bacteria may be removed or significantly reduced by depuration (removing contaminated mussels into clean water), although outbreaks of diseases

have resulted from poor depuration and viruses may not be removed by depuration. Recent improvements in waste water treatment and shellfish water quality regulations may reduce the risk of bacterial and viral contamination. Shellfish should also be thoroughly cooked, not 'quick steamed', to ensure destruction of viruses (Shumway, 1992). The accumulation of toxins from toxic algal blooms may result in paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP) or amnesic shellfish poisoning (ASP). These toxins are not destroyed by cooking. Shumway (1992) suggested that mussels should only be collected from areas routinely monitored by public health agencies, or obtained from approved sources and never harvested from waters contaminated with raw sewerage.

## Habitat preferences

| | |
|---|---|
| **Physiographic preferences** | Open coast, Strait / sound, Sea loch / Sea lough, Ria / Voe, Estuary, Enclosed coast / Embayment |
| **Biological zone preferences** | Lower eulittoral, Mid eulittoral, Sublittoral fringe, Upper eulittoral, Upper infralittoral |
| **Substratum / habitat preferences** | Artificial (man-made), Bedrock, Biogenic reef, Caves, Crevices / fissures, Large to very large boulders, Mixed, Muddy gravel, Muddy sand, Rockpools, Sandy mud, Small boulders, Under boulders |
| **Tidal strength preferences** | Moderately Strong 1 to 3 knots (0.5-1.5 m/sec.), Strong 3 to 6 knots (1.5-3 m/sec.), Weak < 1 knot (<0.5 m/sec.) |
| **Wave exposure preferences** | Exposed, Moderately exposed, Sheltered, Very exposed, Very sheltered |
| **Salinity preferences** | Full (30-40 psu), Reduced (18-30 psu), Variable (18-40 psu) |
| **Depth range** | Intertidal to ca. 5m. |
| **Other preferences** | No text entered |
| **Migration Pattern** | Non-migratory / resident |

### Habitat Information

### Global distribution

Previous records of *Mytilus edulis* on north African coasts, and in the Mediterranean were probably *Mytilus galloprovincialis* and *Mytilus edulis* is absent from the Pacific coast of North America (Gosling, 1992c; Seed, 1992). Previous records of *Mytilus edulis* from the Pacific coast of North America were probably *Mytilus trossulus* and/or *Mytilus galloprovincialis* (Seed, 1992; Seed pers comm.). *Mytilus edulis* has been reported from Iceland (Varvio *et al*., 1988). *Mytilus edulis* occurs on the east and west coasts of South America, and the Falkland Islands (Seed, 1992). Records of mussels form the Kerguelen Islands may be *Mytilus edulis* (MacDonald *et al*., 1992; Gosling, 1992c; Seed, 1992).

### Factors affecting zonation

Although sometimes abundant in the subtidal *Mytilus edulis* is primarily an intertidal species. *Mytilus edulis* can withstand extreme wave exposure, maintaining byssal attachment in high energy environments (Seed & Suchanek, 1992). The upper limit of *Mytilus edulis* populations on rocky shores is determined by its tolerance of temperature and desiccation, which may be synergistic, i.e. sudden mass mortalities at the upper limit of intertidal mussel beds are often associated with prolonged periods of unusually high temperatures and desiccation stress (Seed & Suchanek, 1992).

Recruitment or movement into cracks, crevices or pools provides some protection from extremes of temperature and desiccation as well as from storms. *Mytilus edulis* is relatively tolerant of extreme cold and freezing, surviving a drop in tissue temperature to minus 10 °C (Williams, 1970). However, Bourget (1983) noted that cyclic exposures to sublethal temperatures e.g. minus 8 °C every 12.4hrs resulted in death after 3-4 cycles. This suggests that *Mytilus edulis* can survive occasional, sharp frost events, but may succumb to consistent very low temperatures over a few days (see sensitivity to temperature change).

*Mytilus edulis* is generally unable to maintain attachment to steep or vertical rock surfaces, where they are typically replaced by barnacles and fucoids. Cycles of loss and recruitment may result in a patchy distribution of clumps of mussels on the shore.
The lower limit of distribution is strongly influenced by predation, primarily from starfish but also dog whelks and crabs. For example, on the east coast of England, the starfish *Asterias rubens* and the dog whelk *Nucella lapillus* eliminate mussels from the lower intertidal (Seed, 1969). In Ireland, however, the lower limit is probably controlled by the crabs *Carcinus* sp. and *Liocarcinus* sp., the dog whelk *Nucella lapillus* and the starfish *Marthasterias glacialis* (Kitching & Ebling, 1967).
Daly & Mathieson (1977) reported that the lower limit of *Mytilus edulis* populations at Bound Rock, USA, was determined by burial or abrasion by shifting sands. Burial or abrasion is probably an additional controlling factor on British coasts where mobile sediment, such as sand, cobbles or boulders, occur (Holt *et al.*, 1998).
Subtidal populations often occur on sea mounts, dock pilings and offshore oil platforms, where they grow to a large size, probably due to the lack of predators (Seed & Suchanek, 1992).

## Life history

### Adult characteristics

| | |
|---|---|
| **Reproductive type** | Gonochoristic (dioecious) |
| **Reproductive frequency** | Annual protracted |
| **Fecundity (number of eggs)** | >1,000,000 |
| **Generation time** | 1-2 years |
| **Age at maturity** | 1-2 years |
| **Season** | April - September |
| **Life span** | See additional information |

### Larval characteristics

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

## Life history information

**lifespan**
Longevity is dependant on locality and habitat. On the lower shore, few individuals probably survive more than 2-3 years due to intense predation, whereas high shore populations are

composed of numerous year classes (Seed, 1969b). Specimens have been reported to reach 18-24 years of age (Thiesen, 1973). Mortality is size dependant and can be high, e.g. Dare (1976) reported annual mortalities of 74% in 25mm mussels and 98% in 50 mm mussels in Morecambe Bay, England.

**Spawning**
Spawning is protracted in many populations, with a peak of spawning in spring and summer. For example, in north east England, resting gonads begin to develop from October to November, gametogenesis occurring throughout winter so that gonads are ripe in early spring. A partial spawning in spring is followed by rapid gametogenesis, gonads ripening by early summer, resulting in a less intensive secondary spawning in summer to late August or September (Seed, 1969a). Mantle tissues store nutrient reserves between August and October, ready for gametogenesis in winter when food is scarce (Seed & Suchanek, 1992). Larvae spawned in spring can take advantage of the phytoplankton bloom. The secondary spawning, is opportunistic, depending on favourable environmental conditions and food availability. Gametogenesis and spawning varies with geographic location, e.g. southern populations often spawn before more northern populations (Seed & Suchanek, 1992). Reproductive strategies in *Mytilus edulis* probably vary depending on environmental conditions (Newell *et al.*, 1982).

**Fertilization**
Fertilization is external. Fertilization can occur successfully between 5 -22°C and at salinities of 15 -40psu (Bayne, 1965; Lutz & Kennish, 1992). Fertilized eggs are 60-90µm in diameter (Lutz & Kennish, 1992).

**Fecundity**
Fecundity and reproductive effort increase with age and size, young mussels diverting energy to rapid growth rather than reproduction. Reproductive output is influenced by temperature, food availability and tidal exposure and can therefore vary from year to year. An individual female (ca 7mm) can produce 7-8 million eggs, while larger individuals may produce as many as 40 million eggs (Thompson, 1979).

**Larval development**
In optimal conditions larval development may be complete in less than 20 days but growth and metamorphosis in the plankton between spring and early summer, at ca. 10 °C, usually takes 1 month. However, it is not unusual for planktonic life to extend beyond 2 months in the absence of suitable substrata or optimal conditions (Bayne, 1965; Bayne, 1976a). Pediveligers can delay metamorphosis for up to 40 days at 10 °C (Lutz & Kennish, 1992) or for up to 6 months in some cases (Lane *et al.*, 1985). The duration of the delay is mainly determined by temperature, with longer delays at low temperature (Strathmann, 1987). Larvae become less selective of substrata the longer metamorphosis is delayed.

**Settlement**
In many populations *Mytilus edulis* exhibits a two stage settlement, the pediveliger settling on filamentous substrates and then moving on to suitable adult substrata by bysso-pelagic drifting. However, McGrath *et al.* (1988) and King *et al.* (1990) found little evidence of bysso-pelagic drifting in populations in Norwegian fjords or the Baltic, and pediveligers settled directly into adult beds. Pediveligers typically settle at ca. 260 µm (McGrath *et al.*, 1988) but can delay metamorphosis until ca. 350 µm. Pediveligers can delay settlement for up to 7 weeks (Holt *et al.*, 1998). Pediveligers test the substrata using their sensory foot. Settling pediveligers prefer discontinuities in the substrata (Chipperfield, 1953), and reportedly tend to avoid adults (Lane *et al.*, 1985).

Primary settlement tends to occur on filamentous substrata, such as, bryozoans, hydroids, filamentous algae such as *Polysiphonia* sp., *Corallina* sp. and *Mastocarpus* sp., or the byssus threads of previously settled adults. Primary settlement may allow the pediveligers to avoid competition for food with adults or being inhaled by suspension feeding adults. Post-larvae may remain on their primary attachment until 1-2mm in size (sometimes larger), and many late post-larvae overwinter on algae, moving to adult substrata in spring, although many will leave the algae earlier due to winter storms or death of the algae (Seed & Suchanek, 1992). Newly settled mussels are termed 'spat'.

**Dispersal**
Dispersal is dependant on the duration of planktonic life. Maintenance of their position in the water column by active swimming ensures that larvae can be potentially dispersed over great distances by currents. In addition, post-larvae can become bysso-pelagic up to 2-2.5 mm in size, which may take ca. 2 months to achieve, during which time they may be transported significant distances by currents.

**Recruitment**
Recruitment is dependant on larval supply and settlement, together with larval and post-settlement mortality. Jørgensen (1981) estimated that larvae suffered a daily mortality of 13% in the Isefjord, Denmark. Lutz & Kennish (1992) suggested that larval mortality was approximately 99%. Larval mortality is probably due to adverse environmental conditions, especially temperature, inadequate food supply (fluctuations in phytoplankton populations), inhalation by suspension feeding adult mytillids, difficulty in finding suitable substrata and predation (Lutz & Kennish, 1992). First winter mortality in the Exe estuary averaged 68%, adults suffering 39% mortality after spawning and 24% due to bird predation (McGrorty, *et al.*, 1990). Beukema (1992) reported recruitment failure in *Mytilus edulis* populations in the Wadden Sea after mild winters, which was thought to be due to a resultant increase in the number of small crabs or flatfish on the flats. Recruitment in many *Mytilus* sp. populations is sporadic, with unpredictable pulses of recruitment, possibly from the pool of young mussels on filamentous algae (Seed & Suchanek, 1992). *Mytilus* sp. is highly gregarious and final settlement often occurs around or in between individual mussels of established populations. Competition with surrounding adults may suppress growth of the young mussels settling within the mussel bed, due to competition for food and space, until larger mussels are lost (Seed & Suchanek, 1992).
Persistent mussels beds can be maintained by relatively low levels of recruitment. McGrorty *et al.*, (1990) reported that adult populations were largely unaffected by large variations in spatfall between 1976-1983 in the Exe estuary.

# Sensitivity review

This MarLIN sensitivity assessment has been superseded by the MarESA approach to sensitivity assessment. MarLIN assessments used an approach that has now been modified to reflect the most recent conservation imperatives and terminology and are due to be updated by 2016/17.

## Physical Pressures

| | Intolerance | Recoverability | Sensitivity | Confidence |
|---|---|---|---|---|
| **Substratum Loss** | High | High | Moderate | High |

Removal of the substratum, be it rock or sediment, will entail removal of the entire population and its associated community. Therefore, an intolerance of high has been recorded.
Recovery may occur rapidly through good annual recruitment. However, examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.
Recoverability will depend on recolonization by movement of young or juvenile *Mytilus edulis* from high shore or filamentous algal populations or recruitment of larvae settling directly on the new substratum. A single good recruitment event may return the population to prior levels within 1 -5 years, and an intolerance of high has been recorded. However, recoverability may be protracted in some circumstances (see additional information below).

| | Intolerance | Recoverability | Sensitivity | Confidence |
|---|---|---|---|---|
| **Smothering** | Intermediate | High | Low | Low |

Although apparently sedentary, *Mytilus edulis* is able to move some distance to change its position on the shore or within a bed or to resurface when buried by sand (Holt *et al.*, 1998). Burial of *Mytilus edulis* beds by large-scale movements of sand, and resultant mortalities have been reported from Morecambe Bay, the Cumbrian Coast and Solway Firth (Holt *et al.*, 1998). Daly & Mathieson (1977) suggested that the lower limit of *Mytilus edulis* populations at Bound Rock, USA, was determined by burial or abrasion by shifting sands. Dare (1976) noted that individual mussels swept or displaced from a mussel beds rarely survived, since they either became buried in sand or mud, or were scattered and eaten by oystercatchers. Dare (1976) reported that mussel beds accumulated ca. 0.4-0.75m of 'mussel mud' (a mixture of silt, faeces, and pseudo-faeces) between May and September 1968 and 1971 in Morecambe Bay. Young mussels moved upwards becoming lightly attached to each other, but many were suffocated (Dare, 1976). Therefore, it appears that mussels are able to move upwards through accumulated sediment, but that a proportion will succumb and so an intolerance of intermediate has been recorded.
Recovery may occur rapidly through good annual recruitment. However, examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.

| | Intolerance | Recoverability | Sensitivity | Confidence |
|---|---|---|---|---|
| **Increase in suspended sediment** | Low | Immediate | Not sensitive | High |

Moore (1977) reported that *Mytilus edulis* was relatively tolerant of turbidity and siltation, thriving in areas that would be harmful to other suspension feeders. *Mytilus edulis* possesses efficient shell cleaning and pseudofaeces expulsion mechanisms to remove silt (Moore, 1977), although it should be noted that pseudofaeces production involves an energetic burden (Navarro & Widdows, 1997). De Vooys (1987) examined the removal of sand from the mantle cavity and reported rapid discharge within 15min, with an exponential decrease over the next 4 hrs and slow discharge over 48 hrs. Purchon (1937) reported that *Mytilus edulis* died after an average of 13 days exposure to ca. 1200 mg/l suspended sediment (mud) but survived the length of the experiment (un-stated but >25 days) at 440 mg/l. Widdows *et al.* (1998) also noted that feeding rate was not reduced by current velocities up to 70 cm/s *per se* but by the resultant suspended sediment (at >50 mg/l ). Therefore, *Mytilus edulis* is probably of low intolerance to a change in suspended sediment at the benchmark level ( ±100 mg/l for 1 month). Recoverability is recorded as immediate given the mussels ability to discharge sand form the mantle cavity reported by De Vooys (1987).

**Decrease in suspended sediment** Low Immediate Not sensitive

A decrease in suspended sediment, especially organic particulates, could potentially reduce the food available to *Mytilus edulis* and hence its growth rate. Therefore, an intolerance of low has been recorded. Similarly, a recovery of immediate has been recorded.

**Dessication** Low Immediate Not sensitive Moderate

The upper limit of *Mytilus* populations is primarily controlled by the synergistic effects of temperature and desiccation (Suchanek, 1978; Seed & Suchanek, 1992; Holt *et al.*, 1998). For example, on extremely hot days in the summers of 1974 -1976 on Strawberry Island, Washington State, Suchanek (1978) reported mass mortality of *Mytilus trossulus* (as *edulis*) at the upper edge of the mussel bed. Mortality decreased down the shore. The upper limit of mussels fluctuated, increasing up the shore in winter and decreasing again in summer (Suchanek, 1978).
British *Mytilus edulis* have a sustained upper thermal tolerance limit of 29 °C (Almada-Villela *et al.*, 1982) and occur in the upper eulittoral. Holt *et al.* (1998) suggested that tolerance of high temperatures and desiccation explained the upper limit of *Mytilus edulis* on the high shore. Therefore, *Mytilus edulis* is likely to exhibit a relatively low intolerance to changes in desiccation at the level of the benchmark although individuals at the upper limit of the range are probably more vulnerable to desiccation.

**Increase in emergence regime** Low Very high Very Low Low

*Mytilus edulis* can only feed when immersed, therefore, changes in emergence regime will affect individuals ability to feed and their energy metabolism. Growth rates decrease with increasing shore height and tidal exposure, due to reduced time available for feeding and reduced food availability, although longevity increases (Seed & Suchanek, 1992; Holt *et al.*, 1998). Therefore, there will be a position on the shore where the energetic cost of metabolism is not met by feeding. Baird (1966) estimated that the point of zero growth occurred at 55% emergence but this value will vary between shores depending on local conditions, e.g. wave splash (Baird, 1966; Holt *et al.*, 1998).
Increased emergence will expose mussel populations to increased risk of desiccation and increased vulnerability to extreme temperatures, potentially reducing their upper limit on the shore, and reducing their extent in the intertidal. But *Mytilus edulis* inhabits a wide range of shore heights and is probably relatively tolerant of changes of emergence at the benchmark level (change in emergence of 1hr for 1 year). Therefore, an intolerance of low has been reported. Similarly, once the prior emergence regime returns, the population will probably recover prior condition with a few months.

**Decrease in emergence regime** Low Very high Very Low Low

*Mytilus edulis* can only feed when immersed, therefore, changes in emergence regime will

affect individuals ability to feed and their energy metabolism. Growth rates decrease with increasing shore height and tidal exposure, due to reduced time available for feeding and reduced food availability, although longevity increases (Seed & Suchanek, 1992; Holt *et al.*, 1998). Therefore, there will be a position on the shore where the energetic cost of metabolism is not met by feeding. Baird (1966) estimated that the point of zero growth occurred at 55% emergence but this value will vary between shores depending on local conditions, e.g. wave splash (Baird, 1966; Holt *et al.*, 1998).
Decreased emergence, may allow the population to colonize further up the shore but exposes the lower limit of the population to increased predation, so that the population may effectively, move up the shore. But *Mytilus edulis* inhabits a wide range of shore heights and is probably relatively tolerant of changes of emergence at the benchmark level. Therefore an intolerance of low has been reported. Once the prior emergence regime returns, the population will probably recover with a few months.

| **Increase in water flow rate** | Low | Very high | Very Low | Moderate |
|---|---|---|---|---|

Widdows *et al.* (1998) showed that *Mytilus edulis* beds in sheltered conditions (based on field annular flumes measurements) reduced sediment erosion. Widdows *et al.* (1998) also noted that feeding rate was not reduced by current velocities up to 70 cm/s *per se* but by the resultant suspended sediment (at >50 mg/l ). It should also be noted that mussels probably benefit from high current velocities to supply food (suspended particulates, benthic diatoms and phytoplankton).
As mussel beds increase in size and depth, individual mussels become increasingly attached to each other rather than the substratum. As a result, the bed may become destabilised and susceptible to removal by wave action or tidal scour, although mussels at the edge of the beds are often more strongly attached than mussels within the bed (Seed & Suchanek, 1992).

Young (1985) demonstrated that byssal thread production (and hence attachment) increased with increasing water agitation. Mussels were able to increase their byssal attachment by 25% within 8 hours of a storm commencing. Young (1985) also reported that mussels were able to withstand shock or surges of up to 16 m/s (ca 30 knots). Young (1985) concluded that mussels would be susceptible to sudden squalls and surges, which may sweep them off rocks. Therefore, storms may cause significant mortality in mussel beds (see wave exposure below).
*Mytilus edulis* populations are found in weak to strong tidal streams, suggesting low intolerance to change in water flow rate, although, their intolerance probably owes more to the nature of the substratum than the strength of their attachment. Individuals attached to solid substrata (rock) are likely to be less intolerant than individuals attached to boulders, cobbles or sediment. Overall, *Mytilus edulis* can attach and grow on a variety of substrata in a variety of water flow regimes, and an intolerance of low has been reported. It should be noted that on sedimentary shores, mussel beds are probably more intolerant of increased water flow due to removal of the sediment. Once the prior water flow regime returns, the population will probably recover within a few months.

| **Decrease in water flow rate** | Low | Very high | Very Low | Low |
|---|---|---|---|---|

*Mytilus edulis* probably benefits from high current velocities to supply food (suspended particulates, benthic diatoms and phytoplankton). A decrease in water flow is likely to decrease food availability. However, *Mytilus edulis* populations are found in weak to strong tidal streams, suggesting low intolerance to change in water flow rate, although, their intolerance probably owes more to the nature of the substratum than the strength of their attachment. Overall, an intolerance of low has been reported due their distribution in a variety of water flow regimes. Once the prior water flow regime returns, the population will probably recover within a few months.

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| **Increase in temperature** | Low | Very high | Very Low | High |

In the British Isles an upper, sustained thermal tolerance limit of about 29 °C was reported for *Mytilus edulis* (Read & Cumming, 1967; Almada-Villla *et al.*, 1982). But Seed & Suchanek (1992) noted that European populations were unlikely to experience temperatures greater than about 25 °C. Bayne *et al.* (1976) demonstrated that between 10 -20 °C water temperature had little effect on scope for growth. *Mytilus edulis* is generally considered to be eurythermal and an intolerance of 'low' has been recorded. Similarly, once the prior temperature regime returns, the population will probably recover any loss of condition within a few months.

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| **Decrease in temperature** | Low | Very high | Very Low | High |

*Mytilus edulis* can withstand extreme cold and freezing, surviving when its tissue temperature drops to -10 °C (Williams, 1970; Seed & Suchanek, 1992) or exposed to -30°C for as long as six hours twice a day (Loomis, 1995). In the laboratory, median lethal temperatures (MLT) of -16 °C after 24 hrs were estimated for large individuals (>3mm) while juveniles (<1.5mm) had an MLT of -12.5 °C. As expected, reducing the exposure time increased the MLT (Bourget, 1983). Bourget (1983) also reported that cyclic exposure to otherwise sublethal temperatures, e.g. -8 °C every 12.4 hrs resulted in significant damage and death after 3-4 cycles. This suggests that *Mytilus edulis* can survive occasional, sharp frost events, but may succumb to consistent very low temperatures over a few days. *Mytilus edulis* was relatively little affected by the severe winter of 1962/63, with 30% mortality reported from south-east coasts of England (Whitstable area) and ca. 2% from Rhosilli in south Wales (Crisp (ed.),1964). Crisp (ed.) (1964) noted that most mortality resulted from predation on individuals weakened or moribund due to the low temperatures rather than the temperature itself.
Loomis (1995) reported that freezing tolerance increased after acclimation, high salinity and aerial exposure or anoxia. Freezing tolerance increased in winter, presumably due to increased isolation from the environment (shell closure), commensurate anaerobic conditions and increased mantle cavity fluid salinity with respect to the environment. Increased freezing tolerance may result from the accumulation of amino acids (e.g. taurine, glycine and alanine) involved in maintenance of osmotic balance in high salinities, and the end products of anaerobic metabolism (e.g. strombine, and octopine), which have been shown to also act as cryoprotectants (Loomis, 1995) (see oxygenation). Although *Mytilus edulis* may be intolerant of prolonged freezing temperatures, it is generally considered to be eurythermal and an intolerance of 'low' at the level of the benchmark is recorded. Similarly, once the prior temperature regime returns, the population will probably recover any loss of condition within a few months.

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| **Increase in turbidity** | Tolerant | Not relevant | Not sensitive | Not relevant |

Increased turbidity may reduce phytoplankton primary productivity, therefore reducing the food available to *Mytilus edulis* but mussels use a variety of food sources and the effects are likely to be minimal. Therefore, this species is probably tolerant to changes in turbidity.

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|---|---|---|---|---|
| **Decrease in turbidity** | Tolerant | Not relevant | Not sensitive | Not relevant |

Decreased turbidity may increase phytoplankton primary productivity, therefore potentially increasing the food available to *Mytilus edulis* but mussels use a variety of food sources and the effects are likely to be minimal. Therefore, this species is probably tolerant to changes in turbidity.

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|---|---|---|---|---|
| **Increase in wave exposure** | Intermediate | High | Low | Moderate |

*Mytilus edulis* populations are found in sheltered to wave exposed shores, suggesting low intolerance to change in wave exposure. Their intolerance probably owes more to the nature

of the substratum than the strength of their attachment. Individuals attached to solid substrata (rock) are likely to be less intolerant than individuals attached to boulders, cobbles or sediment. Lewis (1964) noted that *Mytilus edulis* are favoured by damp conditions. Therefore, as wave exposure increases on rocky shores, barnacles and fucoids are replaced by mussel dominated communities.
Storms and tidal surges are known to destroy mussel beds, often over hundreds of hectares in the Wash, Morecambe Bay and the Wadden Sea. Mussel beds persist in sheltered areas whereas beds in exposed areas are more dynamic (Holt *et al.*, 1998). With increasing wave exposure mussel beds become increasingly patchy and dynamic. Young (1985) demonstrated that byssus thread production (and hence attachment) was increased by water agitation. Mussels were able to increase their byssal attachment by 25% within 8 hours of a storm commencing. Young (1985) concluded that mussels would be susceptible to sudden squalls and surges, which may sweep them off rocks. *Mytilus edulis* beds may also be damaged by wave driven logs or equivalent debris (Seed & Suchanek, 1992). Intense mussel settlement may lead to choking and death of underlying mussels causing the population to loosen its attachment to the substratum (Seed, 1969b). Competition for space, especially in areas of rapid growth, may lead to the formation of hummocks, in which individuals mussels may not be attached directly to the substratum. As a result, the population may become unstable and vulnerable to removal by rough seas (Seed, 1969b). Although mussel populations are found from wave exposed to sheltered shores, their intolerance to wave exposure is partly dependant on their substratum, and the size and density of the mussel bed, therefore, an intolerance of intermediate has been recorded to represent the increased susceptibility of mussel beds to damage by wave action.
Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). A recoverability of 'high' has been recorded.

| **Decrease in wave exposure** | Intermediate | High | Low | Moderate |
|---|---|---|---|---|

*Mytilus edulis* populations are found in sheltered to wave exposed shores, suggesting low intolerance to change in wave exposure. Their intolerance probably owes more to the nature of the substratum than the strength of their attachment. Lewis (1964) noted that rocky shore *Mytilus edulis* populations are favoured by damp conditions. Therefore, as wave exposure increases on rocky shores, barnacles and fucoids are replaced by mussel dominated communities. However, on rocky shores, as wave exposure decreases mussels are replaced by barnacle and fucoid dominated shores, possibly due to increased desiccation and predation (presumably by the dogwhelk *Nucella lapillus*). On wave sheltered sedimentary shores decreased wave exposure (i.e. sheltered to very sheltered) is likely to have little affect on mussel beds. Therefore, sheltered shore mussels beds are probably of low intolerance to decreased wave exposure, and may less patchy and more stable (persistent). However, on rocky shores decreased wave exposure may lead to a reduction in population density and dominance of the shore by barnacles and fucoids, therefore an overall intolerance of intermediate has been recorded.
Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.

| **Noise** | Tolerant* | Not relevant | Not sensitive* | Low |
|---|---|---|---|---|

*Mytilus edulis* may detect slight vibrations in its immediate vicinity and probably detects predators by touch (on the shell) or by scent. Therefore, it is likely to be insensitive to noise disturbance at the levels of the benchmark. Birds are major predators and several species are highly intolerant of disturbance by noise. Noise at the level of the benchmark may disturb predatory birds, so that the mussel populations may benefit indirectly.

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| **Visual Presence** | Tolerant* | Not relevant | Not sensitive* | Low |

*Mytilus edulis* can probably detect changes in light commensurate with shading by predators but its visual acuity is probably very limited and it is unlikely to be sensitive to visual disturbance. However, birds are highly intolerant of visual presence and are likely to be scared away by increased human activity, reducing the predation pressure on the mussels. Therefore, visual disturbance may be of indirect benefit to mussel populations.

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| **Abrasion & physical disturbance** | Intermediate | High | Low | Moderate |

Daly & Mathieson (1977) reported that the lower limit of *Mytilus edulis* populations at Bound Rock, USA, was determined by burial or abrasion by shifting sands. Wave driven logs have been reported to influence *Mytilus trossulus* (as *edulis*) populations, causing the removal of patches from extensive beds that subsequently open the beds to further damage by wave action. It is likely that abrasion or impact at the level of the benchmark (a boat anchor being dragged through or landing on the population) would also damage or remove patches of the population.
No studies of the effects of trampling on British or Irish populations of *Mytilus edulis* were found. But the effects of trampling on *Mytilus californianus* beds in Australia were studied by Brosnan & Cumrine (1994). They exposed mussel beds at two sites to low levels of trampling, 250 steps for 1 day every month over a 1 year period, which compared to 228 steps/hr recorded at another site. They reported that a loose, mono-layer bed was highly susceptible, trampling resulting in patches of bare rock that then expanded, beyond the area trampled, due to wave action. A dense, two layer bed was less susceptible, initially showing less disturbance, although the top layer was lost. However, mussels continued to be lost for a year after trampling had stopped, resulting in patches, and patch size had increased two years after trampling stopped. They suggested that continuous trampling may result in loss of the bed. In a heavily trampled site mussels were not common and were confined to crevices (Brosnan & Cumrine, 1994). Overall, the intolerance of trampling appears to be dependent on the density and depth of the affected mussel bed. Brosnan & Cumrine (1994) observed little recruitment in bare patches in the mussel beds until trampling had ceased, and in some cases no recruitment two years later. Storms and wave action (including wave driven logs) often clear patches of mussels in beds but occur primarily in winter and are localised. Trampling is most likely in spring and summer (Brosnan & Cumrine, 1994). The combined effects of trampling and natural winter disturbances may result in loss of mussel beds in the long term.

*Mytilus californianus* bears radiating ribs, and is a larger than *Mytilus edulis* with a divergent ecology (Seed, 1992). Nevertheless, the above evidence suggests that mussel beds are potentially intolerant of the effects of trampling, depending on trampling intensity and frequency. Therefore, physical disturbance due to sand abrasion, impact by an anchor or debris, or due to trampling when emersed, is highly likely to result in the loss of a proportion of the population and an intolerance of intermediate has been recorded.
Recovery may occur rapidly through good annual recruitment. However, examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported

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| **Displacement** | Intermediate | High | Low | Moderate |

Dare (1976) reported that individual mussels swept or displaced from mussel beds rarely survived, since they either became buried in sand or mud, or were scattered and eaten by oystercatchers. Mussels can attach to a wide range of substrata and should a mussel be displaced to a suitable substratum it is likely to be able to attach itself quickly using byssus threads. For example, Young (1985) reported that detached mussels produced 8 byssus threads within the first 24hrs, and between 8-11 byssus threads within 3 days at 13°C (an average of 3.5 threads/ individual/ day), depending on temperature and water agitation. Overall, displacement is likely to result in the loss of some individuals due to vulnerability to predation as well as the danger of smothering, hence an intolerance of intermediate has been recorded.
Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.

## Chemical Pressures

| | Intolerance | Recoverability | Sensitivity | Confidence |
|---|---|---|---|---|
| **Synthetic compound contamination** | Intermediate | High | Low | Moderate |

The effects of contaminants on *Mytilus* sp. were extensively reviewed by Widdows & Donkin, (1992) and Livingstone & Pipe (1992). Mussels are suspension feeders and, therefore, process large volumes of water together with suspended particulates and phytoplankton. Mussels absorb contaminants directly from the water, through their diet and via suspended particulate matter (Widdows & Donkin, 1992), the exact pathway being dependant on the nature of the contaminant.

- Widdows and Donkin (1992) reported 50% mortality from a tissue burden of 20 µg/g TBT.
- Exposure of *Mytilus edulis* to detergent (BP1002) in seawater resulted in 100% mortality at 10 ppm detergent, although all survived at 5 ppm detergent (Smith, 1968).
- Liu & Lee (1975) reported a $LC_{50}$ of 250 µg/l of the herbicide trifluralin in *Mytilus galloprovincialis*
- *Mytilus edulis* has been reported to bioaccumulate the insecticide ivermecten, although no adverse effects were observed (Cole *et al.*, 1999).
- Biphenyl (a dye carrier) reduced the feeding rate of *Mytilus edulis* by 50% at 0.3 mg/l (Donkin *et al.*, 1989).
- PCBs accumulate in gonads, although tissue concentrations are significantly reduced after spawning, although this may affect the next generation (Hummel *et al.*, 1989; Holt *et al.*, 1995).
- Significant increases in the incidence of tumours (neoplasia) were reported in the US Mussel Watch programme in the presence of higher concentrations of combustion related poly-aromatic hydrocarbons, *cis*-chlordane pesticides and cadmium (Hillman, 1993; Holt *et al.*, 1998).
- *Mytilus edulis* survived in a power station cooling water culvert, exposed to 0.1-0.2 mg/l hypochlorite, although their growth rates were reduced by about a third. Mussels were able to recover in hypochlorite free periods between chlorination

dosing (Thompson *et al.*, 1997). *Mytilus edulis* and *Mytilus galloprovincialis* were reported to suffer 100% mortality after 15-135 days continuous exposure to 0.2-1.0 mg/l hypochlorite (Khalanski & Borget, 1980; cited in Thompson *et al.*, 1997).
- Holt *et al.* (1995) also report that mussels may be absent from areas of high boating activity, presumably due to TBT.

Widdows *et al.* (1995) compared 'scope for growth' (SFG) and chemical contaminants in tissues of mussels from 26 coastal and 9 offshore sites around the United Kingdom. They noted that polar organics (probably derived from phytoplankton) accounted for some reduction in SFG, while organo-chlorides showed a significant correlation with an unexplained component of the decline in SFG. However, TBT levels were only high enough to cause an effect (<10% reduction in SFG) at 8 study sites (Widdows *et al.*, 1995). *Mytilus edulis* is probably relatively tolerant of contaminants.
Widdows & Donkin (1992) list tolerances of *Mytilus edulis* adults and larvae (Tables 8.2, 8.3, & 8.4) but note that lethal responses give a false impression of high tolerance, since the adults can close their valves and isolate themselves from the environment for days. They suggest that sublethal effects (shell growth and 'scope for growth') are more sensitive indicators of the effects of contaminants. Also, adults are ca. 4 times more sensitive than larvae to TBT (Widdows & Donkin, 1992, see larval sensitivity).

Overall, the above evidence of contaminant induced mortality suggests that a proportion of the population may be lost and an intolerance of intermediate has been recorded.

Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.

**Heavy metal contamination** Intermediate High Low Low

The effects of contaminants on *Mytilus* sp. were extensively reviewed by Widdows & Donkin, (1992) and Livingstone & Pipe (1992). Widdows & Donkin (1992) list tolerances of *Mytilus edulis* adults and larvae (Tables 8.2, 8.3, & 8.4) but note that lethal responses give a false impression of high tolerance, since the adults can close their valves and isolate themselves from the environment for days. They suggested that sublethal effects e.g. shell growth and 'scope for growth' (SFG), are more sensitive indicators of the effects of contaminants. Reported effects of heavy metals follow.

- Adult 15 day $LC_{50}$ to 50µg/l Cu (Widdows & Donkin, 1999).
- Crompton (1997) reported that adult bivalve mortalities occurred after 4-14 day exposure to 0.1-1 µg/l Hg, 1-10 µg/l Cu and Cd, 10-100 µg/l Zn but 1-10 mg/l for Pb and Ni.
- Widdows *et al.* (1995) reported 'no observed effect thresholds' on feeding or SFG in *Mytilus edulis* tissues of 150 µg Cd/g dry wt, 25 µg Cu/ g dry wt, (lethal at 60 µg Cu/g dry wt), 12 µg Hg/g dry wt, 10 mg Pb/g dry wt, and 300 µg Zn/g dry wt. However, the tissue concentration of heavy metals at the sites studied was not high enough to reduce SFG significantly.
- Mussels were reported to be missing from an wider area than other shore organisms on a Cumbrian shore in the vicinity of a phosphate rich effluent outfall contaminated by a number of heavy metals (Holt *et al.*, 1998).
- Adults are ca >10 fold more intolerant than larvae to Cu, petroleum hydrocarbons

and sewage sludge (Widdows & Donkin, 1992) (see larval sensitivity).

Overall, *Mytilus edulis* is probably relatively tolerant of heavy metal contamination. But the potential mortality indicated above suggest an intolerance of intermediate.
Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of 'high' has been reported.

| **Hydrocarbon contamination** | Intermediate | High | Low | Moderate |
|---|---|---|---|---|

Widdows & Donkin (1992) list tolerances of *Mytilus edulis* adults and larvae (Tables 8.2, 8.3, & 8.4) but note that lethal responses give a false impression of high tolerance, since the adults can close their valves and isolate themselves from the environment for days. They suggested that sublethal effects e.g. shell growth and 'scope for growth' (SFG), are more sensitive indicators of the effects of contaminants.

- Widdows *et al.* (1995) demonstrated that toxic hydrocarbons, primarily poly-aromatic hydrocarbons, made a large contribution the decline in SFG observed along the North Sea coast. Hydrocarbons reduce clearance rate through 'non-specific narcosis'.
- Mussel populations in Sullom Voe experienced moderate hydrocarbon pollution and a reduced SFG but had sufficient capacity to grow, reproduce and maintain a viable population (Widdows *et al.*, 1992).
- Widdows *et al.* (1987) examined the response of *Mytilus edulis* to high oil (water accommodated fraction of diesel oil) (125 ± 28 µg/l) and low oil (28 ±7 µg/l) over a 8 month period, and subsequent recovery. They observed a marked reduction in SFG (due to reduced feeding rate and food absorption efficiency), and a correlation between the reduction in SFG and the hydrocarbon tissue burden (Widdows *et al.*, 1987; Widdows & Donkin, 1992; Widdows *et al.*, 1995). Mussels exposed to high oil conditions showed a negative SFG and weight loss. During recovery, 22 days after removal to 'clean' sea water the high oil mussels depurated (removed) hydrocarbons more rapidly than low oil mussels, and showed an increased clearance rate and growth rate associated with 'catch-up' growth. Both high and low oil mussels recovered completely within 55 days.
- Widdows *et al.* (1987) also reported that high and low oil contamination of the experimental basins resulted in 100% mortality amongst mussels kept in the basins from autumn 1982 to summer 1983 and from spring 1983 to summer 1984 respectively.
- Widdows *et al.* (1992) reported the following tolerances of adult *Mytilus edulis* to hydrocarbons; a 4 day $LC_{50}$ of 1-10 mg/l of crude oil, and a 4 month $LC_{50}$ to 125 µg/l of diesel.
- A sunflower oil tanker spill off the Anglesey coast resulted in ingestion of oil droplets and subsequent mortalities after spawning (Mudge *et al.*, 1993; Holt *et al.*, 1998).
- Bokn *et al.*, (1993) demonstrated that *Mytilus edulis* was lost from mesocosm experiments continuously dosed with 30.1 to 129.4 µg/l of the water accommodated fraction of diesel, and was the most intolerant of the intertidal species studied.
- *Mytilus edulis* dominated jetty piles immediately adjacent to an oil refinery effluent in Milford Haven, suggesting a high tolerance of hydrocarbon contamination (K. Hiscock, pers. comm.).

Overall, hydrocarbon tissue burden results in decreased SFG and in some circumstances may

result in mortalities, reduced abundance or extent of *Mytilus edulis*. Therefore, an intolerance of intermediate has been recorded. Larval mytilids are less sensitive than adults (see larval sensitivity).
Recovery may occur rapidly through good annual recruitment but examination of patches in beds of *Mytilus* sp. revealed that they may take many years to recover (see additional information below), depending on shore height, competition and environmental conditions. Repeated loss and recruitment results in a patchy distribution of mussels on the shore (Seed & Suchanek, 1992). Therefore, a recoverability of high has been reported.

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| **Radionuclide contamination** | | Not relevant | | Not relevant |

The periostracum of *Mytilus edulis* was reported to concentrate uranium (Widdows & Donkin, 1992). Mussels have also been reported to bioaccumulate $^{106}$Ru, $^{95}$Zr, $^{95}$Nb, $^{137}$Cs and $^{90}$Sr (Cole *et al.*, 1999). While the above data demonstrates that *Mytilus edulis* can accumulate radionucleides, little information concerning the effects of radionucleides on marine organisms was found.

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| **Changes in nutrient levels** | Intermediate | High | Low | Low |

Butler *et al.* (1990) examined the effects of sewage sludge on adult and larval *Mytilus edulis*. Exposure of adults to 0.02 - 0.04% industrial/domestic sewage sludge resulted in a reduced respiration rate and a 50% decrease in net energy surplus after 4 weeks. There was no clear relationship between the tissue concentration of heavy metals and physiological stress and it was unclear whether the observed effect was due to increased levels of nutrients or contaminants within the sewage sludge. *Mytilus edulis* may benefit from moderate nutrient enrichment, especially in the form of organic particulates and dissolved organic material. The resultant increased food availability may increase growth rates, reproductive potential and decrease vulnerability to predators.
Long term and/or high levels of organic enrichment may result in deoxygenation (see oxygenation below) and algal blooms, which may have adverse effects indirectly. Algal blooms have reportedly had adverse effects on *Mytilus edulis*. Blooms of the toxic dinoflagellate *Gyrodinium aureolum* caused mortality of *Mytilus edulis* in Norway and sublethal effects on clearance rate and cellular damage in the UK (Holt *et al.*, 1998). A bloom of *Phaeocystis poucheri* that produced copious amounts of glutinous material prevented *Mytilus edulis* from feeding, and hence reproductive failure in the Dutch Wadden Sea (Pieters *et al.*, 1980; Holt *et al.*, 1998). Landsberg (1996) also suggested that there was a correlation between the incidence of neoplasia or tumours in bivalves and out-breaks of paralytic shellfish poisoning in which bivalves accumulate toxins from algal blooms, although a direct causal effect required further research. Therefore, a proportion of the population may be lost as a result of nutrient enrichment, and an intolerance of intermediate has been recorded. Recoverability is likely to be high (see additional information below).

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| **Increase in salinity** | Low | Very high | Very Low | Low |

*Mytilus edulis* is likely to encounter hyper-saline conditions in rock pools exposed on hot days, where evaporation can increase the salinity, e.g. Newell (1979) presented data on salinity fluctuations in rock pools, which reached salinities up to 42 psu. High shore rock pools show marked fluctuations in salinity. But *Mytilus edulis* is considered to be tolerant of a wide range of salinities (see Holt *et al.*, 1998). Therefore, an intolerance of low, at the benchmark level, is recorded. On return to the prior salinity regime, *Mytilus edulis* will probably recover within a few days or weeks.

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|---|---|---|---|---|
| **Decrease in salinity** | Low | Very high | Very Low | Moderate |

*Mytilus edulis* exhibits a defined behaviour to reducing salinity, initially only closing its siphons to maintain the salinity of the water in its mantle cavity, which allows some gaseous exchange and therefore maintains aerobic metabolism for longer. If the salinity continues to fall the valves close tightly (Davenport, 1979; Rankin & Davenport, 1981). In extreme low salinities, e.g. resulting from storm runoff, large numbers of mussels may be killed (Keith Hiscock pers comm.). In the long term (weeks) *Mytilus edulis* can acclimate to lower salinities (Almada-Villela, 1984; Seed & Suchanek, 1992; Holt *et al.*, 1998). Almada-Villela (1984) reported that the growth rate of individuals exposed to only 13psu reduced to almost zero but had recovered to over 80% of control animals within one month. *Mytilus edulis* can also survive considerably reduced salinities, growing as dwarf individuals at 4-5psu in the Baltic. Differences in growth being due to physiological and/or genetic adaptation to salinity. *Mytilus edulis* is an osmoconformer and maintains its tissue fluids iso-osmotic (equal ionic strength) with the surrounding medium by mobilization and adjustment of the tissue fluid concentration of free amino acids (e.g. taurine, glycine and alanine) (Bayne, 1976; Newell, 1989). But mobilizing amino acids may result in loss of protein, increased nitrogen excretion and reduced growth. Koehn (1983) and Koehn & Hilbish (1987) reported a genetic basis to adaptation to salinity at the aminopeptidase-1 locus, involved in the production of some free amino acids. In addition, *Mytilus edulis* thrives in brackish lagoons and estuaries, although, this is probably due to the abundance of food in these environments rather than the salinity (Seed & Suchanek, 1992).

Overall, *Mytilus edulis* can acclimate to a wide range of salinities and a change of salinity at the benchmark level is unlikely to adversely affect this species, and an intolerance of low has been recorded.

| **Changes in oxygenation** | Low | Very high | Very Low | High |
|---|---|---|---|---|

*Mytilus edulis* is regarded as euryoxic, tolerant of a wide range of oxygen concentrations including zero (Zwaan de & Mathieu, 1992). Diaz & Rosenberg (1995) suggest it is resistant to severe hypoxia. Adult mytilids exhibited high tolerance of anoxia, e.g. Theede *et al.* (1969) reported $LD_{50}$ of 35 days for *Mytilus edulis* exposed to 0.21mg/l $O_2$ at 10°C, which was reduced to 25 days with the addition of sulphide (50 mg/l $Na_2S$ .9$H_2O$). *Mytilus edulis* is capable of anaerobic metabolism. In aerial exposure (emersion) the mussel closes its valves, resulting in a low rate of oxygen exchange and consumption (Zwaan de & Mathieu, 1992; Widdows *et al.*, 1979). Therefore, the mussel conserves energy and utilizes anaerobic metabolism. Anaerobic metabolism also increases at low temperatures and some of the end products of anaerobic metabolism may be cryoprotectant (see changes in temperature above).
Jorgensen (1980) observed, by diving, the effects of hypoxia (0.2 -1 mg/l) on benthic macrofauna in marine areas in Sweden over a 3-4 week period. Mussels were observed to close their shell valves in response to hypoxia and survived for 1-2 weeks before dying (Cole *et al.*, 1999; Jorgensen, 1980). In hypoxic or anoxic conditions *Mytilus edulis* increases oxygen consumption until oxygen levels fall below 60% saturation, the proportion of anaerobic metabolism increases as the oxygen concentration falls below 90% saturation (Famme *et al.*, 1981; Newell, 1989). In *Mytilus galloprovincialis* anaerobic metabolism increases once the oxygen concentration falls below 8kPa ( 3.5 mg/l) becoming maximal at and below 4kPa (1.76 mg/l) (Zwaan de & Mathieu, 1992). Anaerobic metabolism allows the mussel to maintain is metabolism close to aerobic levels (Newell, 1989), although it incurs an 'oxygen debt' in the process (Widdows *et al.*, 1979). Although *Mytilus edulis* is highly tolerant of hypoxia at the benchmark level (2mg/l $O_2$ for 1 week), it incurs a metabolic cost and, hence, reduced growth, therefore, an intolerance of low has been recorded. Tolerance of anoxia increases during larval development (see larval sensitivity).

Once oxygen levels return to prior levels, *Mytilus edulis* will probably recover condition within a few weeks.

## Biological Pressures

| | Intolerance | Recoverability | Sensitivity | Confidence |
|---|---|---|---|---|
| **Introduction of microbial pathogens/parasites** | Intermediate | High | Low | High |

Landsberg (1996) suggested that there was a correlation between the incidence of neoplasia or tumours in bivalves and out-breaks of paralytic shellfish poisoning in which bivalves accumulate toxins from algal blooms. However, demonstration of a direct causal effect requires further research.
*Mytilus* spp. hosts a wide variety of disease organisms. parasites and commensals from many animal and plant groups including bacteria, blue green algae, green algae, protozoa, boring sponges, boring polychaetes, boring lichen, the intermediary life stages of several trematodes, copepods and decapods (Bower, 1992; Bower & McGladdery, 1996; Gray *et al.*, 1999). For example:

- The polychaete *Polydora ciliata*, bores into the shell, causing blisters, atrophy of adductor muscle, interferes with gamete production and reduces the strength of the shell, hence increasing their vulnerability to predation. *Polydora ciliata* has been, therefore, responsible for substantial mortalities among European mussel populations (Ambariyanto & Seed, 1991; Bower, 1992; Bower & McGladdery, 1996).
- The boring sponges *Cliona celata* and *Cliona lobata*, perforate the shell of mytilids leaving them vulnerable to predators. Infections of *Cliona* sp. may be confused with infections of the shell boring lichen *Arthopyrenia sublitoralis* reported in the Isefjord, Denmark.
- *Mytilus edulis* may also be infected by the copepod *Mytilicola intestinalis* (red worm disease). *Mytilicola intestinalis* may infect 100% of the mussel population at levels often greater than 30 copepods per mussel. Although its presence may reduce fecundity, it exhibits the features of a commensal rather than a harmful parasite.