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Puccinellia maritima salt-marsh community

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

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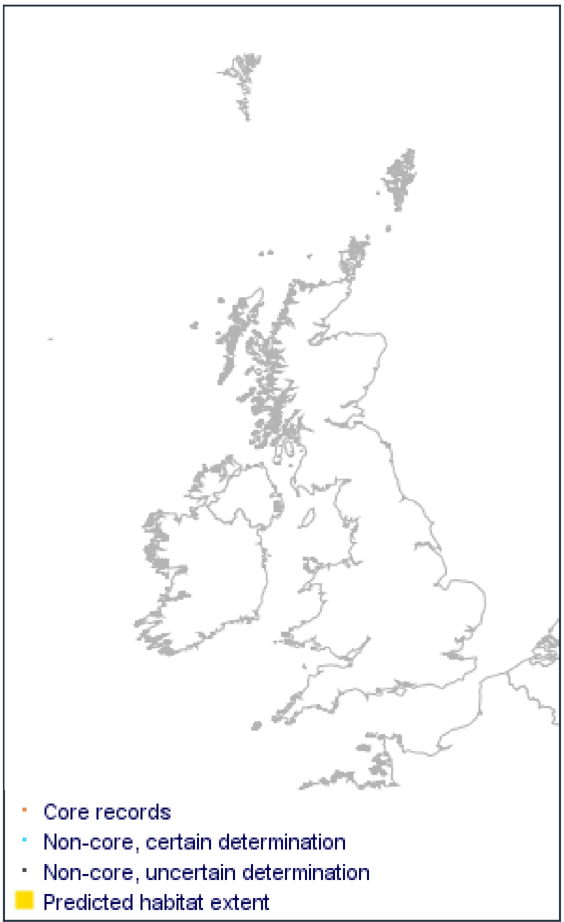
***Puccinellia maritima* salt marsh.**
Photographer: Kathy Duncan



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

Researched by Dr Harvey Tyler-Walters **Refereed by** This information is not refereed.

Summary

UK and Ireland classification

EUNIS 2008	A2.541	Atlantic saltmarsh grass lawns
JNCC 2015	LS.LMp.Sm.SM13	*Puccinellia maritima* salt-marsh community
JNCC 2004	LS.LMp.Sm.SM13	*Puccinellia maritima* salt-marsh community
1997 Biotope	LS.LMU.Sm.SM13	*Puccinellia maritima*

Description

Muds, silts, clays and muddy sands of high organic content and saline influence routinely inundated by the sea support vascular salt marsh plant communities dominated by dense tufts or hummocks *Puccinellia maritima*. These habitats typically occur in sheltered conditions of estuaries and bays. *Puccinellia maritima* dominated communities may also be pioneer communities, forming on lower shore muds, on the fallen edges of saltmarsh, on the edges of creeks or pans, and in recently disturbed areas of saltmarsh, such as the ruts left by vehicles or grazing animals. Isolated swards may occur in the higher marsh in disturbed or slumped areas. Up to six plant sub-communities can be recognised (Rodwell, 2000) but sea milkwort *Glaux maritima*, common sea lavender *Limonium vulgare*, thrift *Armeria maritima*, sea plantain *Plantago maritima*, the sea aster *Aster tripolium* are common associated species. Glassworts *Salicornia* spp. occurs in lower marsh examples and small cord grass *Spartina maritima* may occur occasionally. Filamentous algae such as *Rhizoclonium* sp. and *Vaucheria* sp. may form a mat on the sediment surface and around the stems of plants together with the blue green algae *Rivularia nitida*. Fucoids such as *Ascophyllum nodosum* ecad *mackayi*, *Fucus vesiculosus* and *Pelvetia canaliculata* form an understorey in the *Puccinellia maritima* turf fucoid sub-community found in western Scotland and northern Ireland. The resident fauna varies depending on shore height becoming more marine in the lower marsh and more terrestrial in origin towards the higher marsh. The annelid *Hediste diversicolor*, the bivalve *Limecola balthica* and especially the amphipod *Corophium volutator* and the mud snail *Hydrobia ulvae* may be abundant in the pioneer zone. Invertebrates of the mid and higher marsh are primarily terrestrial and include plant sucking aphids, other true bugs (Hemiptera), thrips (Thysanoptera), flies (Diptera), butterflies and moths (Lepidoptera) and beetles (Coleoptera). [**NB** biotope description composed by author.]

Depth range

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Additional information

The literature on saltmarsh habitats is extensive and it would be impossible to include all available information in this review. Therefore, the following review is based on more extensive reviews and texts to which the reader is directed for further information (Ranwell, 1972; Long & Mason, 1983; Adam, 1993; Packham & Willis; 1997; Rodwell, 2000). However, little of the information found examines the *Puccinellia maritima* community separately and most examines the saltmarsh as a whole. Wherever possible specific references have been used and cited (e.g. Gray & Scott, 1977a,b).

Listed By

- none -

Further information sources

Search on:

G G G JNCC

Habitat review

Ecology

Ecological and functional relationships

Saltmarsh occurs in sheltered, low energy habitats at the top of the intertidal where sediment has built up above mean high water of neap tides (MHWN) and to dry out between high neap tides. Saltmarsh plants stabilize and consolidate accreting sediment, reducing erosion and increasing the net accretion rate, so that saltmarsh increases in height over time. Therefore, saltmarsh plants (halophytes) especially pioneer species such as *Puccinellia maritima* and *Salicornia* sp. significantly modify the habitat providing benthic habitat as well as plant substratum and habitat for a wide range of species. Dynamic changes, occasional events such as storms and disturbance, and succession, provide a complex habitat for a diverse species assemblage (see habitat complexity below). As accretion causes the saltmarsh to grow upwards in relation to tidal height, seawater influence decreases and the invertebrate fauna, halophytic and algal flora changes. With increasing distance from the sea the fauna and flora change from mainly marine in the lower and pioneer marsh and creeks or pans to mainly terrestrial in origin in the mid to high marsh. Few species are mainly or solely associated with *Puccinellia maritima* dominated communities themselves. Pioneer saltmarsh communities represent colonizing species early in saltmarsh development (succession) and zonation and occupy a zone between MHWN and MHW. The major environmental relationships are listed below.

- *Puccinellia maritima* and other halophytes provide primary productivity to the ecosystem. However, a relatively small proportion of this primary productivity is used directly by grazers and the majority (dead plant material) enters the detrital food chain (Long & Mason, 1983).
- Additional primary productivity is provides by mats of filamentous algae (e.g. *Rhizoclonium* sp. and *Vaucheria* sp.), mats of cyanobacteria (e.g. *Rivularia nitida*), epiphytic algae and cyanobacteria, and microphytobenthos. Microphytobenthos may help to bind the surface sediment and facilitate colonization by plants, and is grazed by a variety of invertebrates (Long & Mason, 1983; Adam, 1993). Algal productivity is grazed by several invertebrates, however, the majority is thought to enter the detrital food chain (Adam, 1993).
- Detritus (in the form of decaying plant material and organic particulates) may be decomposed by bacteria in the saltmarsh or may provide an important source of organic carbon to the wider ecosystem of the estuary or bay, depending on the local hydrographic regime (Long & Mason, 1983; Adam, 1993; Packham & Willis, 1997).
- Hundreds of species of bacteria, fungi, and microalgae may be attached to surfaces of vascular plants and in the sediment. These are grazed by meiofauna (protozoa, foraminifera,) and nematodes.
- The epiphytic microalgae on plant stems and the algal mats are probably grazed by gastropods (e.g. *Ovatella* spp. and *Hydrobia ulvae* and intertidal mites (acarids), in the lower marsh, by littorinids
- The majority of saltmarsh insects occur in the mid the high marsh and are sap sucking aphids or chewing grasshoppers, e.g. the saltmarsh aphid, *Sipha littoralis* feeds mainly on *Puccinellia maritima* and *Spartina anglica*, and the aphid *Macrosiphonella asteris* feeds on stems of *Aster tripolium* with lowest salt content, but may not be found in pioneer saltmarsh biotopes. The leaves of *Limonium* spp. are eaten by caterpillars of the plume moth *Agdistis bennetii*. *Puccinellia maritima* supports a number of species of true bugs (Hemiptera), thrips (Thysanoptera), flies (Diptera), butterflies and moths (Lepidoptera)

and beetles (Coleoptera) (Gray & Scott, 1977; Adam, 1993).

- *Macoma baltica*, *Corophium volutator* and *Arenicola marina* and numerous oligochaetes are deposit feeders while *Hydrobia ulvae* grazes the microflora from sediment grains.
- The lower shore supports suspension feeding invertebrates such as *Mya arenaria*, *Macoma baltica*, *Scrobicularia plana* and *Cerastoderma edule*
- Infaunal or epifaunal predators include the polychaetes *Hediste diversicolor* and *Nephtys hombergi* , the nemertines *Tetrastemma* sp. and *Lineus* spp. and doliochopodid flies.
- Crabs and prawns (e.g. *Carcinus maenas*) are probably generalist predators or scavengers in the lower marsh or salt pans.
- Gobies e.g. *Pomatoschistus minutus* (sand goby) are significant predators on *Corophium volutator* and together with the three spined stickleback *Gasterosteus aculeatus* and juvenile flatfish prey on small invertebrates. In Norwich salt marshes, sticklebacks were found to be a significant part of the diet of the otter (*Lutra lutra* (Long & Mason, 1983).
- Intertidal spider species prey on insects and other invertebrates (Packham & Liddle, 1970; Packham & Willis, 1997)
- Salt marshes are also used as feeding grounds for wildfowl, grazing the saltmarsh plants directly or preying on the invertebrate fauna. Estimates of the amount of plant material consumed by wildfowl in saltmarsh and seagrass beds range from 1 - 50 percent (Raffaelli & Hawkins 1999). For example, the brent goose (*Branta bernicla*) grazes *Puccinellia maritima* and *Aster tripolium* in high marsh at end of winter, while white fronted geese feed on *Agrostis stolonifera* and *Puccinellia maritima*. The shelduck *Tadorna tadorna* feeds extensively on *Hydrobia ulvae*.
- Saltmarsh also support large numbers of small birds such as linnets and greenfinch, starlings, pipits and wagtails, feeding on insects and seeds, as well as gulls and birds of prey.
- Saltmarsh is also used for grazing by rabbits and livestock such as sheep, cattle and horses.

More detailed accounts of the saltmarsh ecosystems are provided by Ranwell (1972), Long & Mason (1983), Adam (1993)and Packham & Willis (1997).

Seasonal and longer term change

Seasonal change

Puccinellia maritima remain green over winter but ceases growth, then begins to grow in April, flowering by the end of July - August, although the exact time and duration vary, and growth is fastest in August to October (Gray & Scott, 1977). Filamentous algae, show considerable more temporal and seasonal variation than the vascular plants (see Polderman, 1979; Adam, 1993). In submergent *Spartina -Salicornia* saltmarsh in Norfolk, UK (Packham & Willis 1997) annelid numbers increased in spring and declined in June-July and increased again in late summer. Many species of insect have short life cycles and/or hibernate over winter as pupae or adults. The sand goby *Pomatoschistus minutus* entered the marsh in early summer, moved away in August -September but was abundant again in autumn (Packham & Willis 1997). There is a continual change in bird species in the coastal zone. January brings wildfowl back from their annual moult migration e.g. shelduck, wigeon, mallard, teal and pintail. Waders become conspicuous in May e.g. godwits, grey plover, and spotted redshank. Terns, ringed plover, oystercatcher and shelduck breed in June. However, the exact array of species varies between sites depending on the types of coastal habitats and feeding grounds present, disturbance and availability of nesting sites.

Succession

Accretion of sediment and accumulation of plant material increases the height of the marsh and reduces tidal influence (with the exception of creeks). Reduced water-logging of the soil, and increased freshwater percolation reduces the salinity of the soil. As a result, plant communities change with shore height and frequency of submergence, eventually reaching effectively terrestrial l but coastal plant communities. *Puccinellia maritima* appear in pioneer communities and at the lower parts of the marsh as *Puccinellia maritima* - turf fucoid communities. Towards the mid marsh *Puccinellia maritima* dominated communities occur with increasing amounts of the *Glaux maritima*, *Limonium vulgare*, *Plantago maritima* and *Armeria maritima* sub-communities. In the high marsh, except in depressions or pans or the collapsed side of creeks, *Puccinellia maritima* becomes out-competed by *Festuca rubra* and *Juncus maritimus* communities where the soil salinity has decreased. Without intervention (e.g. grazing regimes) or occasional disruptive events (e.g. storms and floods) that erode areas of saltmarsh the saltmarsh communities would essentially move further offshore with the gradual accumulation of sediment.

Habitat structure and complexity

Spatial complexity

- In areas subject to wave action, the extent of the saltmarsh may be limited to the level of the highest astronomical tides but in very sheltered areas may extend to MHWN. The extent of saltmarsh is affected by topography and may be extensive on flat, gently sloping shores or limited to a few metres in width on steep shores.
- Sedimentation rates, and hence accretion rates vary between sites (e.g. 8 mm/yr. at Scolt Head, east England and 78 mm/yr. in the Dovey Estuary, Wales) and is determined by the hydrographic regime, and sediment supply from eroding cliff or riverine sources. Sediment may be bound by mucilaginous diatoms of the microphytobenthos, tubes of burrowing polychaetes, vegetation, or destabilized by bioturbation due to infauna e.g. *Corophium volutator*
- Pioneer saltmarsh communities may be washed away by tides, currents and storms and appear patchy until the vegetation becomes re-established. For example, pioneer *Puccinellia maritima* communities develop from scattered plants into hummocks, which eventually give way to a continuous sward of *Puccinellia* dominated communities. The tops of the hummocks may develop a *Puccinellia-Salicornia-Suaeda* community (Rodwell, 2000).
- Saltmarsh are characterized by a network of creeks formed by freshwater runoff. Growth of pioneer plants on raised areas concentrates water flow into channels that form deepening creeks as the marsh develops. Depressions of salt pans form when areas are surrounded by vegetation or by the die back of an area of vegetation and subsequent erosion. These salt pans hold water that evaporates after high tide, in many respects, the saltmarsh equivalent of rockpools. However, typically 70% of the surface is dominated by saltmarsh flat.
- *Puccinellia* dominated communities may colonize the high marsh in slumped creek banks, salt pans or disturbed soil but is otherwise restricted to areas below MHWN by competition with other halophytes, e.g. *Festuca rubra*.
- The substratum varies but contains more silt and clay than underlying intertidal sediment e.g. saltmarsh soil at Bull Island, Dublin Bay was 75% sand whereas at Colne Point, east England it was 5%. The relative composition of sand affects porosity and water holding capacity. *Puccinellia maritima* favours water logged soil and is out-competed in dryer soils.
- Organic matter is derived from deposited detritus and particulate matter together with degraded plant material from saltmarsh vegetation. Therefore, the organic content increases with time and shore height.

- The high organic content encourages microbial activity, which together with poor oxygen exchange in silty sediments results in anoxic conditions, releasing toxic methane and hydrogen sulphide. Typically saltmarsh soil has a high salinity, is commonly anaerobic, and has low levels of nitrogen and phosphorus compared to other terrestrial soils.

Community complexity

- *Salicornia* sp. and *Atriplex* sp. dominate around MHWN in presence of wave action but where occasional smothering by marine debris keeps vegetation open. Low water marsh is dominated by *Spartina* sp., *Aster tripolium*, and *Puccinellia* sp.
- Seventy two species of Bryophytes (mosses & liverworts) are found on British saltmarsh, especially *Pottia heimii*.
- Macrophytes may predominate the lower saltmarsh, e.g. dwarf *Fucus vesiculosus* and *Ascophyllum nodosum*; *Pelvetia canaliculata*ecad *libera* is found in pans entangled in vascular plant stems, and *Ulva nana* and *Catanella repens* may be epiphytic on vascular plant stems. Filamentous brown algae colonize steep creek banks (e.g.*Vaucheria thuretti*); cyanobacteria may be found amongst vascular plants (e.g. *Calothrix* sp.); exposed mud may be colonized by filamentous green algae e.g. *Ulothrix*, and mats of cyanobacteria and microphytobenthos may colonize the sediment surface.
- The sediment in saltmarsh of the Stour estuary was found to support the polychaete *Nereis diversicolor*, the oligochaetes *Tubificoides benedini* and *Tubiflex costatus*, the crustacean *Corophium volutator*, and the mud snail *Hydrobia ulvae*. In the lower marsh other infauna include bivalves *Mya arenaria*, *Cerastoderma edule* and *Macoma baltica*.
- The intertidal collembolan *Anurida maritima* may be confined to the transition zone from mudflat to marsh.
- Several intertidal insects may live in burrows in the sediment, closing off the entrances at high tide, e.g. the beetle *Bledius spectabilis*, while other insects such as aphids live attached to the stems of vascular plants.
- The plant roots support nematodes, oligochaetes and fungi.
- Salt pans have highly variable salinities from hypersaline after evaporation to hyposaline after rain and support a more marine fauna of *Littorina saxatilis*, the isopod *Sphaeroma* sp. and shore crabs *Carcinus maenas*.
- Epibenthic fish are restricted to pools and creeks at low tide but may feed over a wider area at high tide e.g. *Pomatoschistus minutus* (sand goby) and *Gasterosteus aculeatus* (three-spined stickleback).
- Few birds species nest on saltmarsh due to flood risk; shelduck use saltmarsh for rearing young but nest elsewhere. Other bird species nest in middle to higher saltmarsh, e.g. redshank, common terns, skylark, meadow pipit, reed bunting and black-headed gulls.

Productivity

Primary producers include the vascular plants and microalgae and any filamentous algae and macrophytes present. Adam (1993) suggested that algae made an important contribution to net productivity. Saltmarsh is highly productive, although most of the productivity is consumed secondarily. Dead plant material is broken down by bacteria on the surface of the sediment. This increases its food value by degrading cellulose in digestible carbohydrates. The remaining detritus forms the basis of a food chain for a wide variety of organisms and may be a major source of organic carbon for surrounding communities, depending on the hydrographic regime. For example, primary productively for *Spartina*, *Salicornia* and *Limonium* saltmarsh in the UK was estimated to be 400 g C /m^2/ year (Mann, 1982 cited in Raffaelli & Hawkins, 1999).

Recruitment processes

Puccinellia maritima is perennial and dioecious, flowering towards the end of July / August. Flowers are wind pollinated and seedlings large enough to survive have been reported in the field by autumn. Seeds germinate on moist surfaces within 14 days of being shed, with maximum germination occurring at 10 °C although germination will occur slowly at lower temperatures (e.g. <2 °C) (Gray & Scott, 1977). Most seed fall within a few centimetres of the parent plant but they are probably dispersed by the tides. Seedling survival depends on successful rooting before the next high spring tide. However, as a pioneer community, it establishes by the rooting of vegetative fragments generated by grazing by wildfowl or livestock and dispersed by the tides.

Plants of the genus *Salicornia*, *Atriplex* and *Suaeda* are annuals, flowers carried in the shoot and have extensive seed banks that persist for more than a year. Plants of these species need 2-3 days without flooding to root effectively. Filamentous algae and cyanobacteria produce enormous numbers of spores, which are carried by the tides and would probably recolonize new habitat within a year.

Recruitment in infaunal sediment dwelling invertebrates may be patchy and sporadic depending on the hydrographic regime and post-settlement mortality (from scour, smothering and predation). However, polychaetes probably recolonize habitats by a mixture of migration (swimming) and passive transport and thought to be rapid in some species, e.g. *Arenicola marina* and *Hediste diversicolor*. Nematodes are ubiquitous are probably colonize by a mixture of larval settlement, and active and passive transport of adults and juveniles. Marine bivalves such as *Macoma baltica*, *Mya arenaria* and *Cerastoderma edule* have sporadic and unpredictable recruitment via settling pelagic larvae or passive bedload transport of juveniles together with significant larval and post-settlement mortality. While a single recruitment event may re-establish the population within a year and longer period (e.g. up to 5 years) has been suggested for recovery (see individual reviews).

Most insects have short life cycles and hibernate over winter as dormant stages such as eggs or pupae. Although, many of the associated insects have the ability to fly, many intertidal species exhibit partial or complete winglessness. However, the later species are capable of dispersal over considerable distances and a wide area by floating on the incoming tide, e.g. the root aphid *Pemphigus trehernei* (Treherne & Foster, 1979). Most insect species are not closely associated with *Puccinellia maritima* communities an would probably recolonize available habitat from the surrounding area. Similarly, mobile species such as shrimp, crabs and shore fish species are not closely associated with the *Puccinellia maritima* communities and would occupy new habitat by migration from other habitats.

Time for community to reach maturity

Gray & Scott (1969) reported that *Puccinellia maritima* established 5 -30% cover in bare areas left by turf cutting within 1-2 years. Packham & Willis (1997) reported that *Puccinellia maritima* formed radially spreading hummocks (clonal growth) and that in the newly expanding Cefni Marsh, Anglesey, roughly circular patches of 120-150cm in diameter formed in the newly developed *Puccinellia* community with 3 -4 years.

Beeftink (1979) reviewed the effects of disturbance on *Haliminone portulacoides* saltmarsh communities in the Netherlands. After die back of the *Haliminone portulacoides* communities a successional recolonization occurred, beginning with *Suaeda maritima* (and sometimes *Salicornia* sp.) followed by *Aster tripolium*, then *Puccinellia maritima* until *Haliminone portulacoides* returned. The time take for recovery depended on the initial level of disturbance to the *Haliminone portulacoides* community, taking less time after minimal disturbance, e.g. *Puccinellia maritima* showed the greatest abundance after 4 years after water-logging, 6-10 year chemical destruction by herbicides), 5-7 years after changes in tidal regime.

Rodwell (2000) noted that *Puccinellia maritima* colonizes ruts left by cars or livestock. *Glaux maritima* and *Limonium vulgare* sub-communities representing further stages in succession form *Puccinellia maritima* and would probably take longer to establish.
Recolonization of the lower marsh communities by marine infauna would probably be rapid (ca <5 years). The insect fauna would probably recolonize recovered plant communities in the mid to high marsh rapidly but avoid pioneer communities until they had built up sufficient height, which could itself take many years.

Additional information

None entered.

Preferences & Distribution

Habitat preferences

Depth Range	
Water clarity preferences	
Limiting Nutrients	Nitrogen (nitrates), Phosphorus (phosphates)
Salinity preferences	
Physiographic preferences	
Biological zone preferences	
Substratum/habitat preferences	
Tidal strength preferences	
Wave exposure preferences	
Other preferences	Waterlogged, saline soil.

Additional Information

Habitat preferences
Nitrogen was reported to be limiting in many salt marsh ecosystems and added nitrogen resulted in increased primary production, decomposition and animal growth rates (Valiela & Teal, 1974; Long & Mason, 1983). Vascular plants communities are exposed to greater fluctuations in day and night temperatures than their marine counterparts, and are probably tolerant. In addition, flood tides result in temperatures shocks, e.g. in winter the frozen marsh surface may be exposed to tidal waters 10 °C warmer. Although temperature shock probably has physiological effects, they have not been studied (Adam, 1993).

Species composition

Species found especially in this biotope

- *Armeria maritima*
- *Aster tripolium*
- *Glaux maritima*
- *Limonium vulgare*
- *Plantago maritima*
- *Puccinellia maritima*
- *Salicornia spp.*

Rare or scarce species associated with this biotope

- *Salicornia pusilla*
- *Spartina maritima*
- *Suaeda vera*

Additional information

Puccinellia maritima dominated communities are generally regarded as species poor habitats (Rodwell, 2000). However, this statement generally refers to the vascular plant communities alone. The dynamic and heterogeneous salt marsh habits and their plant communities support a diverse array of marine and terrestrial invertebrates, microalgae, cyanobacteria, fungi, fish, birds and in some cases mammals (including livestock). For examples of species found in saltmarsh habitats refer to reviews by Long & Mason (1983), Adam (1993) and Packham & Willis (1997) and the references therein. Floristic table for *Puccinellia maritima* sub-communities are given by Rodwell (2000)
Saltmarsh habitats support a number of rare or scarce plant species, together with some UK BAP species e.g. the ground beetles *Arnara strenua* and *Anisodactylus poeciloides*. This biotope may contain the British Red Data Book species, *Limonium bellidifolium* (Wigginton, 1999).

Sensitivity review

Explanation

Puccinellia maritima is the dominant halophyte in this biotope, however it may only represent <10% of the sward in the *Limonium vulgare-Aremaria maritima* sub-communities. It is, therefore, regarded as a constant, important characterizing species for the purpose of assessment. Most other invertebrate species (marine or terrestrial) are not directly associated with the community and could probably survive in its absence within another plant community. Grazers and plant feeding insects probably affect reproductive output of plants and primary productivity. Similarly, grazers (including birds) and detritivores are important for nutrient cycling within the biotope. However, many species are involved and vary with shore height and salinity so that it is difficult to identify any particular species for sensitivity assessment. Therefore, a general assessment has been undertaken.

Species indicative of sensitivity

Community Importance	Species name	Common Name
Important characterizing	*Armeria maritima*	Thrift
Important characterizing	*Glaux maritima*	Sea milkwort
Important characterizing	*Limonium vulgare*	Common sea lavender
Important characterizing	*Plantago maritima*	Sea plantain
Key structural	*Puccinellia maritima*	Common saltmarsh grass
Important characterizing	*Salicornia agg.*	Glasswort s

Physical Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Substratum Loss	High	Moderate	Moderate	Major decline	High

Removal of the substratum (by e.g. erosion, tuft cutting, or via borrow pits) will remove the vascular plants, algal mats, infauna and their associated community. Therefore, an intolerance of high has been recorded.
Recovery will depend on recruitment of the plant communities and their invertebrate fauna and a recoverability of moderate has been recorded (see additional information below).

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Smothering	Low	Very high	Very Low	Minor decline	Moderate

Saltmarsh is a sedimentary habitat dependant on accretion and erosion of sediment. Therefore, most communities and associated species are probably adapted to levels of sedimentation and occasional smothering. For example, *Puccinellia maritima* can tolerate accretion rates of 5cm /year (Packham & Willis, 1997). Swards of tall *Puccinellia maritima* can be up to 80cm in height and are unlikely to be adversely affected by smothering at the benchmark level. However, in areas influenced by grazing, *Puccinellia maritima* may form prostrate growth, as little as 1cm high, which would be liable to smothering. However, Gray & Scott (1977) suggested that *Puccinellia maritima* was extremely tolerant of burial by wind or water borne sediment. Algal mats may not survive smothering for a month. Burrowing infaunal species such as *Hediste diversicolor*, *Arenicola marina*, oligochaetes, nematodes and possible burrowing beetles will probably be little affected by smothering a the benchmark level. However, suspension feeding *Cerastoderma edule* and *Mya arenaria* may be adversely affected. The *Puccinellia* sward will probably survive, while some members of the community

may be lost. Therefore an intolerance of low has been recorded with a reduction in species richness
The vascular plant sward and most of the community will probably recover in less than 6 months, although some bivalve species may take longer to return (see additional information).

Increase in suspended sediment	Intermediate	High	Low	Minor decline	Moderate

Saltmarsh habitats are dependant on a balance of accretion and erosion. For example, Ranwell (1964) reported a regular summer accretion and winter erosion pattern in the Bristol Channel, a pattern typical of most salt marshes (Holt *et al.*, 1995). Under suitable conditions the saltmarsh may accrete, gain in height and increase in seaward extent (prograde) (Packham & Willis, 1997). Increased sedimentation may, therefore, benefit pioneer or low marsh communities (e.g. *Puccinellia* communities) by providing additional sediment to colonize. However, gains in the lower marsh will be compensated by loss of extent, due to competition with more terrestrial species, in the higher marsh (e.g. *Festuca rubra*). Packham & Willis (1997) reported that *Puccinellia maritima* could tolerate accretion rates of 5cm /year, while Gray & Scott (1977) reported accretion rates of 10cm /yr. in the *Puccinellia maritima* zone. Sedimentation rates, and hence accretion rates vary between sites e.g. 8mm /year at Scolt Head, east England and 78mm /year in the Dovey estuary, Wales, and are determined by the hydrographic regime, and sediment supply from eroding cliff or riverine sources. Most of the marine species associated with the biotope are probably relatively tolerant of increased sedimentation, except *Mya arenaria*, which is more intolerant. Therefore, an increase in sedimentation rate is likely to change the extent and distribution of *Puccinellia maritima* communities (depending on the local hydrographic regime) and an intolerance of intermediate has been recorded. A recoverability of high has been recorded (see additional information below).

Decrease in suspended sediment	High	Moderate		No change	Moderate

Saltmarsh habitats are dependant on a balance of accretion and erosion. For example, Ranwell (1964) reported a regular summer accretion and winter erosion pattern in the Bristol Channel, a pattern typical of most salt marshes (Holt *et al.*, 1995). Decreases in sedimentation may result in net erosion of the saltmarsh and a decrease in deposition of organic particulates affecting productivity, especially secondary. Holt *et al.* (1995) suggested that saltmarsh should be regarded as highly intolerant of changes in sedimentation. Any activity that affects the sedimentary regime is likely to have a marked effect on net erosion and the long term stability of the saltmarsh, especially the lower marsh. Therefore an intolerance of high has been recorded.

Dessication	Intermediate	High	Low	Minor decline	Low

Gray & Scott (1977a) reported that the aerial leaves of *Puccinellia maritima* died back after exposure to prolonged summer drought but rapidly regrew from leaf bases. Gray & Scott (1977a) also suggested that autumn and spring drought were critical for the survival of seedlings, extensive drought being detrimental. *Puccinellia maritima* is restricted to waterlogged soils by competition with more terrestrial species such as *Festuca rubra*. However, an increase in desiccation equivalent to an increase in one vertical biological zone on the shore (the benchmark) is likely to increase competition and effectively result in a regression of succession and loss of the upper portion of the *Puccinellia maritima* sward. Therefore, an intolerance of intermediate has been recorded. A recoverability of high has been recorded (see additional information below).

Increase in emergence regime	Intermediate	High	Low	Minor decline	Moderate

The degree and periodicity of inundation by tides controls the amount of water in the sediments, the sediment chemistry, and salinity fluctuations. Therefore, the tidal regime controls the zonation and succession of vascular plant communities and the marine or terrestrial species associated with them. Treherne & Foster (1979) suggested that tidal regime was of overwhelming importance to the insect fauna of saltmarsh communities.

Puccinellia maritima communities occur primarily in saline influenced, waterlogged substrata routinely inundated by the sea. *Puccinellia* communities may experience between 150 -225 submergences per year on Scolt Head, Norfolk salt marshes and over 350 submergences /year at their lower limit in Morecambe Bay (Gray & Scott, 1977b; Rodwell, 2000). Beeftink (1979) reported that the Volkerak barrage (built in 1969) stopped tidal influence in some areas of saltmarsh resulting in desiccation, desalination (due to rainfall and lowered water table), increased aeration of sediments, increase mineralization of nutrient and loss of the original halophyte community within 1 -7 years and *Puccinellia* communities within 3 years. The halophytes being replaced by glycophytic communities.

At the benchmark level, the *Puccinellia* communities are likely to suffer increased desiccation and reduced salinity, resulting in their replacement by high marsh communities such as *Festuca rubra* and *Agrostis stolonifera* communities. The insect fauna will probably benefit whereas the marine fauna will restricted to the lower levels of the marsh. However, a reduction in tidal regime will probably allow the *Puccinellia* communities to colonize adjacent mudflat, allowing recovery within about five years (see Cefni marsh example in Packham & Willis, 1997). Therefore, the extent of *Puccinellia maritima* communities will probably be reduced temporarily and an intolerance of intermediate has been recorded with a recoverability of high.

Decrease in emergence regime	Intermediate	High	Low	Minor decline	Moderate

The degree and periodicity of inundation by tides controls the amount of water in the sediments, the sediment chemistry, and salinity fluctuations. Therefore, the tidal regime controls the zonation and succession of vascular plant communities and the marine or terrestrial species associated with them (see above)
Beeftink (1979) reported that increases in tidal height (decreased emergence) resulted in changes in the plant communities, equivalent to regression succession towards lower marsh communities. *Puccinellia* dominated communities were able to tolerate an increase in tidal height of about 10cm, whereas *Puccinellia - Armeria* communities only tolerated about a 3-5 cm increase. Increases >30cm resulted in replacement of the *Puccinellia* community with *Salicornia* dominated communities in the Netherlands Scheldt. Plant communities stabilized within about 2-4 years. Similarly, Dijkema *et al.* (1990) concluded that accretion in salt marsh may kept up with the predicted sea level rise due to climate change in the Wadden Sea but that pioneer communities were more intolerant due to the increased erosion.

The marine fauna, infauna, gastropods and intertidal fish would probably benefit from an decrease in the emergence regime, whereas the insect fauna would probably retreat further up the shore. High saltmarsh communities will probably retreat further inland where possible but if prevented by sea defences these communities will be lost. Overall, the *Puccinellia* communities may experience a temporary reduction in extent and species richness while they adapt to the new regime, at the benchmark level. Therefore, an intolerance of intermediate has been recorded. Once the tidal regime returned to prior level community will recover rapidly, probably within five years.

Increase in water flow rate	High	Moderate	Moderate	Decline	Low

Salt marshes develop in sheltered environments where sediments accumulate. Increased water flow rate will change the accretion and erosion rates in the saltmarsh, especially at low water exposed to immersion for longer periods. Increases in water flow rate may erode areas at the face of the raised salt marsh, resulting in a 'cliff' and may undermine the edges of creeks. Most of the invertebrate marine infauna may be adversely affected by increased water flow due to loss or changes in the sediment. Therefore, increases in water flow at the benchmark level are likely to remove lower marsh communities such as *Puccinellia* dominated communities, their substratum and associated species and an intolerance of high has been recorded. Recovery will depend on recruitment of the plant communities and their invertebrate fauna and a recoverability of moderate has been recorded (see additional information below).

Decrease in water flow rate	Tolerant		Not sensitive*	No change	Moderate

Salt marshes develop in sheltered environments and any further decrease in water flow is likely to increase sedimentation rates, especially in the lower marsh, but otherwise have minor effects. Decreased water flow may reduce the distribution and hence recruitment of saltmarsh species, e.g. of plants by seed and vegetative fragments and by insects due to rafting.

Increase in temperature	Low	Very high	Very Low	Minor decline	Low

Vascular plants communities are exposed to greater fluctuations in day and night temperatures than their marine counterparts, and are probably tolerant. In addition, flood tides result in temperatures shocks, e.g. in winter the frozen marsh surface may be exposed to tidal waters 10 °C warmer. Although temperature shock probably has physiological effects, they have not been studied (Adam, 1993). *Puccinellia maritima* was thought to be limited to habitats below 70 deg N, Norway in the eastern Atlantic (62 deg N in southern Greenland, western Atlantic) by temperature and day-length and rarely flowers in the northern limits of its range (Gray & Scott, 1977a). However, *Puccinellia maritima* extends south to Spain and is, therefore, probably tolerant of summer temperatures in Britain and Ireland.
Increased temperatures may affect reproduction in the polychaetes *Hediste diversicolor* and *Arenicola marina*, whereas *Hydrobia ulvae* can survive exposure to the air for several days. However, the marine infauna of the lower marsh are probably at the upper limit of their range and their abundance may decrease, or they may be lost as a result of an increase in temperature. Therefore, although the vascular plant communities are relatively tolerant of temperature increases and temperature shock and of low intolerance, several marine species may be lost, reducing species richness.

Decrease in temperature	Low	Very high	Moderate	Minor decline	Low

Vascular plants communities are exposed to greater fluctuations in day and night temperatures than their marine counterparts, and are probably tolerant. In addition, flood tides result in temperatures shocks, e.g. in winter the frozen marsh surface may be exposed to tidal waters 10 °C warmer. Although temperature shock probably has physiological effects, they have not been studied (Adam, 1993).
Puccinellia maritima extends to 70 deg N and is probably tolerant of winter temperatures in the UK. Gray & Scott (1977a) reported that established *Puccinellia maritima* plants were rarely, if ever, killed by even exceptional frosts in Britain. However, several marine infaunal species are known to be susceptible to severe winters, e.g. *Cerastoderma edule*, *Mya arenaria*, *Arenicola*

marina and *Gobius* spp. Decrease in temperature at the benchmark level are likely to reduce their extent or abundance. Terrestrial fauna may be less intolerant of temperature extremes or over-winter as dormant stages. Overall, the *Puccinellia* dominated communities are likely to survive although their species richness may be slightly decreased.

Increase in turbidity	Not relevant	Not relevant	Not relevant	Not relevant	High

The vascular plants photosynthesise at low tide and are probably not completely covered at high tides, so that the turbidity of the water is probably not relevant. Macroalgal mats and microphytobenthos are probably covered by some tides, and photosynthesis reduced, but will probably compensate when exposed to air and low tides.

Decrease in turbidity			Not sensitive*	Not relevant	High

The vascular plants photosynthesise at low tide and are probably not completely covered at high tides, so that the turbidity of the water is probably not relevant. Macroalgal mats and microphytobenthos are probably covered by some tides, and photosynthesis reduced, but will probably compensate when exposed to air and low tides.

Increase in wave exposure	Intermediate	High	Low	Minor decline	Low

Change in wave exposure and hence the hydrographic regime will change the accretion and erosion rates in the salt marsh, especially on the low marsh exposed to immersion for longer periods. Increases in wave action may erode areas at the face of the raised salt marsh, resulting in a 'cliff' and may undermine the edges of creeks. Low marsh pioneer communities are likely to be the most intolerant. Holt *et al.* (1997) suggested that saltmarsh were relatively tolerant of wave action, presumably since their low profile attenuates the wave energy and the sediment is bound by plant material. However, an increase in wave exposure above 'sheltered' will probably result in net erosion and loss of pioneer communities, including *Puccinellia maritima*, and their associated fauna. Therefore, an intolerance of intermediate has been recorded. A recoverability of high has been recorded (see additional information below).

Decrease in wave exposure	Tolerant		Not sensitive*	No change	Moderate

Saltmarsh habitats occur in areas of net accretion, sheltered from wave action. A further decrease in wave action is unlikely to has a significant effect.

Noise	Intermediate	Very high	Low	Minor decline	High

Wildfowl and seabirds are important grazers within this biotope. Disturbance by noise and visual presence of human activities to birds population will be considered together. Disturbance is species dependant, some species habituating to noise and visual disturbance while other become more nervous. For example, brent geese, redshank, bar-tailed godwit and curlew are more 'nervous' than oyster catcher, turnstone and dunlin. Turnstones will often tolerate one person within 5-10m. However, one person on a tidal flat can cause birds to stop feeding or fly off affecting c. 5 ha for gulls, c.13ha for dunlin, and up to 50 ha for curlew (Smit & Visser, 1993). Goss-Custard & Verboven (1993) report that 20 evenly spaced people could prevent curlew feeding over 1000 ha of estuary. Industrial and urban development may exclude shy species from adjacent tidal flats. Disturbance causes birds to fly away, increasing energy demand and feeding on the flats later or cause them to move to alternative sites. Least human disturbance is likely in winter, however during breeding period for some species and moulting periods of northerly breeding species in late summer and early autumn most recreational activity takes place. Removal of predators may allow some species to dominate, enable recruitment of others and affect the community structure. However, visual or noise disturbance is unlikely to affect epibenthic or infaunal species, therefore although wildfowl may be regarded as highly intolerant, and overall assessment of intermediate is given. Recovery of birds population may be immediate for some species, while shy species may find more isolated sites.

Visual Presence	Intermediate	Very high	Low	Minor decline	High

Wildfowl and birds are important grazers within this biotope. Disturbance by noise and visual presence of human activities to birds population have been considered together (see above).

Abrasion & physical disturbance	Intermediate	High	Low	Minor decline	Low

Abrasion in saltmarsh biotopes is most likely to result from trampling and vehicle use. In coastal plant communities trampling may favour plants with high growth rates, basal meristems, and low growth forms. Low levels of trampling encourage growth and species richness but these fall as trampling increases (Packham & Willis 1997). *Puccinellia maritima* was reported to colonize slumps sides of creeks, ruts lefts by vehicles or animals, areas of turf cutting, ditches and even reclaimed land (Gray & Scott, 1967, 1977a; Rodwell, 2000). Most of the marine infaunal species are likely to be adversely affected by abrasion that penetrates the sediment, and a proportion of the population will probably be lost. Mobile species such as fish are unlikely to be directly affected. Burrowing insects may also be adversely affected, and sucking insects such as aphids may be displaced or crushed. However, aphids in particular reproduce rapidly (most species are parthenogenic) and will recover quickly. Insects capable of flight will avoid the impact, while small birds are likely to benefit from the flushing of insects from the saltmarsh sward. Overall, an intolerance of intermediate has been recorded. However, it should be noted that, disturbance by grazing birds releases vegetative fragments of the plant, which are important for dispersal and the establishment of pioneer communities while *Puccinellia maritima* plants may be damaged by physical disturbance, disturbance may allow the *Puccinellia* communities to colonize the high marsh and result in a more heterogeneous and diverse saltmarsh. Therefore, *Puccinellia* communities and their associated species are likely to recover within about 5 year or less (see additional information).

Displacement	High	Moderate	Moderate	Decline	Low

Removal of the vascular plants from their substratum will probably result in their break-up and loss. However, vegetative fragments of *Puccinellia maritima* are capable of colonizing available habitat and will probably regrow from plant fragments left in the soil. Most infaunal species can burrow back into sediment, but may suffer significant predation as a result of being removed from the sediment. *Hydrobia ulvae* can survive on a wide variety of substrata and exhibits mucus rafting and is unlikely to be affected. Mobile fish and insects will be unaffected, and aphid and most plant feeding species will find other plant species or other *Puccinellia* swards up which to feed, although they may suffer predation as a result of displacement. Overall, an intolerance of high has been recorded to represent the damage to the plant communities. Recovery is likely to take 5-10 years (see additional information below)

Chemical Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Synthetic compound contamination	Intermediate	Moderate	Moderate	Decline	Moderate

Sheltered, low energy areas in enclosed bays or estuaries act as a sink for sediment and detritus. Low dispersion within these areas also acts as a sink for complex mixtures of

pollutants, especially since many become adsorbed onto organic particulates and fine sediments e.g. chlorinated hydrocarbons, DDT (Clark 1997). Therefore the sediments act as a sink for a wide variety of contaminants, many with a long half life in the environment, e.g. PCBs, dieldrins, and pesticides. Some pollutants may bioaccumulate within the food chain, e.g. PCBs and mercury. The sublethal or toxic effects vary with concentration, the bio-availability of the contaminant, and the physiology of the affected organism (Nedwell 1997 cited in Elliot *et al.* 1998). Recovery requires dilution, biodegradation or removal of the contaminant from the sediments. Contaminants with long half lives may remain in sediments for decades, at least, in sheltered areas with little dispersion. Intertidal sediments in Southampton Water and the Tees had reduced benthic communities due to contamination with phenols, oil effluent, sulphides and nitrogen compounds (Elliot *et al.* 1998).
Cole *et al.* (1999) suggested that herbicides (e.g. atrazine) were very toxic to marine macrophytes, which is probably true of most plants. Beeftink (1979) demonstrated that *Puccinellia maritima* was one of the first species to recolonize areas of marsh denuded by herbicide treatment (see additional information below). Tributyl tin has been shown to cause mortality or impair reproduction in marine bivalves such as *Cerastoderma edule*, *Mya arenaria* and *Macoma baltica*. *Arenicola marina* and *Hediste diversicolor* has been found to be intolerant of the pesticide ivermectin, and may be intolerant of pesticides with similar molecular structures. Similarly, *Gobius* spp. are thought to be intolerant of pesticides. It is highly likely that the resident insect fauna will be intolerant of insecticides by design. Therefore, it the absence other evidence, it is likely that the build up of pesticides, TBT or other synthetics in the marsh may adversely affect primary and secondary productivity and may result in loss of a proportion of the plant and animal communities. An intolerance of intermediate has been recorded. Recovery is likely to take about 6-10 years based on the results of Beeftink (1979) (see additional information below).

Heavy metal contamination	Low	Very high	Very Low	Minor decline	Moderate

Sediment particulates, organic or inorganic adsorb heavy metals, so that saltmarsh may act as a sink for heavy metals. Saltmarsh plants take up heavy metals through their roots, and is affected by soil chemistry. Uptake is species specific but in general monocotyledons (such as *Puccinellia maritima*) tend to exclude heavy metals while dicotyledons tend to accumulate. Williams *et al.* 1994 list levels of heavy metals found in *Puccinellia maritima* and other saltmarsh plants. Symptoms of acute toxicity in halophytes have not been reported (Adam, 1993; Packham & Willis, 1997). Williams *et al.* (1994) suggested that the concentrations of heavy metals in most estuaries was not sufficient to cause ill effects to saltmarsh plants. Cole *et al.* (1999) suggested that Pb, Zn, Ni and As were very toxic to algae, while Cd was very toxic to Crustacea (amphipods, isopods, shrimp, mysids and crabs), and Hg, Cd, Pb, Cr, Zn, Cu, Ni, and As were very toxic to fish. Gobies were reported to be particularly intolerant of Hg (see *Pomatoschistus minutus*). Bryan (1984) reported sublethal effects of heavy metals in crustaceans at low (ppb) levels. Bryan (1984) suggested that polychaetes are fairly resistant to heavy metals, based on the species studied. Short term toxicity in polychaetes was highest to Hg, Cu and Ag, declined with Al, Cr, Zn and Pb whereas Cd, Ni, Co and Se were the least toxic. However, he suggested that gastropods (were relatively tolerant of heavy metal pollution. Heavy metals have been shown to bioaccumulate in wading birds (Parslow 1973). Overall, Holt *et al.* (1995) concluded that saltmarsh may be relatively tolerant of heavy metals. Therefore, an intolerance of low has been recorded. However, some marine infaunal species may be lost, or reduced in extent suggesting a loss of species richness.

Hydrocarbon contamination	High	Moderate	Moderate	Major decline	High

Salt marshes are very sensitive to oil spills since they trap sediments, adsorb oils, and occur in sheltered environments where the oils persist (Holt *et al.*, 1997) The effect of spills depends on the type of oil and its extent with lighter oils being the most toxic. Heavy oils tend to cause death by smothering (Baker, 1979). In successive experimental oiling Baker (1979) demonstrated the 5 levels of intolerance to Kuwait crude oil, for example:

- very susceptible, *Salicornia* sp., *Suaeda maritima* and seedling of all species were quickly killed by a single spill;
- intermediate, species that recovered well from up to four spills but rapidly succumbed if further oiled, e.g. *Puccinellia maritima*, *Spartina anglica* and *Festuca rubra*;
- resistant due to underground storage organs e.g. *Armeria maritima*, *Plantago maritima* and *Triglochin maritima*.

Therefore, the *Puccinellia maritima* sub-communities may differ in their response, depending on the frequency of oiling and the sub-communities species composition.
Chronic hydrocarbon pollution may also greatly affect saltmarsh communities, e.g. Dicks & Hartley (1982) reported that large areas of vegetation were lost due to refinery discharges between 1953 and 1970 at Fawley (Holt *et al.*, 1995). Trampling and disturbance caused by clean up operations may increase the levels of damage.
Long term chronic petrochemical effluent also affects the infauna (McLusky, 1982). Studies of intertidal mudflats in the Forth estuary contaminated by petroleum effluent discharge showed that *Hydrobia ulvae*, *Macoma baltica* and *Hediste diversicolor* survived at low abundance in severely polluted areas of low oxygen content, and increased in abundance in polluted areas while oligochaetes and spionids were able to colonize. *Cerastoderma edule*, *Corophium volutator* and *Mya arenaria* were more intolerant being restricted to areas of moderate pollution (McLusky, 1982). No information concerning insect fauna was found, however a proportion of the fauna is likely to be adversely affect or leave the saltmarsh. The intolerance of bird species is well known.
Overall, saltmarsh habitats are considered to by highly sensitive to oil spills (Gundlach & Hayes, 1978; Holt *et al.*, 1995; Packham & Willis, 1997). Therefore, an intolerance of high has been recorded.
Recovery depends on the retention of oil within the saltmarsh, e.g. after the *Amoco Cadiz* spill some areas of saltmarsh still had oily footprints 5 years later (Holt *et al.*, 1995). Similarly Baker (1979) reported that the effects of oiling were still apparent 10 years after oiling. Dicks & Hartley (1982) suggested that saltmarsh could recover in 10 years once chronic pollution had been removed, and Seneca & Broome (1982; cited in Holt *et al.*, 1995) suggested that recovery from the *Amoco Cadiz* spill would have taken 5-10 years without restoration.

Radionuclide contamination		Not relevant		Insufficient information	Not relevant

Insufficient information

Changes in nutrient levels	Tolerant	Not relevant	Not relevant	No change	Very low

Moderate enrichment with nutrients may be beneficial to both plant and infaunal communities. Nitrogen was reported to be limiting in many salt marsh ecosystems and added nitrogen resulted in increased primary production, decomposition and animal growth rates (Valiela & Teal, 1974; Long & Mason, 1983) although Holt *et al.* (1995) suggested care should be taken when applying this conclusion in all salt marshes. Increased nutrient levels has been associated with increased algal mats, which may smother some burrowing specie, such as *Mya arenaria*. (Packham & Willis, 1997). Higher levels of nutrient enrichment may result in a decrease in the oxygen levels of the sediment (see below). Plots of salt marsh treated with sewage sludge in Massachusetts, USA, stimulated growth of *Spartina alterniflora* which eliminated other plants from the area (Long & Mason 1983). However, at the benchmark level, an increase in nutrients is unlikely to have a significant effect on communities.

Increase in salinity	Tolerant*	Not relevant	Not sensitive*	No change	Low

Puccinellia maritima was reported to be highly salt tolerant, communities growing at 12-30 g/l in the Exe estuary, while *Puccinellia maritima* can grow at 0, 10 and 30 g/l, although it is probably exposed to much higher salinities due to evaporation (Gray & Scott, 1977a; Rodwell, 2000). The salinity in salt pans may vary markedly and *Puccinellia maritima* was found to grow around the edge of pans in the high marsh. However, with increasing height the salinity decreases due to percolation or rainwater. Increases in salinity are likely to favour *Puccinellia maritima*, by excluding its competitors (Gray & Scott, 1967, 1977b). Increases in salinity may allow more marine species to colonize further into the marsh, for example salt pans often have marine fauna such as *Carcinus maenas* and *Sphaeroma* sp. Terrestrial fauna may become reduced and restricted to the high marsh, for example the aphid *Macrosiphoniellia asteris* selects stems of *Aster tripolium* with the lowest salt content, and survived on plants grown in 0, 15 and 30% seawater but died quickly on plants grown in 60% seawater. Overall, therefore, the relative composition of marine and terrestrial species is likely to change but the *Puccinellia maritima* communities may be able to expand due to increased salinity.

Decrease in salinity	High	Moderate		No change	Moderate

Puccinellia maritima was reported to be highly salt tolerant, communities growing at 12-30 g/l in the Exe estuary, while *Puccinellia maritima* can grow at 0, 10 and 30 g/l (Gray & Scott, 1977a; Rodwell, 2000). However, in areas of low sodium content (reduced salinity) such as the high marsh, or areas affected by freshwater runoff, *Puccinellia maritima* is replaced by high marsh species such as *Festuca rubra* (Gray & Scott, 1967, 1977b). Therefore, the *Puccinellia* communities will probably be lost in areas subject to reduced salinity and an intolerance of high has been recorded. The marine fauna will also probably reduce in extent while the terrestrial fauna will probably expand.

Changes in oxygenation	Low	Very high	Very Low	Minor decline	Low

Oxygen levels in the soils in *Puccinellia* communities vary markedly with neap or spring tides (Packham & Willis, 1997). Free sulphide was not recorded in soil occupied by *Aster tripolium*, *Puccinellia maritima*, *Spartina anglica* and *Suaeda maritima* and growth of *Puccinellia maritima* was significantly inhibited by sulphide while *Salicornia europaea* was not (Packham & Willis, 1997). However, the waterlogged soils of salt marshes, favoured by *Puccinellia maritima* are generally anoxic. Vascular plants may not be intolerant of deoxygenation since photosynthesis liberates oxygen, they are uncovered for the majority of the tidal cycle, and in some species, e.g. *Spartina alterniflora* air spaces in the leaf sheaths aid gas transport to the roots. Most infaunal polychaetes and oligochaetes are probably tolerant of low oxygen conditions, while some species of oligochaete and nematode may be dependant on the locally oxygenated areas around the roots of vascular plants. *Hydrobia ulvae* can tolerate emersion for several days and many insects live on stems and leaves of vascular plants and avoid anoxic conditions, e.g. aphids. However, *Cerastoderma edule* is probably intolerant to anoxic conditions and would be lost from the lower marsh. Overall, the vascular plants are probably tolerant of anoxic soils and are exposed to the air at low tide, so that the *Puccinellia* communities would probably be little affected by increases in hypoxia at the benchmark level, whereas a few fauna may be lost. Therefore an intolerance of low has been recorded. Recovery will probably be rapid (see additional information below).

Biological Pressures

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Introduction of microbial pathogens/parasites	Low	Very high	Very Low	No change	Low

Puccinellia maritima may develop saprophytic fungi or 'rust' fungus on its leaves and 'choke' disease may prevent flowering. Nematodes are know to infect *Puccinellia maritima*, e.g. *Ditylenchus radicicola* while *Anguina* spp. and *Anguillulina argostis* occur in inflorescences (Gray & Scott, 1977a). A number of aphid species also feed of *Puccinellia maritima*, although not exclusively (Gray & Scott, 1977a). Most of the above diseases and parasites probably impair production and flowering but no mass mortalities were reported, therefore an intolerance of low has been recorded.

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Introduction of non-native species	Intermediate	High	Low	Decline	Low

Introduction of North American cord grass *Spartina alterniflora* to stabilise and reclaim high intertidal mudflats has significantly altered UK saltmarsh. *Spartina alterniflora* hybridised with native *Spartina maritima* producing an infertile hybrid (*Spartina townsendii*) which gave rise to fertile *Spartina anglica*. *Spartina anglica.* is fast growing and aggressive and has colonized extensive areas of intertidal mudflats, increasing the area of saltmarsh in the UK but reducing intertidal feeding grounds for shorebirds. The success of *Spartina anglica* may dominate the community to the detriment of other species reducing species richness (Eno *et al.* 2000).

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Extraction of this species	Tolerant*	Not relevant	Not sensitive*	Rise	Moderate

Saltmarsh is subject to grazing by wildfowl, rabbits and livestock in the Britain and Ireland (see ecological relationships). Grazing is important in maintenance of *Puccinellia* communities although the response of species varies between sites (Rodwell, 2000). Grazing by livestock causes trampling and introduces nutrients (faeces). Grazing varies with species, livestock probably removing only the leaves while some species of wildfowl also remove or disturb the roots. Grazing affects the species composition of the sward *Salicornia europaea*, *Puccinellia maritima* and *Armeria maritima* are favoured by grazing while *Spartina anglica* and *Limonium vulgare* are harmed by intensive grazing. (Long & Mason 1983). Grazing favours prostrate growth of *Puccinellia maritima* over tall plants, increases species richness, and controls the balance between *Puccinellia maritima* and *Festuca rubra*, which is less tolerant of grazing. Grazing, therefore, also slows floral succession (Packham & Willis, 1997; Rodwell, 2000). Removal of 50% of the biomass (the benchmark level) would result in an intolerance of intermediate being returned, but the extent and longevity of *Puccinellia* communities benefits form low to moderate grazing, so that a rank of not sensitive* is more appropriate. However, over intensive or inappropriate grazing may result in loss of the vascular plant communities, disturbance and erosion of the marsh,

	Intolerance	Recoverability	Sensitivity	Richness	Confidence
Extraction of other species	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant

Additional information

Recoverability

Rates of recovery and recolonization depend on the level of damage or disturbance, and will probably be protracted where the sediment has been disturbed (Beeftink, 1979). *Puccinellia maritima* acts as a pioneer species and therefore may be expected to colonize relatively quickly as seed but primarily as vegetative fragments, depending on the local hydrographic regime.

Subsequent development of an extensive *Puccinellia maritima* dominated sward may take several years. For example, Gray & Scott (1977a) noted that where the aerial growth died back due to drought, isolated individuals recovered rapidly, regrowing leaves from the base of the plant. Gray & Scott (1969) reported that *Puccinellia maritima* established 5 -30% cover in bare areas left by turf cutting within 1-2 years. Packham & Willis (1997) reported that *Puccinellia maritima* formed radially spreading hummocks (clonal growth) and that in the newly expanding Cefni Marsh, Anglesey, roughly circular patches of 120-150cm in diameter formed in the newly developed *Puccinellia* community with 3 -4 years. After die back of *Haliminone portulacoides* communities in the Netherlands a successional recolonization occurred, beginning with *Suaeda maritima* (and sometimes *Salicornia* sp.) followed by *Aster tripolium* , then *Puccinellia maritima* until *Haliminone portulacoides* returned (Beeftink, 1979). The time taken for recovery depended on the initial level of disturbance to the *Haliminone portulacoides* community, taking less time after minimal disturbance, e.g. *Puccinellia maritima* showed the greatest abundance after 4 years after waterlogging, 6-10 year after chemical destruction by herbicides, 5-7 years after changes in tidal regime (Beeftink, 1979). Rodwell (2000) noted that *Puccinellia maritima* colonizes ruts left by cars or livestock. *Glaux maritima* and *Limonium vulgare* sub-communities representing further stages in succession from *Puccinellia maritima* and would probably take longer to establish. Other pioneer species such as *Salicornia* sp. and *Aster tripolium* are likely to recover quickly.

Most mobile species and invertebrates would probably recognize newly established *Puccinellia* communities relatively rapidly from adjacent sites. Recruitment in infaunal sediment dwelling invertebrates may be patchy and sporadic depending on the hydrographic regime and post-settlement mortality (from scour, smothering and predation). However, polychaetes probably recolonize habitats by a mixture of migration (swimming) and passive transport and thought to be rapid in some species, e.g. *Arenicola marina* and *Hediste diversicolor*. Nematodes are ubiquitous are probably colonize by a mixture of larval settlement, and active and passive transport of adults and juveniles. Marine bivalves such as *Macoma baltica*, *Mya arenaria* and *Cerastoderma edule* have sporadic and unpredictable recruitment via settling pelagic larvae or passive bedload transport of juveniles together with significant larval and postsettlement motility. While a single recruitment event may re-establish the population within a year and longer period (e.g. up to 5 years) has been suggested for recovery (see individual reviews).

Overall, therefore, where disturbance is slight, or only the aerial parts of the plant are damaged, recovery is likely to be rapid due to regrowth (immediate in the summer months, longer in winter) but overall probably taking less than 6 months, including recolonization by most invertebrates and algae. However, where the sediment has been disturbed and plants lost, recovery of plant communities together with infauna may take between 4 -10years.

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