

## The establishment of the invasive alga *Sargassum muticum* on the west coast of Scotland: Rapid northwards spread and identification of potential new areas for colonisation

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### Abstract

The invasive alga *Sargassum muticum* has recently been reported in the Firth of Lorn, west coast of Scotland. This represents the first sighting of the species north of the Kintyre Peninsula, a land barrier that had been expected to slow the northwards spread of *S. muticum*. This paper presents a thorough review of literature concerning the dispersal and establishment of this invasive alga and predicts potential dispersal trajectories and likely areas for future establishment in Scotland. From previous dispersal rates, *S. muticum* is likely to spread throughout the west coast of Scotland in the next few years, predominantly via natural pathways although anthropogenic vectors may also contribute to dispersal. Sheltered and moderately exposed sea lochs and shorelines, on the west coast of Scotland in particular, are likely to provide favourable conditions for the establishment of persistent populations of *S. muticum*. Conditions on the north and east coasts of Scotland were considered less favourable, both for the dispersal and establishment of *S. muticum*. The spread of *S. muticum* is unlikely to cause serious widespread ecological impacts, however, it does have the potential to cause economic damage to the aquaculture industry which is a major employer on the west coast of Scotland. The establishment of dense highly visible canopies would also constitute a degradation of the natural heritage value of Scottish shorelines. It would be prudent to investigate means of preventing persistent populations from establishing in areas of economic importance or with high natural heritage value.

**Key words:** dispersal, marine invasive species, marine non-native species, Scotland, *Sargassum muticum*

### Introduction

*Sargassum muticum* (Yendo) Fensholt is well known as a successful invasive species (Critchley et al. 1990). It is native to the waters around Japan and the North West Pacific where it is a relatively minor and ecologically insignificant component of the algal flora (Norton 1977b, Critchley 1983c). In the 1940s, it appeared in British Columbia on the Pacific coast of North America probably as a consequence of the importation of cultivated Pacific Oysters from Japan (Scagel 1956). *S. muticum* has subsequently spread along the Pacific coast, extending from southern Alaska to Mexico

(Aguilar-Rosas and Galindo 1990, Boaden 1995). It is thought to have first arrived in Europe in the late 1960s (Critchley et al. 1983) and now occurs in locations ranging from the Mediterranean to Scandinavia (Boaden 1995, Wernberg et al. 2000).

*S. muticum* was first recorded in UK waters attached to boulders in Bembridge, east coast of the Isle of Wight in 1973 (Farnham et al. 1973, Jones and Farnham 1973, Fletcher and Fletcher 1975a, b) (Figure 1) and it subsequently extended its range along the entire south coast of England (Critchley et al. 1983). Over recent years, a northward expansion of its range has been recorded along the western coasts of the

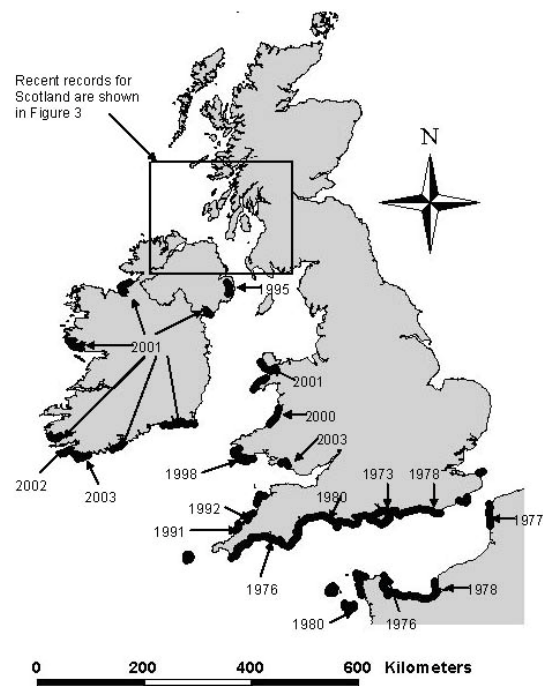
UK, with *S. muticum* recorded on the north coast of Cornwall in 1991 (Eno et al. 1997, Davison and Hughes 1998), Pembrokeshire in 1998 (Davison 1999) and north to Anglesey by 2001 (ICES 2006). *S. muticum* was first recorded in Strangford Lough, Northern Ireland in 1995 (Boaden 1995) and in Cashel Bay, Co Galway, Republic of Ireland in 2001 (Loughnane and Stengel 2002). It is now known to occur at several other locations on the south and west coasts of Ireland (Loughnane and Stengel 2002, Kraan 2004, Simkanin 2004, ICES 2006) (Figure 2).

*S. muticum* was first recorded in Scotland in Loch Ryan, Wigtownshire in 2004 (Reynolds 2004, Pizzola 2005) (Figure 3). Other established populations have been recorded subsequently on the east coast of the Isle of Cumbrae (Harries et al. 2007) and the adjacent mainland shore at Hunterston Power Station (P. Barnett pers. comm.) since 2005 and Whiting Bay, east coast of the Isle of Arran (Underdown 2007, H. Wood pers. comm.) and Davaar Bay, near Campbeltown Loch, south-east Mull of Kintyre (R. Harvey pers. comm.) since August 2007 (Figure 4). The original point (or points) and time of introduction, however, are uncertain. The nearest known source populations are those in Strangford Lough in Northern Ireland and those in Pembrokeshire in South West Wales. It is not possible to establish how *S. muticum* was introduced with any certainty.

Unattached fronds of *S. muticum* have also been sighted in the Clyde Marina, Ardrossan in 2006 and 2007 (Ashton et al. 2006, E. Cook pers. obs.), Loch Fyne (O. Paisley pers. comm.) and for the first time, over 100 km north of the southern end of the Mull of Kintyre, in the Firth of Lorn at the Garvellachs in May 2007 (D. Donnan pers. obs.) and Ganavan Bay (near Oban) in July 2007 (T. Pröschold pers. comm.). The latter sightings reflect the potential for a significant expansion northwards of this species, as it was thought that the Kintyre Peninsula would provide a temporary physical barrier to the continued spread of this invasive species along the west coast of Scotland. It has been suggested that newly introduced populations of *S. muticum* require several years to build up sufficient breeding stock to allow for rapid expansion (Critchley et al. 1983). However, the rapid spread northwards of this species in the UK since the early 1990s suggests that a continued expansion of *S. muticum* distribution in western Scotland is likely to occur over the next few years.



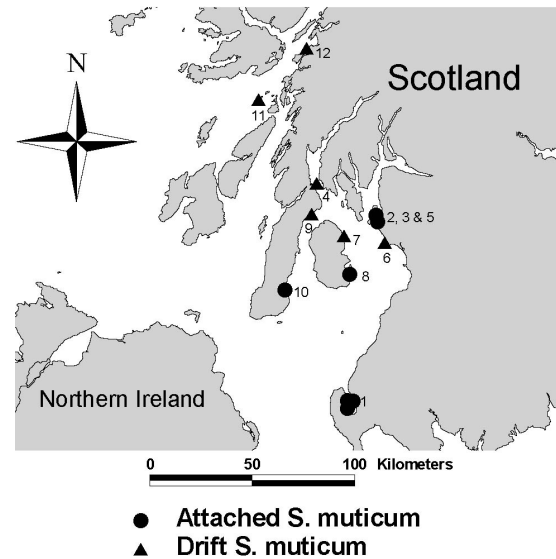
**Figure 1.** *Sargassum muticum* (approximately 2 m in length) found in Bembridge, Isle of Wight in 1973 (H. Powell)



**Figure 2.** Indicative map of *Sargassum muticum* distribution with year of 1st record for selected regions (sources include: Critchley et al. 1983, Eno et al. 1997, ICES 2006, Kraan 2004, Pizzola 2005)

Although *S. muticum* may not cause widespread ecological impacts (Harries et al. 2007), it has the potential to cause significant economic damage, particularly to the aquaculture industry. In the UK, the west coast of Scotland accounts for a large proportion of the aquaculture production, concentrating on the farming of Atlantic salmon *Salmo salar* (Linnaeus 1758) with 278 active sites (FRS 2006), the blue mussel *Mytilus edulis* (Linnaeus 1758) and the Pacific Oyster *Crassostrea gigas* (Thunberg 1793) with 90 active sites (FRS 2007). *S. muticum* is known to grow densely on floating structures (Fletcher and Fletcher 1975a) and if dense growths of this large, fast growing alga develop on salmon cages and mussel ropes the increased level of fouling could cause significant economic damage. It has caused similar problems to commercially farmed oysters (Critchley et al. 1986). An additional point of concern is the degradation of the natural heritage value of Scottish shorelines as a consequence of the establishment of highly visible dense canopies of *S. muticum*. The concern applies particularly to the suite of nationally and internationally important marine protected areas that have been established around the Scottish coast. It is important, therefore, that predictions are made based on dispersal mechanisms, environmental tolerances and habitat preferences to determine which regions within Scottish waters are at greatest risk to the negative impacts of *S. muticum*. This may allow time for the development of effective management strategies for controlling the spread and establishment of *S. muticum* in environmentally or economically sensitive areas.

However, previous attempts at controlling or eradicating *S. muticum* have proved fruitless and have sometimes been counter-productive (Critchley et al. 1986, Davison 1999). Manual or mechanical removal of plants failed to remove all the holdfasts and small plants allowing regrowth to occur (Fletcher and Fletcher 1975b). Regrowth was often more dense and vigorous than the previous population because removal of the algal canopy created patches of bare substrate that were favourable to *S. muticum*. It has also been suggested that such attempts could facilitate dispersal by the creation of large numbers of drift fragments (Fletcher and Fletcher 1975a). The potential for control by biocides has been investigated and discounted due to environmental concerns (Davison 1999). There is no species-specific effective biocide available and dilution effects would require very



**Figure 3.** Map of distribution of recent records of *Sargassum muticum* on the west coast of Scotland. Additional information on these numbered records is given in Annex



**Figure 4.** *Sargassum muticum* collected from Davaar Bay, near Campbeltown Loch, Mull of Kintyre in August 2007 (E. Cook). Maximum frond length approximately 3.5 m

high levels of dosing creating unacceptable levels of non target mortality. The potential for biological control also appears to be limited (Critchley et al. 1986), although observations on the coast of British Columbia, Canada suggest that in certain circumstances grazers (the sea urchin *Strongylocentrotus droebachiensis*, Müller 1776) can control *S. muticum* abundance (De Wreede 1983). However, it has also been suggested that grazing pressure may accelerate dispersal by increasing fragmentation of the fronds (Critchley et al. 1986).

### Rates and mechanisms of dispersal

The primary reproductive mechanism of *S. muticum* facilitates only short range dispersal (Davison 1999). During reproduction, the oogonia of *S. muticum* are fertilised while on the surface of the receptacle and are retained for 2-3 days before being released into the water column as relatively well-developed germlings. The germlings sink rapidly and adhere to the substrate on contact (Norton 1980, Norton and Fetter 1981). The vast majority of germlings, therefore, settle within a few metres of the parent plant (Deysher and Norton 1982) serving to increase the local population density and leading to the development of gradually expanding dense beds (Arenas et al. 2002). The local expansion of a population may be accelerated if buoyant plants are attached to small pebbles or shell fragments. At high tide, the attachment point may be floated or dragged along the substrate, so that the plant is transferred to a new location (Nicholson et al. 1981, Critchley 1983b, Strong et al. 2006, Thomsen et al. 2006).

Longer range dispersal is facilitated by drifting detached fronds which are supported by buoyant vesicles (Fletcher and Fletcher 1975a, Norton 1977b). Abscised fertile fronds tend to decay and lose buoyancy rapidly (within 14 days) so have a limited potential for dispersal. Vegetative fronds remain viable for considerably longer and may self fertilise while drifting, thus releasing germlings to colonise distant locations (Farnham et al. 1981, Deysher and Norton 1982, Critchley et al. 1983). Fronds may become detached due to wave action, grazing damage or other forms of physical disturbance (Fletcher and Fletcher 1975a) and extensive accumulations of detached drifting fronds are not uncommon. Wind is thought to play the main role in determining the direction of drift and has considerably more influence than water currents (Deysher and Norton 1982). It has been noted that the appearance of drifting plants in an area has often been followed by the appearance of an established attached population (Deysher and Norton 1982, Critchley et al. 1983) some 2-3 years later (Rueness 1989). Dispersal by drift is thought to have been largely responsible for the spread of *S. muticum* from its initial points of introduction along the Pacific coast of North America (Norton 1978). This covered a range of some 3000 km (Lewey and Farnham 1981) and a single step of 1100 km was recorded in one instance (Deysher and Norton 1982). The

dispersal of *S. muticum* along Scandinavian coasts has also been attributed to drift (Karlsson and Loo 1999, Staehr et al. 2000) and it is thought that its initial introduction to the UK was due to drift from sites in Northern France (Critchley et al. 1983). In Scotland the predominant wind direction, although highly variable, is from the south-west and Scotland experiences a greater frequency of strong winds than the rest of the UK (Met Office 2007). Near surface water currents are highly influenced by local geography, but have a general clockwise trend around the Scottish coast moving northwards up the west coast and southward down the east coast (BODC 1998). It is, therefore, highly likely that the apparent northwards dispersal of *S. muticum* along the west coast of Scotland is the result of drift fragments driven by the prevailing south westerly winds and the northward water flow in this region (McKay and Baxter 1985). The source of the drift fragments might include the known *S. muticum* populations in the Clyde Sea area, populations in the Irish Sea, such as Strangford Lough (Davison 1999) or the north-west coast of Ireland.

In addition to natural dispersal mechanisms there are several possible anthropogenic vectors for long distance dispersal of *S. muticum* (Davison 1999). There is evidence to suggest that translocation of shellfish stock for cultivation may be the activity that poses the greatest risk. *S. muticum* plants can be attached to oyster shells and the fronds used as a packing material when transferring live stock (Jones and Farnham 1973, Critchley and Dijkema 1984). The initial introduction of *S. muticum* to the Pacific coast of North America was probably due to the importation of Pacific oysters *Crassostrea gigas* from Japan (Norton 1978, Deysher and Norton 1982, Britton-Simmons 2004). Its first appearance in European waters was similarly thought to be associated with oysters imported to Northern France from the Canadian Pacific coast (Druehl 1973, Jones and Farnham 1973, Critchley et al. 1983, Critchley and Dijkema 1984, Rueness 1989). It has also been suggested that subsequent spread within Europe was associated with oyster transplantation in many instances, either from other European sites or from further afield. Examples include introductions of *S. muticum* to the Mediterranean (Knoepffler-Peguy et al. 1985, Rueness 1989), Netherlands (Critchley and Dijkema 1984), Denmark (Staehr et al. 2000), Republic of Ireland (Loughnane and Stengel 2002) and Strangford Lough in Northern Ireland

(Boaden 1995). It is possible that the introduction of *S. muticum* to Loch Ryan in Scotland may have been caused by oyster transplantation. *S. muticum* is thought to have been introduced to Strangford Lough in the late 1980s (Boaden 1995) and it is known that during this period oysters were transported from Strangford Lough to Loch Ryan (Howson 1989). It is possible that *S. muticum* could have remained undetected in Loch Ryan between the late 1980s and 2004 because no extensive biological surveys were conducted in the area over this period and the existing *S. muticum* population is sparsely distributed due to limited suitable substrate. The potential for introduction by oyster translocation is supported by the presence in Loch Ryan of other invasive species (e.g. *Styela clava*, Herdman 1882) (Eno et al. 1997), which are also known to be transferred via oyster shells. There is also risk of subsequent spread on the west coast of Scotland, particularly in Argyll and the Clyde Sea by the aquaculture industry through the movements of oyster stock, as 95% of Pacific oyster production in Scotland is concentrated in these areas (FRS 2006).

The potential of other anthropogenic vectors playing a significant role in *S. muticum* dispersal is thought to be limited. Translocation in ballast water is highly unlikely as germlings would lose their ability to attach before the water was discharged. Translocation of plants attached to boat hulls is similarly considered to be unlikely because they would become abraded or detached by the vessel's movement through the water long before they were large enough to become fertile (Deysher and Norton 1982). However, plant fragments may become entangled in anchor chains and steering gear and subsequently be carried to new locations. This has been noted in yachts arriving in the Channel Isles (Critchley and Morrell 1982, Critchley et al. 1983) and in the Mediterranean where the spread of *S. muticum* has been partly attributed to transfer by recreation and fishing boats (Knoepffler-Peguy et al. 1985). Similarly, in Ireland there has been a high incidence of *S. muticum* establishment near moorings and pontoons which implies a dispersal role for small boats (Kraan 2004). The dispersal of *S. muticum* on the west coast of Scotland attached or entangled with boats cannot be discounted and unattached plants have been reported in the Clyde Marina, Ardrossan in 2006 and 2007 (Ashton et al. 2006, E. Cook pers. obs.). Moreover, drift plants loose in the Irish Sea could be carried into Loch Ryan by entang-

lement with the ferries plying the busy route between Northern Ireland and Loch Ryan.

Documented rates of dispersal are often rapid, but are variable and may be dependent on coastal geography, the availability of suitable substrate and wind / current direction. On the south coast of England and north coast of France, populations of *S. muticum* became established along hundreds of kilometres of coastline within a 10 year period (Critchley et al. 1983). Dispersal on the north coast of Spain was at a similarly rapid rate (Fernandez 1999) and dispersal around the coasts of Wales and Ireland also appears to have been rapid, with several widely separate populations having established within less than ten years of the first recorded occurrence of *S. muticum* (Kraan 2004, ICES 2006). Rapid colonisation occurred on the west coast of Sweden with populations becoming established along 100s of kilometres of coastline within a 10 year period (Karlsson and Loo 1999). In Limfjorden in Denmark dispersal occurred at 15-17 km yr<sup>-1</sup> (Staehr et al. 2000). Expansions of other specific populations have been estimated at 2-3 km yr<sup>-1</sup> in two bays on the Irish coast (Kraan 2004) and in the Mediterranean, *S. muticum* was confined to a sheltered lagoon for 4 years before wider dispersal occurred (Knoepffler-Peguy 1985).

Drift dispersal on the west coast of Scotland is likely to be facilitated by the combined influence of strong winds and currents driving drift fragments to the north and east. However, the west coast is highly complex and many drift fragments may become trapped within semi-enclosed sea lochs with prevailing winds likely to drive fragments towards the inland ends of lochs rather than towards the open coast to the west. Slower dispersal rates might be expected on the more complex Scottish west coast than has been the case on more open linear coasts of southern England, Wales and Ireland. However, dispersal rates for *S. muticum* on the west coast of the UK, have averaged approximately 44 km yr<sup>-1</sup> since the population was recorded on the north coast of Cornwall in the early 1990s. It is, therefore, highly likely that *S. muticum* has the potential of reaching the Outer Hebrides and the north coast of Scotland within the next few years.

Dispersal beyond Cape Wrath to the north coast of Scotland and onward down the east coast is likely to be slower and establishment less pronounced. Prevailing winds are likely to drive drift fragments away from the coast and

many shores in the north of Scotland are unsuitable for establishment of *S. muticum* because of high levels of exposure. Although surface currents may carry drift fragments round the north of Scotland and down into the North Sea most fragments which reach the shore are likely to end up at exposed locations where *S. muticum* is unable to establish.

### Environmental tolerance and habitat suitability

The optimal tidal zone for *S. muticum* establishment is the extreme lower shore and sublittoral fringe. Its low tolerance to desiccation prevents colonisation of regularly emersed littoral areas (Norton 1977a). It does colonise eulittoral rockpools (Viejo 1997, Connor et al. 2004), but plants are often small and reproduction may be impaired (Fletcher and Fletcher 1975a). It rarely occurs deeper than a few meters subtidally although it has been recorded as deep as 24 m (Norton 1977a). However, such records of occurrence in deeper water may relate to plants attached to pebbles that have floated clear of the substrate and have subsequently sunk in deeper water (Nicholson et al. 1981). The subtidal range is thought to be linked to water clarity and the availability of sufficient light for growth (Norton 1977a, Thomsen et al. 2006). High levels of wave action cause the plants to fragment and populations are unable to establish in exposed locations (Viejo et al. 1995). Thus, sheltered and moderately exposed sites offer optimal conditions for establishment (Critchley 1983a, Critchley et al. 1983, Andrew and Viejo 1998a, b). The west coast of Scotland offers numerous sites that are likely to be favourable for *S. muticum* establishment in terms of their physical environment. This coastline is highly complex with a high proportion of the shoreline falling within the exposure range suitable for *S. muticum*. In contrast, the north and east coasts of Scotland are characterised by more open linear shorelines, where exposure levels are likely to be too high for the establishment of *S. muticum*.

*S. muticum* can establish on most substrates that provide an attachment point for the holdfast. Substrates can range from bedrock to pebbles or shell fragments scattered on a sediment surface (Fletcher and Fletcher 1975a, Critchley et al. 1983, Connor et al. 2004). *S. muticum* can occasionally be found growing epiphytically on other algae such as fucoids or laminarians

(Fletcher and Fletcher 1975a, Withers et al. 1975, Critchley 1983a) and in some locations it has been noted to form dense populations on floating structures such as pontoons (Fletcher and Fletcher 1975a). The west coast of Scotland has a high proportion of mixed substrate and floating artificial substrates, including aquaculture infrastructure and marina pontoons. Long stretches of shoreline in many lochs are composed of loose cobbles and pebbles overlying sediments. This substrate tends to extend subtidally to several metres depth with cobbles and pebbles becoming increasingly sparse with depth. Beyond these depths the substrate tends to be predominantly sedimentary generally composed of poorly sorted muddy sand (e.g. Black et al. 2000, Bates et al. 2004, ERT (Scotland) Ltd. 2006).

The presence of mixed substrates, however, on the lower shore and sublittoral fringe in sheltered conditions will provide a suitable environment for the establishment of *S. muticum*. Shores and shallow sublittoral margins of sea lochs are often relatively steep, so the zone available for *S. muticum* colonisation will tend to be narrow in width. Where cobbles are larger and more numerous their increased stability is likely to allow a persistent canopy of native algae to develop which can present a physical barrier to settlement of *S. muticum* germlings and can totally inhibit colonisation (Deysher and Norton 1982, De Wreede 1983, De Wreede and Vandermeulen 1988, Andrew and Viejo 1998a, Britton-Simmons 2006). Consequently, the establishment of *S. muticum* often requires a disturbance event that creates an area of open substrate with no barrier to settlement. The timing of such events is critical because some native algal species will also rapidly colonise open rock and the window of opportunity for *S. muticum* settlement is limited (Deysher and Norton 1982, De Wreede 1983). Mixed substrates of pebbles or shells on sand or mud are often more favourable for *S. muticum* establishment than stable rock because the increased frequency of disturbance is likely to prevent the establishment of a persistent canopy of competing algae (Davison 1999). Once *S. muticum* is established it often competes effectively for light and space with native algae (Fletcher and Fletcher 1975a, Nicholson et al. 1981, Ambrose and Nelson 1982, De Wreede 1983, Viejo 1997, Cosson 1999, Staehr et al. 2000, Bartsch and Tittley 2004, Britton-Simmons 2004, Sanchez et al. 2005) by virtue of

its pseudo-perennial lifestyle, rapid growth rate, large frond size and dense canopy (Wernberg et al. 2000). On the west coast of Scotland, therefore, *S. muticum* canopies are likely to establish as a narrow discontinuous band around the lower shore of sea lochs where suitable areas of mixed substrate exists.

*S. muticum* is known to have a broad tolerance range for temperature (Norton 1977a). It has successfully established in the cold waters of southern Alaska (Hales and Fletcher 1989) and Scandinavia (Karlsson and Loo 1999), as well as in the warmer waters of the Mexican Pacific and the Mediterranean. Experimental evidence suggests that the optimal temperature for growth and reproduction is about 25°C (Hales and Fletcher 1989). However, reproduction can occur at 10°C (Hales and Fletcher 1990) and growth is possible at 5°C (Norton 1977a) with *S. muticum* able to outgrow some native species at temperatures well below its own optimum (Norton 1977b). In Sweden, newly established populations of *S. muticum* were noted to survive the winter despite formation of ice on the nearby sea surface (Karlsson and Loo 1999). It is, therefore, unlikely that sea temperature will limit the establishment of *S. muticum* in Scotland (Hales and Fletcher 1989).

*S. muticum* is known to have a broad tolerance for conditions of reduced salinity, although growth rate and reproduction are impaired with a likely reduction of competitive ability (Norton 1977a, Hales and Fletcher 1989, Steen 2004). The results of experimental testing of salinity tolerance limits are somewhat variable, but it has been estimated that *S. muticum* will be unable to reproduce if salinity is consistently <15ppt and may be unable to compete effectively if salinity is <25ppt (Steen 2004). In Scotland, particularly on the west coast, many of the more enclosed sea lochs are subject to conditions of reduced or variable salinity and at locations where this is pronounced, the establishment of *S. muticum* may be constrained. Such conditions are likely to occur at the inland end of a loch where seawater exchange is reduced and freshwater input is greatest. However, salinity levels are likely to remain relatively higher during the summer reproductive growth period when freshwater input is lowest and the dormant holdfasts are likely to survive the reduced salinity associated with increased freshwater input in the winter. Consequently, the pseudo-perennial lifecycle of *S. muticum* may allow it to survive despite the

potential constraints of reduced salinity in sea lochs.

### Control by grazers

Although a variety of grazers can feed on *S. muticum*, there is little evidence to indicate that they are a controlling factor in its abundance or distribution. Norton (1977a) speculated that the shallow depth distribution of *S. muticum* off the coast of Washington state, USA might be due to increased grazing pressure by sea urchins at deeper locations. More recent work (Britton-Simmons 2004) indicates that the dominant grazer, the sea urchin *Strongylocentrotus droebachiensis* tended to avoid *S. muticum* and did not appear to control plant abundance. Similarly, studies in Scandinavia indicate that although some grazers, such as the sea urchin *Psammechinus miliaris* (Gmelin 1778) and the gastropod *Littorina littorea* (Linnaeus 1758) actively feed on *S. muticum* there was no evidence to indicate control of its abundance (Pedersen et al. 2005, Thomsen et al. 2006). However, observations on the coast of British Columbia, Canada suggest that in certain circumstances grazers (*S. droebachiensis*) can control *S. muticum* abundance (De Wreede 1983). In the Solent, the most effective grazer of *S. muticum* was the sea-slug *Aplysia punctata* (Cuvier 1803) but they showed a feeding preference for other algae and were not sufficiently numerous to control algal populations (Critchley et al. 1986). *P. miliaris* is a common macroalgivore in many of the sea lochs on the west coast of Scotland (Kelly 2000), however, it is unlikely that this species would be able to control the spread of *S. muticum*, unless populations were artificially enhanced with commercially reared sea urchins.

### Conclusion

*S. muticum* appears to be rapidly dispersing northwards along the west coast of Scotland. Northward dispersal via natural drift is likely to be facilitated by the prevailing wind and current directions, although anthropogenic vectors, such as the movement of shellfish stock and recreational boating may play an equally important role in dispersal. Many locations on the west coast are likely to provide favourable conditions for *S. muticum* establishment in terms of exposure and substrate. The north and east

coasts of Scotland offer less favourable conditions on a predominantly open and linear coastline. The prevailing wind direction is also less favourable for dispersing drift fragments along these coasts.

It is highly likely that *S. muticum* will extend throughout the west coast of Scotland within the next few years, becoming established on mixed substrate in sheltered or moderately exposed areas. Where conditions are optimal, dense canopies of *S. muticum* will develop, although these are likely to be restricted to narrow fringing bands around the margins of sea lochs due to seabed topography. Where there are extensive shallow areas of mixed substrates more extensive beds of *S. muticum* may develop.

It appears that *S. muticum* is now an established member of the Scottish marine flora but the implications of this are difficult to establish with certainty. Current evidence suggests that ecological effects are inevitable, but not necessarily deleterious. Dense canopies of *S. muticum* alter the community structure in the immediate surrounding area (Strong et al. 2006, Harries et al. 2007), but are unlikely to cause significant reductions in the abundance of native biota on a wide scale. By colonising areas of mixed substrate where algal cover was formerly sparse (Jephson and Gray 1977) *S. muticum* may increase local productivity (Viejo 1999, Pedersen et al. 2005, Sanchez et al. 2005), increase habitat heterogeneity (Buschbaum et al. 2006) and provide cover for mobile macrofauna and fish (Critchley 1983b, Davison 1999). However, development of dense canopies may alter the visual appearance of affected shores and constitute a degradation of the natural heritage value. Consequently, where practical, control measures should be established at environmentally sensitive marine protected sites. *S. muticum* also has the potential to be a significant nuisance to the numerous salmon farms, mussel longline systems and other aquaculture installations in the west coast sea lochs. Dense growth may also create a nuisance in some small harbours (Fletcher and Fletcher 1975a, Critchley 1983b, Critchley et al. 1983), but extensive free-floating rafts like those which created problems off the south coast of England (Critchley et al. 1983) are unlikely to occur unless *S. muticum* beds are particularly extensive. It would be prudent, therefore, to develop effective control methods for *S. muticum* both in areas of aquaculture activity and in marine protected areas and to prevent the transfer of this alga when commer-

cial species are moved to new areas for on-growing.

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*Sargassum muticum* on the west coast of Scotland

**Annex**

Recent records of *Sargassum muticum* on the west coast of Scotland. Locations of the records are shown in Figure 3

Number on Figure 3	Location	Position (British National Grid, OSGB36 datum)	Position (Decimal degrees, WGS84 datum)	Year	Notes	Source of record
1	Loch Ryan, Wigtownshire	NX046681	54.969109N 5.054191W	2004	Attached to scattered pebbles on sand. Sparsely distributed on lower shore & sublittoral fringe.	Scottish Natural Heritage
		NX069677	54.966416N 5.018046W			
		NX036648	54.939105N 5.067530W			
2	Isle of Cumbrae, Ayrshire	NS175544	55.748465N 4.909251W	2005	Attached to cobbles and pebbles forming dense canopy on lower shore & sublittoral fringe.	University Marine Biological Station, Millport
		to NS182555	to 55.758599N 4.898848W			
3	Hunterston power station, Ayrshire	NS180520 (approx)	55.727117N 4.899697W (approx)	2005	Attached.	University Marine Biological Station, Millport
4	Loch Fyne, Argyll	NR900700 (approx)	55.877243N 5.358648W (approx)	2006	Unattached drift fragments.	Owen Paisley (Seasearch Coordinator)
5	Isle of Cumbrae, Ayrshire	NS175543 to NS181593	55.747568N 4.909184W to 55.792661N 4.902976W	2006	Attached, further expansion of bed noted in 2005.	Scottish Natural Heritage
6	Clyde Marina, Ardrossan, Ayrshire	NS226422	55.640878N 4.820207W	2006	Unattached drift fragments.	Scottish Association for Marine Science
7	Corrie, Isle of Arran	NS026420	55.631373N 5.137325W	2007	Unattached drift fragments.	Scottish Natural Heritage
8	Whiting Bay, Isle of Arran	NS046259	55.487731N 5.094222W	2007	Attached and well established	Howard Wood (Community of Arran Seabed Trust)
9	Clonaig, Kintyre, Argyll	NR875560	55.750580N 5.387594W	2007	Unattached drift fragments.	Scottish Natural Heritage
10	Campbeltown Loch, Kintyre, Argyll	NR754195	55.417797N 5.550281W	2007	Attached	Scottish Association for Marine Science
11	Garvellachs, Firth of Lorn, Argyll	NM645096	56.220467N 5.800145W	2007	Unattached drift fragments.	Scottish Natural Heritage
12	Ganavan, Oban, Argyll	NM862327	56.437871N 5.469656W	2007	Unattached	Scottish Association for Marine Science