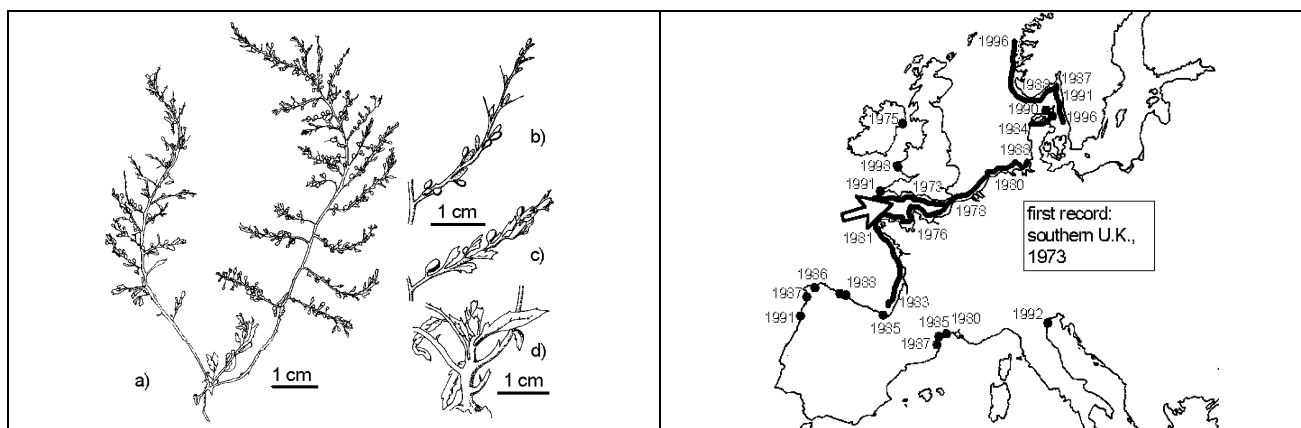


***Sargassum muticum*** (Yendo) Fensholt, Sargassaceae, Fucales, Phaeophyceae  
Common names: Japweed, Wire weed, Strangle weed, (English), Sargassosnärje (Swedish)



*Sargassum muticum* [after 46]. a) Winter morphology, b) detail branch: summer morphology, c) winter morphology, d) detail: perennial primary shoot.

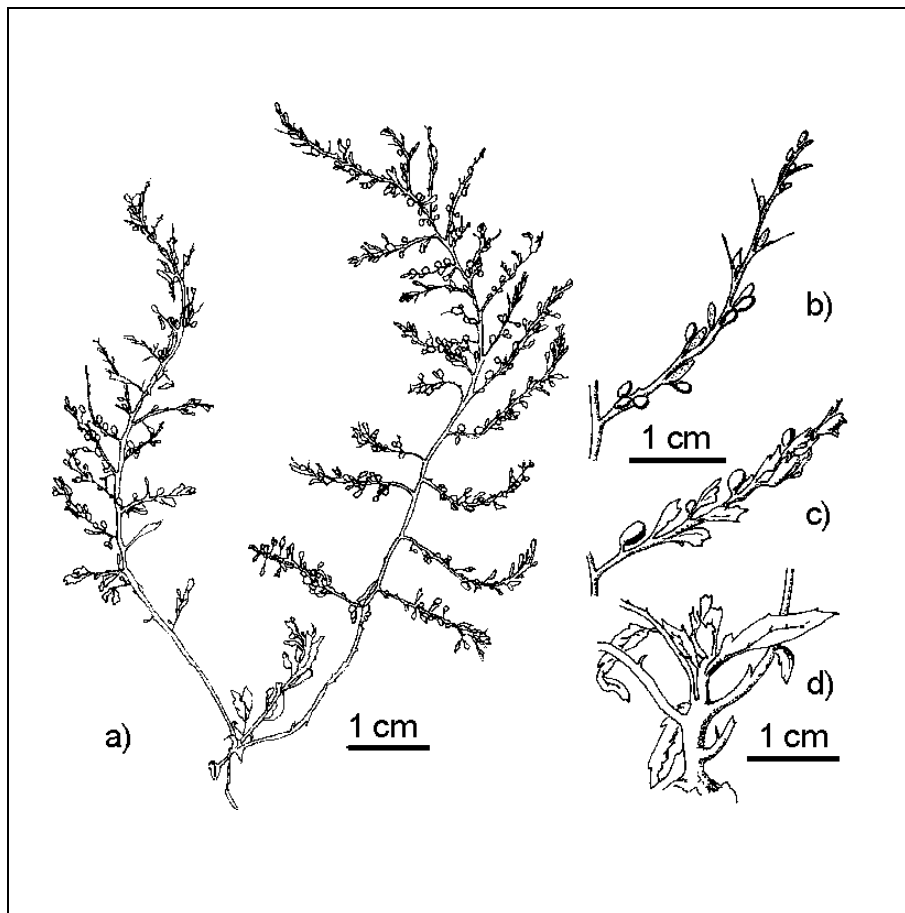
Known coastal distribution of *Sargassum muticum*.

**Impact:** (\* = possibly harmful, \*\* = harmful, \*\*\* = very harmful, ? = not known, \$ = beneficial)

Resources/Environment			Uses of the Sea		
Commercial stocks	?	Commercial uses tried without much success.	Fisheries	* or \$	Clog and foul nets, hinder to sport fishery. Attract fish.
Other biota	**	Competing with other seaweeds. Seagrass beds may be second-arily affected by habitat changes.	Aquaculture	**	Foul ropes, lines, bags etc., grow on molluscs and may drift away. Difficult to spot oysters.
Human health	?	Can harbour epiphytic invertebrates causing allergy.	Water abstractions	*	Drifting plants may block water intakes.
Water quality	*	Dense canopies accumulate silt.	Aquatic transport	**	Entangle in boat propellers, tricky manoeuvring in beds, foul pontoons and piers.
Habitat modification	* or \$	Large, long canopies change the habitat, reduce light and water movements. Shelter for animals	Tourism	**	Sandy bays can become dense algal beds. Detached plants accumulate on beaches.

**Vulnerable habitats:** Especially sheltered to semi-exposed areas not densely covered by other seaweeds, harbours or aquaculture sites. Sandy areas with small stones, pebbles and shells, or free patches in seagrass beds. It may become established in all warm and cold temperate areas of the world in not too exposed areas, also in brackish water (at least in salinities above 16 ‰). Enhanced by polluted and nutrient-rich waters, but does not tolerate desiccation. Easily spread by drifting fertile branches or transfer of molluscs.

**Biology:** The life cycle consists only of the large pseudo-perennial plant, up to 5-10 m long. The long, annual branches have numerous small (<0.5 cm) round air-bladders, making plants stand upright in the water or float on the surface, and small leaf-like branches. Attached by a disc-shaped holdfast to rocks, stones, pebbles, artificial substrates (ropes and mariculture structures, glass, plastic, metal etc.) and also to shells, barnacles, tunicates and occasionally seaweeds. Plants on pebbles or shells often drift away. The lateral branches detach in summer-autumn in cold waters, leaving only a short perennial stem with coarse, broad leaf-like branches which overwinter. In warm waters long plants may persist all year. Even small pieces of holdfasts can regenerate branches. Reproduce by the <1 cm long receptacles producing both eggs and spermatozoids. Thus one single plant can multiply with a potential for many millions of germlings. Fertility depends on temperature, in summer-autumn in cold waters, may occur all year in warm waters. The small embryos remain on the receptacles until rhizoids are developed, giving a competitive advantage. After detaching they sink and reattach immediately to any surface encountered by the rhizoids and develop a new plant with a holdfast. Old germlings loose ability to reattach.



*Sargassum muticum*

***Sargassum muticum*** (Yendo) Fensholt: Sargassaceae, Fucales, Phaeophyceae, Heterokontophyta.

**Common names:** Tama-hahaki-moku, (Japanese), Japweed, Wire weed, Strangle weed (English); Japanischer Beerentang (German), Sargasse (French), Sargasso (Spanish and Portuguese; also incl. other seaweeds), Japans bessenwier (Dutch), Butblæret sargassotang (Danish), Japansk drivetang (Norwegian), Sargassosnärje (Swedish)

**Identification:** The up to 5-10 m long plant [3, 13, 29] is attached by a disc-shaped holdfast, which can regenerate [23]. In the basal region it has a short perennial stem (3-4 cm, often branched), and some broad leaf-like branches with a midrib [7, 13, 37, 45]. The long, thin primary laterals and those of higher order bear many small leaf-like branches and numerous small (<0.5 cm) stalked, round or slightly pear shaped, air vesicles. Colour varies from dark brown (especially in winter and in nutrient-rich areas) to pale, almost yellowish. The air vesicles make the plants stand upright in the water or float on the surface. *Sargassum muticum* was previously ranked as a form, *S. kjellmanianum* f. *muticus*. The species *S. kjellmanianum* Yendo, which is dioecious (cf. below), is now renamed *S. miyabei* Yendo [45] but the old name is still in use, especially in Asia [13], and thus may include both species. The genus *Sargassum* has about 400 species [45], several of which are very difficult to separate, especially if not fertile and without a holdfast.

**Generalised life history:** The life cycle only has one stage: a large pseudo-perennial plant. Every late winter/ spring/ early summer, depending on temperature, annual laterals grow out, but in some warmer areas the plants can have such branches and be fertile all year through [19, 29]. At rather exposed sites the size is usually smaller [14, 19, 40, 43] and plants often broken. At senescence (late spring/ summer/ early autumn, depending on temperature), the laterals detach, but they can survive and even grow while floating free and loose vegetative branched may even become reproductive [17]. In late autumn/ winter only the perennial holdfast and short stem with some broad leaf-like branches remain.

Less than 1 cm long, cigar-shaped receptacles develop in single where the "leaf" attach to the branch, but can also sit on top of the branches [7, 45]. Receptacles have both oogonia and antheridia producing eggs and spermatozoids in small separate cavities (conceptacles), visible as dark dots (monoecious plant). The plant is self-fertile, thus one is enough to multiply with potentially millions of germlings [29]. Fertilization occurs when eggs are still attached by a mucilage stalk and the young embryos remain attached to the receptacles until 16-32 cells large (hardly visible by the eye), and rhizoids are developed [22]. They then detach from the receptacles, sink and reattach immediately to any surface by a cement of acid polysaccharides on the rhizoids, and later develop an holdfast. Reproduction occurs in winter-spring in the native area [16, 45] and in introduced populations in early spring/ summer/ early autumn depending on a combination of number of days above a certain temperature [16]. Fertile plants can occur all year through in Mexico and southern US [19, 29]. Germling dispersal only occurs within some few metres from the parent plants [2, 17] thus recruitment depends on drifting plants. Some other *Sargassum* species can develop vegetative embryos on rhizoids which grow out to new plants [33].

**Relative abundance:** Plant densities are very variable depending on environmental factors and season. Maximum densities up to 130-300 per m<sup>2</sup> have been recorded [1, 5, 21], and weights up to 2.7-4.2 kg ww m<sup>-2</sup> [12, 42], or nearly 1 kg dw [5, 14]. Maximum growth rates may reach 2-4 cm per day in the field [27, 29, 43] and up to 7 cm (depending on season and part of the plant) in laboratory experiments [27]. *Sargassum muticum* exhibits several opportunistic characters [8, 20, 36, 39, 43] such as rapid colonisation of free space, a large number of propagules, incl. cast off branches, rapid growth of young germlings [24], high photosynthetic rates, while respiration rates still are low [21, 35]. Being monoecious with self-fertilization and keeping the young embryos on the adults, highly increases the chances of establishment, and the perennial base secures the continued existence of the

plant. Also other species of the genus *Sargassum* may have the characters being typical of an invasive species [33]. Flourishing growth in mussel and oyster cultures points to nutrient enhancement. It also grows in polluted waters [12] and seems to be favoured by high nitrate concentrations [3]. The holdfasts withstand a high drag [17, 22] as do very small germlings. In Sweden it grows well in a strong current created by discharged cooling water from a nuclear power plant (J. Karlsson pers. comm.).

*S. muticum* has in several cases been found to be a superior competitor and the large size of the plants during spring/ summer effectively blankets the light for understory species [1, 5, 12, 22, 39], especially when the summer branches are floating on the water surface. Dense populations may reduce the light intensities down to  $2 \mu\text{E s}^{-1} \text{m}^{-2}$  [5] or 97% of surface value [12]. Accumulation of silt among densely branched specimens further reduce the possibilities for other species to survive [6, 8, 12] as do occupation of space [39]. Thus several perennial species have shown decreased abundance or poor recruitment in areas with dense cover of *Sargassum muticum*, e.g. kelps [1, 4, 6, 29], fucoids [4, 5, 18, 38, 39], and also filamentous and foliose algae may loose in competition [8, 14, 39]. In exposed areas *S. muticum* loses against native turf-forming and foliose species which occupy space, since it needs open areas to settle [2, 17, 21]. When colonizing areas without large canopy species it may also attract various invertebrates important as fish food [29, 44] and even fish such as eels [8, 44].

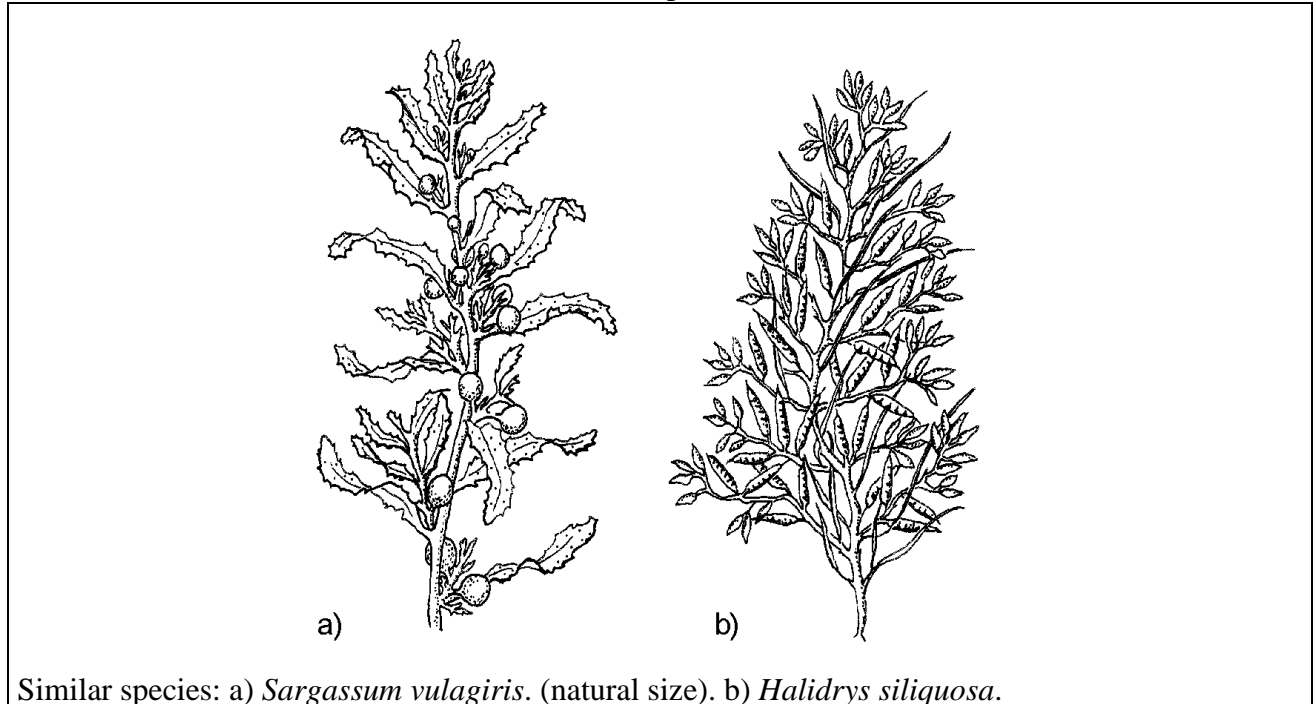
The snail *Lacuna*, amphipods and sea urchins are grazers on the American Pacific coast, which in summer can remove more tissue than is grown [31]. In the Mediterranean sea urchins can be heavy grazers [3]. However, in general grazing pressure is not able to suppress established populations, and in spring grazing cannot keep pace with the growth [31]. High contents of phlorotannins [3, 31] may also deter some grazers. Periwinkles graze heavily on [20] or physically remove [31] young germlings and gammarids often occur on adults [7]. Intact but killed germlings were found in fecal pellets of sea cucumbers [29]. Several exotic animals have been reported on introduced *S. muticum* [3, 13] and the total number of animals may be more than 700 per 100 g ww [31].

**Similar species:** In northern Europe only one native species, *Halidrys siliquosa*, can possibly be confused with *S. muticum*. In *Halidrys* the whole thallus is perennial, being broader and much more flattened, with no long lateral branches in summer and no leaf-like structures. Its several cm long air vesicles are not spherical but oblong, and divided into separate compartments and the receptacles are longer and broader. On the south-east Atlantic coasts of Europe (U.K., Ireland, France, Spain and Portugal) as well as in the Mediterranean there are several species of the closely related genus *Cystoseira* and in the south also some other *Sargassum* species. Depending on taxonomic training the number of similar species differ and the different appearance of *S. muticum* in summer and winter might add to the confusion. Members of the genus *Cystoseira* do not have any large leaf-like structures, nor the conspicuous stalked air vesicles, which instead constitute swollen parts of the thallus. The fertile receptacles constitute part of the upper branches and are not axillary.

Other *Sargassum* on the European Atlantic shores: *S. vulgare*, many long, quite narrow, leaf-like branches; small, stalked, round air vesicles; small (1 cm or less), simple or branched receptacles in clusters on a sterile stalk), *S. flavifolium* (long, dentate, leaf-like branches; small round air vesicles; small branched, monoecious receptacles), *S. desfontainesii* (leaf-like branches several times furcated; air vesicles frequent or might be missing), *S. natans* (only non-fertile plants on drift from the Sargasso Sea without holdfasts; long, narrow, dentate leaf-like branches with a hook in the top; many round, small, long-stalked air vesicles), *S. fluitans* (drifting sterile plants from the Sargasso Sea without holdfasts; coarse and with broad, dentate leaf-like branches with an evident midrib; air vesicles the size of a pea).

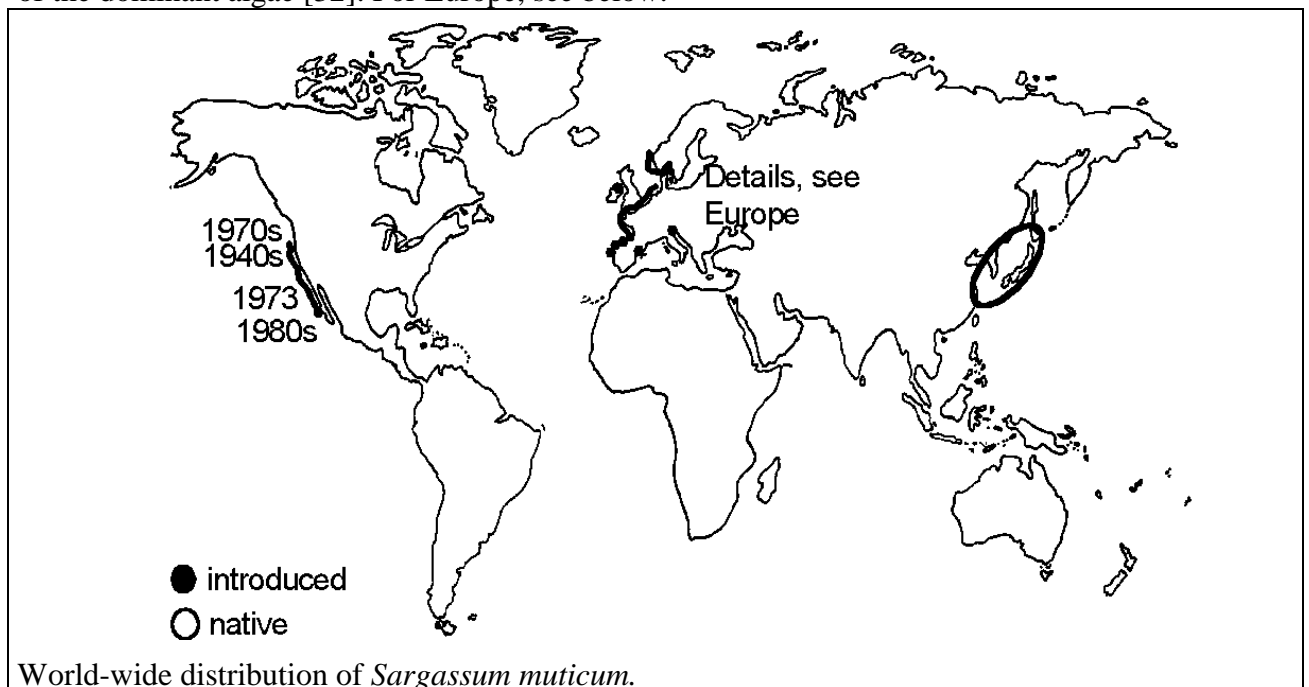
In the Mediterranean: *S. vulgare* (see above), *S. hornschurchii* (undulated leaf-like branches; roundish air vesicles up to 8 mm in the top of the plants; flat or triangular large receptacles sitting like grapes on a long sterile stalk), *S. acinarium* (irregular, leaf-like, dentate branches several cm broad; ca

0.5 cm round air vesicles; cylindrical receptacles on a long sterile stalk), *S. trichocarpum* (small, stalked, round air vesicles; small, monoecious receptacles branched several times).



Similar species: a) *Sargassum vulagiris*. (natural size). b) *Halidrys siliquosa*.

**Worldwide distribution:** *Sargassum muticum* is native on the northwestern Pacific shores: Japan, Russia, Korea, China (for references see [13, 45]). In the north-eastern Pacific it was first recorded in 1944 around the Strait of Georgia, British Columbia, presumably brought by Japanese oysters before 1940 [37], but not present in the early part of the century. It was found in Oregon in 1947 and in Washington in 1953, also areas with imports of oysters from Japan [37]. The spread further south the Pacific US coast may be due to drift of vegetative branches becoming fertile [17], and it was recorded in 1973 in California and Mexico [19, 41]. Now occurring northwards to south-east Alaska (references in [13]) and southwards to the Mexican San Ignacio Lagoon where it in the 1990s is one of the dominant algae [32]. For Europe, see below.



World-wide distribution of *Sargassum muticum*.

**Range Expansion in Europe:** The first introduction into Europe has been a question of much debate, attached plants first recorded in southern U.K. in 1973 [10, 20] while not found until in 1976 at the Atlantic French coast [3,10]. Many consider the latter to be the primary introduction area by imports of oysters from British Columbia or Japan in the 1960s [see e.g. 3, 13, 20] and that drifting plants brought it to U.K. It was further spread along the English south coast [10, 13, 18] and in 1998 found in southern Wales (C. Eno pers. comm.). Drifting spread plants northwards to the Netherlands, in 1980 found attached on Texel and in the southern parts [10, 12, 13, 34]. In Scandinavia attached plants were first recorded in western Limfjorden, Denmark, as early as in 1984 [36, 41, 42, 43 and references therein], where it later has spread all the way to the Kattegat coast [41, 42] and also to the north coast [41]; in 1987 in Sweden [28, 41] and later spread by drift to the middle part of the Kattegat coast [28]; in 1988 in Norway [36] and later spread to north of Bergen in 1993 [26] and Rogaland in 1996 (H. Botnen pers. comm.). In 1988 it came to Helgoland, Germany [41] and in 1993 to the island of Sylt, northern Waddensee (A. Chapman pers. comm.). The first record in Northern Ireland in 1995 [4] most probably is due to import of oyster from the Channel Islands since *S. muticum* grew on old oyster bags. Southwards, it in 1983 reached southern France [3] and was recorded in northern Spain in 1985 [21]. It has since spread to several places on the Spanish north and northwest coast [21, 39, 40] and was recorded in northern Portugal in 1991 [20, R. Melo pers. comm.]. New imports of Japanese oysters to l'Étang de Thau, the Mediterranean, resulted in records of attached plants in 1980, together with several other introduced species [5, 13, 41], but so far it has not been reported from the Spanish Mediterranean coast. The establishment in the lagoon outside Venice in 1992, where also two other introduced species occur [14] probably also is related to commercial transfer of molluscs.

**Invasion patterns:** Since drifting plants and branches play such a large role for dispersal, many areas at first show disjunct populations, often starting in bays accumulating debris [17, 28]. Dispersal rates have been estimated to 10 km per year in Limfjorden [42], and around 50 km per year in Sweden (J. Karlsson pers. comm.), while large jumps were seen along the north-eastern Pacific shores [17, 19]. In some areas saturation (all suitable habitats occupied) may occur after the first expansive phase, when the increase rates stop, being about 6 years in the Netherlands [12] and southern England [8], 11 years in Limfjorden [38] and 15 years in France [3]. On the other hand the Swedish populations did not seem to have reach that phase after 9 years [28].

Unintentional introductions emphasize the need of proper quarantine treatment in aquaculture, and only the next generation should be released to avoid that molluscs act as vectors. New rules for free trade and transfers of shellfish for fattening between disease-free coastal areas within Europe may bring in *S. muticum* from areas where it grows, and might especially be a threat for the Irish and British coasts, where such transfers have frequently occurred (suggested vector for Northern Ireland, [4]). Experimental work in areas where the species already occurs can result in locally higher densities around e.g. field stations (own obs.).

**Further likely areas for colonisation:** Europe: All the rest of England, Wales and Ireland, Isle of Man, Scotland, the islands of Orkney, Shetland and the Hebrides, the Faroe Islands, the Danish North Sea coast, all Kattegat coasts, the Norwegian northwest and north coasts, southern Iceland. All the rest of Spain, Portugal, and the Mediterranean Sea. How far into the brackish Baltic Sea area it may progress is less easy to predict since different salinity tolerance limits have been reported (see above) incl. reduced fertilization. Also the northern distribution limit is difficult to predict depending on risks for ice scouring and low growth rate at low temperatures, which may make it less competitive. Cold and warm temperate Atlantic coasts of Canada and USA, South America, Africa, Australia and New Zealand.

Disturbed rocky shores, if not too exposed, are likely more at risk than those with a dense perennial vegetation [2, 39, 40]. Settling and growth on small stones, shells and most artificial substrates also makes areas with sediments susceptible (incl. ports and aquaculture sites), but soft substrate is not

colonized. Eelgrass beds may also deteriorate, when there is a clearing of the beds by e.g. natural population dynamics or storms [15].

### Abiotic factors:

Temperature	Growth rates of germlings, adults and receptacles increase with temperature, with optimum round 25° C, but growth also at 30 °C [24, 25]. More vigorous growth in warm areas [19, 29] incl. El Niño [1] and cooling water from a nuclear power plant [28]. A multiplicative number of degrees and days are needed for receptacle initiation [16]. No growth at 0 °C [30], but plants survive winters with ice cover and temperatures below 0 °C [12, 28] as well as exposure to air at -1.5 °C for one hour [30]. Plants in the upper intertidal often have damaged tissues [8, 29].
Salinity	Salinity is the key factor for dispersal into brackish waters. Most introduced populations grow in areas with salinities above 20 ‰. The southernmost Swedish area [28] has a surface salinity of 16-20 ‰. In the brackish Limfjorden, Denmark, it is mainly found above 25 ‰, but may occur in slightly lower salinities (T. Wernberg-Møller pers. comm.). On a Canadian shore influenced by melting water and with surface salinities down to 8.6 ‰, plants only occur below 6-10 m [30]. In Venice only found in the outer area and not in the brackish canals [14]. Lowest salinities for germling growth in laboratory test are around 5-6 ‰, older ones being more tolerant, but no fertilization seen below 17-20 ‰ [24, H. Steen pers. comm., cf. also 30], but receptacles can grow down to 8.5 ‰ [25]. Thus some part of the reproductive cycle is disturbed and spermatozoids may be especially vulnerable [25] or the rhizoids cannot attach with their mucilage.
Light and depth distribution	Optimum light for growth differs between germlings and adult plants. The former have growth optimum around 45 $\mu\text{E s}^{-1} \text{m}^{-2}$ the youngest ones even have high mortality rates between 90-175 $\mu\text{E s}^{-1} \text{m}^{-2}$ , older ones being more tolerant to high light [24]. Around 160-190 $\mu\text{E s}^{-1} \text{m}^{-2}$ is saturating for photosynthesis, varying with season, [35] and compensation levels are around 12-32 $\mu\text{E s}^{-1} \text{m}^{-2}$ . Gamete maturity mostly requires long-day conditions [25], but receptacles kept in darkness can produce viable gametes [25]. Germlings are able to survive, but not grow, for several weeks in darkness (data by Chritchley in [24]). Most populations are best developed close to surface, but a depth of around 6-15 m is not uncommon [28, 29], maximum 24-25 m [10, 30], depending on turbidity, available substrate, grazing and competition. Assimilated products can be transposed along the fronds [20], making plants less vulnerable to the high shelf-shading beneath the canopy [12] and turbidity.

**Main vectors:** Most introduced populations originate from **imports of oysters and mussels**, dispersing later as **drifting branches**. In the Netherlands it was proven that imported oysters can act as a vector for the species [9] and they discussed the risk of **storage of live oysters for consumption** in basins at the seaside. There are no proofs of the species being established by **shipping** activities, but it reached one site on a Channel Island **entangled in the steering gear** of a yacht [10]. If **hull fouling** would be a vector for dispersal, this requires that germlings attach at a very young stage, since old plants do not reattach [17, 30]. However, branches may entangle in other hull fouling species and if being or becoming fertile may release germlings to new sites. Although not tolerating drying out for any longer period [30], plants might survive in heaps of wet fishing nets or ropes, anchor wells etc. since it could survive some days in open oysters bags transported on land for two days [9]. Receptacles and small germlings probably can survive in darkness in ballast tanks (see above), but they may lose the ability reattach. Large **plants** often **lift smaller pieces of substrate** and drift away [8, 29, own obs.], acting as vector also to deeper bottoms ("walking stones" [29]).

**Control measures/management options:** Since secondary introductions by drifting plants is a major vector, control is almost impossible. Several methods, both mechanical and chemical have been tried to eradicate this species [3, 11, 13] without success and a need for repeated croppings. Mechanical treatment even has helped spreading branches to new areas [3, 11, 13]. It is a nuisance in aquaculture [3, 4, 23, 37] growing on lines, supporting structures and oyster bags. The potentially toxic dinoflagellate *Prorocentrum lima* is often found in large quantities in the canopies (*M. Kuylenstierna* pers. comm.) and if coming into water being filtered by molluscs may cause DSP. Proper quarantine treatment is needed in aquaculture to prevent unintentional introductions with molluscs. Transfer of molluscs from disease-free areas with *S. muticum* should be avoided as well as moving of ropes and other structures, since in late autumn and winter the small plants are hard to see, and objects epiphytized with large plants should preferably be taken out of the water. Storage of live oysters for consumption in basins at the seaside could be a potential risk [9], and shells should be carefully inspected. Commercial harvests of *Sargassum* have been attempted and used e.g. as fertilizers [3], but no large scale operations are started. Nets with *Sargassum* may also be used to clean water and as artificial reefs [44].

The effect on fishery is mainly by clogging and fouling nets and floating plants is a hinder to sport fishery [10] and in shallow areas manoeuvring of small boats in dense stands becomes difficult or plants get stuck in the propellers. Propellers should be inspected and removed plants should always be dumped on land. Removal of large fouling species on ships' hulls reduces the risk of having *Sargassum* branches entangled.

Information on colonized sites should be distributed and great care taken not to perform scientific experiments in the field or in open flow-through systems in areas where the species does not yet occur. Also material brought in for demonstrations should be carefully disposed of on land.

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