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A Bibliography of the Invasive Alga *Sargassum muticum* (Yendo) Fensholt (Fucales; Sargassaceae)

A. T. Critchley, W. F. Farnham*, T. Yoshida** and T. A. Norton***

University of the Witwatersrand, Botany Department, P.O. Wits, Johannesburg, 2050, Rep. of South Africa

* *Portsmouth Polytechnic, Marine Laboratory, Ferry Road, Hayling Island, Hants., PO11 ODG, U.K.*

** *Hokkaido University, Department of Botany, Sapporo 060, Hokkaido, Japan*

*** *University of Liverpool, Department of Marine Biology, Port Erin, Isle of Man, U.K.*

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Abstract

A compilation of approximately three hundred publications concerning the brown alga *Sargassum muticum* (Yendo) Fensholt is given. This seaweed has attracted considerable attention amongst the phycological fraternity, because of recent large-scale changes in its geographical distribution and feared consequences of the alga's presence in invaded habitats.

Introduction

Yendo (1907) was the first to describe the brown alga, *Sargassum muticum* from several localities in Japan. The entity was first recorded as *S. kjellmanianum* forma *muticus* Yendo. On the basis of differences in reproductive structure, Fensholt (1955) considered that the forma required elevation to specific status and proposed the new corrected combination *Sargassum muticum* (Yendo) Fensholt (Fig. 1).

Yoshida (1978) subsequently recognized *S. kjellmanianum* Yendo as conspecific with *S. miyabei* Yendo, with the latter having taxonomic priority. Yoshida (1978) continued to recognize the separation of *S. muticum* (Fensholt, 1955) and further erected the forma *S. muticum* forma *longifolium* (derived from the monoecious *S. kjellmanianum* f. *longifolium*; Tseng and Chang 1954). As a consequence of these taxonomic reviews, reports on *S. kjellmanianum* in the literature need to be evaluated critically, since the identification as to *S. muticum* or *S. miyabei* can only be made if details indicate whether the plants are monoecious or dioecious respectively (Yoshida 1978).

The introduction of *S. muticum* to the Pacific coast of North America and European waters has generated a phenomenal research effort. There are many references to this extensively investigated brown alga scattered throughout the scientific literature. In view of the current interest in *S. muticum*, particularly in Europe, the production of a bibliography is appropriate.

The following literature is categorised under general headings. Those papers citing *S. kjellmanianum* are annotated with the identity of the alga (after Yoshida 1978), if the necessary details were provided, otherwise a question mark appears in parentheses if *S. miyabei* and *S. muticum* cannot be determined.

1. *World distribution.*
The world distribution of *S. muticum* can be broadly categorized into three major regions, viz. Far East, Pacific Coast of North America and Europe:

1.1 *Far East:*
Following the information provided the 'indigenous' range of *S. muticum* has been increased significantly:

1.1.1 Japan:
14, 42, 43, 44, 59, 140, 164, 192, 220(?), 221, 223, 224, 225, 252, 258, 259, 280, 281, 284, 285, 286, 287, 303, 304, 306, 307, 308, 309, 310, 311, 312, 314

1.1.2 Korea:
168(?), 169(?)

1.1.3 China:
147(?), 282, 283(?)

1.1.4 Phillipines:
268(?)

1.1.5 Russia:
185, 280, 290, 295

1.2 *Pacific Coast of North America*:
From Scagel (1956) it appears that *S. muticum* was introduced into British Columbia via the importation of *Crassostrea gigas* in the *early* 1940's. The alga has subsequently spread along the Pacific coast of North America,

1.2.1 Canada:
15, 74, 78, 79, 80, 81, 82, 83, 85, 180, 206, 253, 254, 255, 256, 260, 263, 296

1.2.2 United States of America:
1, 2, 3, 7, 38, 76, 84, 85, 87, 99, 108, 127, 128, 129, 134, 153, 158, 159, 160, 161, 175, 176, 180, 181, 182, 183, 194, 195, 196, 199, 206, 213, 229, 230, 231, 236, 246, 254, 255, 260, 261, 264, 265, 271, 272, 273, 274, 275, 296

1.2.3 Mexico:
4, 5, 6, 77, 206

1.3 *Europe*:
The introduction of *S. muticum* to European waters, via the dissemination of oyster spat was uncannily predicted by North (1973). This prediction was realised by the discovery of attached *S. muticum* at Bembridge, Isle of Wight, off the south coast of Britain, Farnham *et al.* (1973). However, the initial site of entry for the invasive brown alga is subject to much controversy, but is most likely the French oyster beds of Normandy, as supported by the discovery of a large *Sargassum* population at St. Vaast La Hougue (Gruet 1976, Farnham 1978).

Sargassum muticum has spread very rapidly within European waters and is cause for concern at a number of localities (see also Sections 3 and 6).

1.3.1 Scandinavia:
46, 156, 157, 166, 249, 250

1.3.2 Netherlands:
13, 28, 58, 67, 68, 72, 187, 197, 198, 238, 239, 240, 241, 242, 243, 244, 245, 250, 266, 267, 289, 291, 292, 293

1.3.3 Belgium:
49, 50, 51, 52, 68, 247, 250

1.3.4 Britain:
8, 25, 26, 32, 34, 35, 54, 55, 57, 59, 63, 64, 68, 70, 86, 89, 90, 91, 92, 93, 94, 95, 97, 98, 101, 103, 104, 109, 120, 133, 137, 144, 145, 146, 152, 167, 170, 172, 189, 204, 210, 218, 250, 277, 279, 299, 300, 301

1.3.5 Atlantic and English Channel Coasts of France:
17, 19, 21, 37, 48, 53, 68, 122, 123, 124, 125, 126, 151, 165, 250, 290

1.3.6 Mediterranean Coast of France:
17, 18, 19, 20, 21, 29, 68, 114, 163, 248, 250, 290

1.3.7 Atlantic Coast of Spain: Guipazcoa Coast; pers. comm. Drs C. Pascual, J. M^{a}Gorostiaga, A. Gomez Garetta and Dr A. Mulder via Dr H. Stegenga.

2. *Vectors for dispersal of* S. muticum
Whilst movement of the oyster *Crassostrea gigas* is held as the major vector responsible for remote dispersal of *S. muticum* (Scagel 1956, North 1973), a number of mechanisms for marginal dispersal have been proposed, viz. surface drifting of fertile material (Critchley 1981, Norton 1981 a and b, Prud'homme van Reine and Nienhuis 1982, Rueness 1989), floating material entagled in the steering-gear of pleasure craft and ships (Boalch and Potts 1977, Critchley and Morrell 1982, Critchley and Thorp 1985) and internal relocation of *Ostrea edulis* L. and *C. gigas* between European oyster growing areas (Critchley and Dijkema 1984, Gruet 1984). However, the more recent importation of *C. gigas*, directly from Japan, to the Mediterranean coast of France (together with a fresh innoculum of *S. muticum*) is inferred by the disjunct distribution of the alga, together with the occurrence of a number of newly introduced algae of Japanese origin (see Boalch 1985, Gerbal *et al.* 1985, Riouall 1985, Ben Maiz *et al.* 1987, Rueness 1989).
9, 10, 11, 12, 25, 26, 30, 41, 55, 65, 66, 70, 71, 85, 89, 90, 92, 109, 122, 125, 126, 152, 186, 188, 199, 201, 205, 206, 207, 244, 250, 266

3. *Consequences for the introduction of* S. muticum
With the development of often very extensive beds of *S. muticum* within it's new habitats, considerable concern has been expressed and research undertaken to determine the deleterious (and beneficial) aspects of the alga's presence. The alga is also reported to interfere with the recreational usage of waterways.
7, 9, 10, 11, 12, 13, 18, 25, 28, 53, 57, 58, 62, 63, 64, 71, 72, 82, 83, 87, 94, 98, 104, 108, 109, 142, 144, 145, 146, 152, 156, 180, 189, 195, 197, 198, 199, 212, 238, 243, 245, 249, 250, 253, 269, 278, 302

4. *Organisms associated with* S. muticum (Epibionts or subsequent introductions): The diversity and abundance of organisms epiphytic on *S. muticum* are comparatively large; greatest colonization occurs after rapid extension of the alga. In Britain the eipiphytic communities on *S. muticum* are similar to those of the brown alga *Cystoseira nodicaulis* (With.) Roberts (Withers *et al.* 1975, Jephson and Gray 1977, Gray 1978).
11, 12, 22, 30, 41, 66, 71, 80, 91, 92, 93, 120, 122, 145, 162, 186, 188, 212, 250, 269, 277, 302

5. S. muticum — *brown macroalga*

5.1 Taxonomy and identification (publications where the alga is illustrated or included in a guide):
2, 8, 27, 42, 43, 47, 50, 51, 52, 60, 61, 73, 76, 99, 122, 135, 178, 239, 254, 256, 258, 260, 264, 267, 282, 283, 284, 296, 303, 308, 309, 310, 311, 312

5.1.1 Marine flora, phycological surveys or checklists, where *S. muticum* is recognised as a consistuent member:
2, 3, 4, 5, 15, 22, 42, 43, 44, 50, 52, 74, 75, 76, 77, 80, 86, 87, 93, 94, 103, 104, 108, 134, 135, 136, 137, 149, 153, 156, 157, 160, 161, 167, 168(?), 169(?), 175, 176, 185, 192, 193, 194, 220, 223, 224, 227, 229, 230, 231, 237, 254, 255, 256, 258, 259, 261, 263, 264, 265, 266, 267, 272, 273, 274, 275, 279, 280, 281, 282, 283, 288, 295, 299, 300, 301, 304, 307, 308, 310, 311, 312, 314

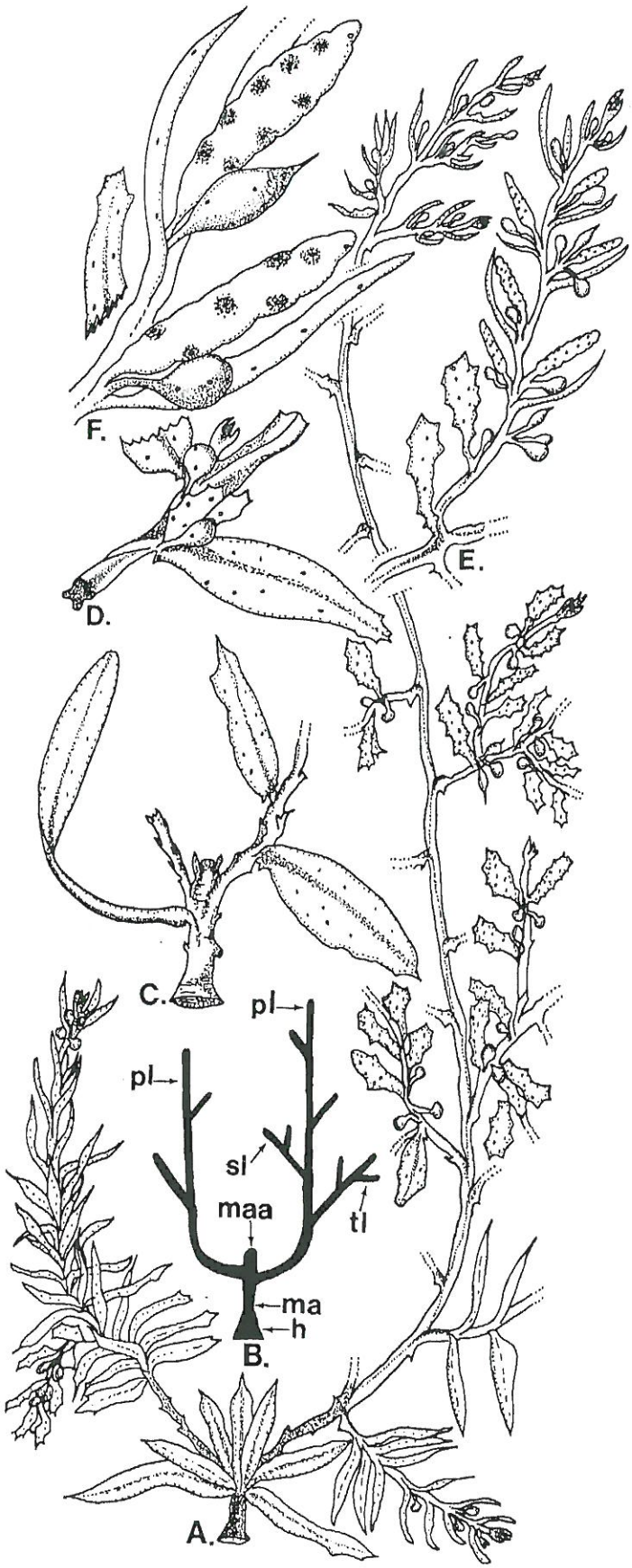

Fig. 1. The morphology of *Sargassum muticum*. A. Juvenile plant, with two primary laterals. B. Stylized plant, h: holdfast; ma: main axis; maa: main axis apex; pl. primary lateral; sl: secondary lateral; tl: teritiary lateral. C: The conical holdfast (for attachment) gives rise to a terete, perennial main axis, from which arise basal laminae and primary laterals. D: The grooved main axis if found to twist, air vesicles and secondary laterals arise in the axil of a lamina. Cryptostomata are evident on the surface of the laminae and air vesicles; E: Receptacles and air vesicles arise in the axils of lanceolate laminae of a tertiary lateral. F: Air vesicles vary in morphology considerably, here spheroidal and pyriform morphologies are illustrated. Conceptacles are arranged spirally upon the receptacle. The conceptacles contain the gametangia. *S. muticum* receptacles contain both male and female conceptacles (androgynous). Plants are self-fertile.

5.2 *Growth – phenology/morphology*:
In Japan *S. muticum* is one of the smaller *Sargassum* species (*ca* 75–12 cm; Yendo 1907) but, as with many other 'weeds', the alga grows considerably larger when transplanted outside its natural range. Lengths of 5–6 m are reported from California, U.S.A. (Nicholson *et al.* 1981) and plants upto 10–12 m have been collected from the Brittany coast of France (personal observation).
36, 39, 40, 46, 55, 56, 60, 61, 72, 78, 79, 82, 84, 88, 106, 110, 111, 113, 117, 118, 133, 145, 154, 155, 164, 182, 184, 191, 196, 202, 203, 216, 217, 222, 271, 272, 273, 285, 286

5.3 *Reproduction, including the phenomenon of 'incubation' of oogonia/germlings on the receptacle surface and early morphogenesis of the sporophyte generation*:
60, 79, 84, 102, 105, 130, 131, 132, 133, 139, 140, 141, 145, 184, 196, 200, 201, 202, 205, 207, 208, 209, 213, 214, 219, 222, 225, 226, 228, 252, 270

5.4 *Physiology, including photosynthesis and temperature/salinity tolerances*:
3, 31, 33, 36, 85, 111, 115, 116, 117, 118, 119, 132, 149, 160, 170, 171, 173, 178, 179, 180, 202, 221, 229, 244, 262, 276, 290, 301

5.5 *Anatomical studies*:
56, 88, 246, 313

6. *Removal/utilisation of* S. muticum
In areas of successful establishment *S. muticum* may form extensive beds. Such populations may affect the ecology of the environment or utilization of a waterway to such an extent that removal of the alga is recommended. This often results in the disposal of large amounts of biomass, which is wasteful, without utilisation. A number of workers have investigated the extraction of commercially useful compounds or the production of biogas from this biomass:

6.1 *Mechanical removal or treatment of problem populations*:
69, 95, 97, 120, 138, 174, 189, 190

6.2 *Applied uses of* S. muticum *e.g. screening for biological activity, storage activity, storage products, toxicity testing and protoplast culture*:
1, 15, 16, 23, 24, 81, 100, 107, 110, 111, 112, 113, 116, 143, 147, 148, 149, 200, 232, 233, 234, 235, 236, 251, 268, 284, 298, 305, 306

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