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An Account of the Attempted Control of an Introduced Marine Alga, *Sargassum muticum*, in Southern England

A. T. Critchley,* W. F. Farnham & S. L. Morrell

Portsmouth Polytechnic, Marine Laboratory,
Ferry Road, Hayling Island PO11 0DG, Hants, Great Britain

ABSTRACT

This paper details the attempted eradication and clearance programme for the introduced brown seaweed Sargassum muticum *(Yendo) Fensholt.*

Since the introduction of this alga to British coastal waters in the early 1970s, populations have increased rapidly, causing a number of recreational and ecological problems. Various methods including hand-picking, herbicides and biological control to combat the spread of the weed have been unsuccessful. Mechanical clearance, a costly alternative, has proved to be a viable proposition; the stages in the development of a working system are presented here.

INTRODUCTION

Sargassum muticum (Yendo) Fensholt, a brown seaweed of Pacific origin related to the common intertidal fucoids, is thought to have been introduced, in recent times, to the coasts of western North America and Europe by the importation of the Japanese oyster *Crassostrea gigas* (Thunberg) (see Scagel, 1956; Anon., 1972, 1982; Druehl, 1973; Farnham *et al.*, 1973; Farnham, 1980; Critchley & Dijkema, 1984). The present distribution of *S. muticum* in European waters is given by Critchley *et al.* (1983).

Sargassum muticum has a perennial holdfast that annually produces

* Present address: University of Natal, Department of Botany, P.O. Box 375, Pietermaritzburg 3200, Natal, South Africa.

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branched long fronds, or primary laterals, which (on the south coast of Britain) rapidly elongate between spring and summer (Jephson & Gray, 1977). In its native waters of Japan the alga appears to be smaller in stature, growing to a length of only *c.* 0·75 m (Yendo, 1907), with other related algae attaining greater lengths and abundance (Yamada, 1955; Segawa, 1968). However, in its new locations of California and southern England, lengths in excess of 5 m have been recorded (Nicholson, *et al.*, 1981; Critchley, 1983*a*, respectively).

Members of the general public in England and N America have coined various vernacular names (Jap-weed, wire-weed and strangle-weed) which indicate some of the problems caused by *S. muticum.* A list of complaints and possible environmental problems includes the following:

(i) Physical hindrance of small boats with outboard engines of up to 20 h.p.
(ii) Clogging of intake pipes, both of boats and industrial installations.
(iii) Floating mats of *S. muticum* foul commercial fishing lines and nets (reports confirmed from Canadian and British sources).
(iv) Floating debris tends to be concentrated by buoyant fronds forming floating mats and creating an eyesore.
(v) Large mats of weeds are eventually cast up on shores and cause problems when rotting, i.e. producing offensive smells on resort beaches.
(vi) Dense growths of *S. muticum* on oyster beds, in British Columbia, made it difficult to see cultured oysters (Scagel, 1956). It was also feared that the buoyant fronds of *Sargassum* attached to the oyster shells could carry them out of the culture area. The extensive development of *Sargassum* populations on French oyster beds may hinder the growth and harvesting of the shellfish.
(vii) Large dense stands of *Sargassum* may cause loss in amenity and recreational use of water areas, e.g. swimming, skiing, sail boarding, dinghy sailing and fishing.
(viii) The presence of dense *Sargassum* stands may affect species diversity of indigenous marine fauna and flora in intertidal pools and the shallow subtidal region.

This report will present the methods used in an attempt to control the alga in southern England, 1973–1981.

Initial discovery, policy formation and publicity campaign

After the initial discovery of attached *Sargassum muticum* at Bembridge, Isle of Wight (Farnham *et al.*, 1973), concern at its presence grew as further populations of the alga were found elsewhere around the Solent. Although *Sargassum* was then only present in relatively small populations, it represented a potentially significant introduction to the British marine flora, the effects of which were feared to be deleterious to the marine ecosystem and usage of shallow coastal waters (Jones & Farnham, 1973). It was also feared that the alga could spread rapidly, as had already been reported upon the western coast of N America (Scagel, 1956; Setzer & Link, 1971).

Owing to the growing concern expressed about the attached presence of *S. muticum*, a group of about 20 scientists (representing a number of marine laboratories, the Ministry of Agriculture, Fisheries and Food, the Marine Biological Association, the Nature Conservancy Council (NCC), Natural Environment Research Council (NERC) and the Scottish Marine Biological Association) convened a meeting at Portsmouth Polytechnic, in May 1973, to discuss possible courses of action available. Although the meeting had no official status, arguments for and against the eradication of *S. muticum* were presented. After discussion it was decided that eradication of *Sargassum* populations should be attempted. As the major areas affected were intertidal (and of particular ecological importance, as at Bembridge, a Site of Special Scientific Interest, SSSI), they were not regarded as suitable for clearance by the then available mechanical methods; neither were commercially available herbicides desirable, because of ecological damage and lack of selectivity. It was felt that hand-picking, though time-consuming, difficult and labour intensive (but highly selective) was the most suitable method (Farnham & Jones, 1974). Such a programme of eradication required a large number of volunteers, each with some knowledge of the identification of the alga and the need to remove the entire plant (to prevent regeneration from the basal holdfast; Fletcher & Fletcher, 1975). The entire holdfast had to be removed and the whole plant taken away from the shore. Any fertile individuals left free to float away, although not able to re-attach, have the potential to spread and initiate new populations (see Norton, 1976, 1981; Farnham *et al.*, 1981; Critchley, *et al.*, 1983).

In September 1973, a *Sargassum* Working Party was formed by the City of Portsmouth Secretariat, to organise the eradication campaign and to collect funds from local authorities. The committee included representatives from local councils, water authorities, harbour authorities, Portsmouth Polytechnic, NCC, NERC and the Department of the Environment (DoE). Subsequently, similar working parties were established by Dorset and Devon County Councils, after large amounts of drift *Sargassum* were found cast upon their shores. To aid the publicity campaign, a *Sargassum* 'Wanted' poster was produced and distributed to suitable outlets (harbour masters, marinas, coastguards, etc.) along the entire south coast of England. The poster described and illustrated the alga, requesting members of the public to report any sightings and to send specimens to Portsmouth Polytechnic. Despite receiving many common seaweeds, this campaign provided a most important method whereby new *Sargassum* populations were discovered.

THE CLEARANCE OF *Sargassum muticum* BY HANDPICKING

Clearance operations began in May 1973, at Bembridge and Portsmouth Harbour, using volunteers from the Polytechnic and the general public, who were made aware of the programme by appeals in the media (Gray & Jones, 1977). This work continued fortnightly upon spring tides until October 1973. *S. muticum* plants became fertile from May onwards that year and released zygotes before they could be removed. Consequently, repeated visits to both sites were necessary to remove developing germlings.

From the beginning of June 1975 until the middle of October 1975, a total of 394 volunteer collecting trips were made, resulting in the removal of 26 tonnes of wet *Sargassum*. In 1974, 356 trips were made, and 5 tonnes were collected (Gray, 1978). The larger collections of *Sargassum* in 1975 were due not only to the increased recruitment of volunteers but also to the increased density and extent of the weed. Volunteers included schoolchildren, local residents, holidaymakers, anglers, fishermen and conservation workers. Unfortunately, despite the increased amount of *Sargassum* collected, overall efficiency of the operation was low, particularly when the settlement of germling plants was prolific and areas previously completely cleared of adult plants quickly became recolonised. Furthermore, in late autumn the *Sargassum* plants were much smaller, and failing light and weather conditions were unfavourable.

As handpicking was very labour-intensive and time-consuming, mechanical clearance methods were considered by a meeting of the DoE Advisory Group in July 1976. Experiments were carried out using tractors fitted with harrows, cultivators and fore-end loaders. Obviously the use of such machinery was restricted to areas of the shore which were accessible at low water. These methods, especially the harrow, removed the *Sargassum* effectively but there were problems with the containment of collected material, and there was also considerable physical damage to the shore. Therefore, operations returned to handpicking. The then available mechanical methods had a limited use upon areas of firm shore, with a low ecological importance, e.g. the beach at St Helen's, Isle of Wight.

Handpicking of *Sargassum* continued until September 1976, when it became obvious that the method was no longer effective and was thus abandoned (Gray & Jones, 1977).

OTHER METHODS INVESTIGATED FOR THE CONTROL OF *Sargassum muticum*

Herbicide treatment

The effects of a wide range of herbicides on the growth of *Sargassum muticum* have been tested and evaluated by Lewey (1976) and Lewey & Jones (1977). However, none of those compounds tested were found satisfactory for use, due to lack of selectivity, the large doses required, the period of time the herbicides need to be in contact with the alga and the problem of chemical application in the marine environment. The most effective herbicides of those tested were Diquat, Stomp, copper sulphate, sodium hypochlorite, K-lox and Nortron. However, all these compounds affected not only *S. muticum* but also other algae tested, including *Ulva* spp. and *Ceramium* sp. Because of these effects and lack of specificity, the herbicide programme has largely declined, although new compounds are still being evaluated.

Biological control

Gray (1978) investigated the grazing of *S. muticum* as a possible means of biological control. However, he found that only small germling stages and pieces of *Sargassum* already damaged by desiccation were susceptible to mollusc grazing. The grazing of *S. muticum* by various amphipods (e.g. *Gammarus* spp.), which seemed to graze preferentially on the primary lateral apices of the alga, has been investigated. Grazing by sea urchins *Echinus esculentus* L. was also investigated as these are known to control the distribution of *S. muticum* in North America (Phillips & Fleenor, 1970; De Wreede, 1978, 1980), but maintaining experimental animals in turbid Solent waters was unsuccessful. The best animal used in grazing experiments was found to be the sea-hare *Aplysia punctata* Cuvier. The problem in the use of this animal was one of supply, since they were scarce within the Solent area. Small numbers were obtained from the Channel Islands and south-west Britain and they were found to graze at a significant rate (e.g. four adults consumed 15 g of *Sargasssum* in 24 h). However, all grazing species tested, when given a choice, preferred a diet of other macro-algae, with the exception of *Chondrus crispus* and, in the case of *Aplysia, Fucus serratus* L.

It was concluded that no marine herbivore was likely to restrict *S. muticum* distribution appreciably within southern England. This is a consequence of the scarcity of animals which graze heavily on *S. muticum* and the preferences shown by them for a diet comprising other algae.

Although there may be heavy losses of germling plants of *S. muticum*, especially during summer, this is part of the natural thinning process which is dependent upon germling density and leads to fewer adult plants competing with one another (De Wreede, 1980; Critchley, unpublished data). The grazing of winkles *Littorina* spp. along the fronds may even aid the dissemination of *Sargassum* by causing fertile laterals to break off and float away.

THE DEVELOPMENT OF A MECHANICAL CLEARANCE PROGRAMME FOR THE CONTROL OF *Sargassum muticum* POPULATIONS

As the removal of *Sargassum muticum* by hand was found to be unsuitable for large-scale clearance, a meeting of the DoE Advisory

Group decided in July 1976 to consider mechanical methods of clearance. Possible options for mechanical clearance were investigated and it was concluded that no suitable, commercially produced machinery was available. Most of the devices were intended for controlling macrophytes in freshwater bodies such as rivers, canals and lakes. In such situations both herbicides (see Robson, 1978) and biological control (Room *et al.*, 1981) may be effective, in addition to the traditional cutting methods. A further more detailed report was commissioned by the Design and Projects Division of Vickers Limited Engineering Group, based at Eastleigh, Hampshire.

The available methods of weed collection were reviewed, given the constraints of operating areas, manning costs, running costs, operating depth, etc. Devices had to be assessed for their suitability for use in the marine environment, including operating in open sea conditions. It was considered that the device would be operated by relatively inexperienced people in exposed, tidal waters between the months of March and July (when *Sargassum* plants are longest and potentially most troublesome). Further considerations included transportability and manoeuverability of the craft, on land and sea, and operator protection and safety. When the relative cost of devices were considered, their versatility for other applications was also considered to be important. The 'weed clearing season' was judged to last up to 5 months and a craft that could be used during the remainder of the year, for other purposes, would be financially attractive.

The cutting and collecting machinery was also studied for their suitability for use in a salt water environment, varying depths of operation, length of weed needed for efficient cutting and the entire capture of weed removed.

The main conclusion of the Vickers' appraisal was that none of the available devices satisfied all of the criteria for the efficient removal of *Sargassum*. Two devices were mentioned for possible consideration. The first was extremely expensive at around £80 000–100 000 (December 1976 price) and was not considered to be entirely satisfactory even for its intended use in harvesting *Ascophyllum nodosum* (L.) Le Jol., a seaweed of commercial value, similar in many features to *Sargassum muticum*. The second was cheaper (£25 000 for the basic craft; December 1976 price), but the then available cutting device (for freshwater weeds) was not considered to be of a basically suitable design. In both of these designs a reciprocating blade was used as the cutting device and was judged to have a number of disadvantages, including the following: indiscriminate cut, uneven cutting profile, problems with collecting weed once cut and a short working life.

The Vickers' report gave consideration to collecting attached *Sargassum* by a pulling device rather than a cutter. Such a device was considered to have the following advantages: (1) greater selectivity (*Sargassum* plants tend to float above other seaweeds); (2) mechanical simplicity; (3) greater ease or efficiency in collecting detached plants; and (4) greater likelihood of a more complete removal of plants.

RESEARCH AND DEVELOPMENT OF MECHANICAL METHODS SPECIFICALLY FOR THE REMOVAL OF *Sargassum muticum*

As reports of the general unsuitability of commercially available weed-clearance machinery were received, the Department of Mechanical

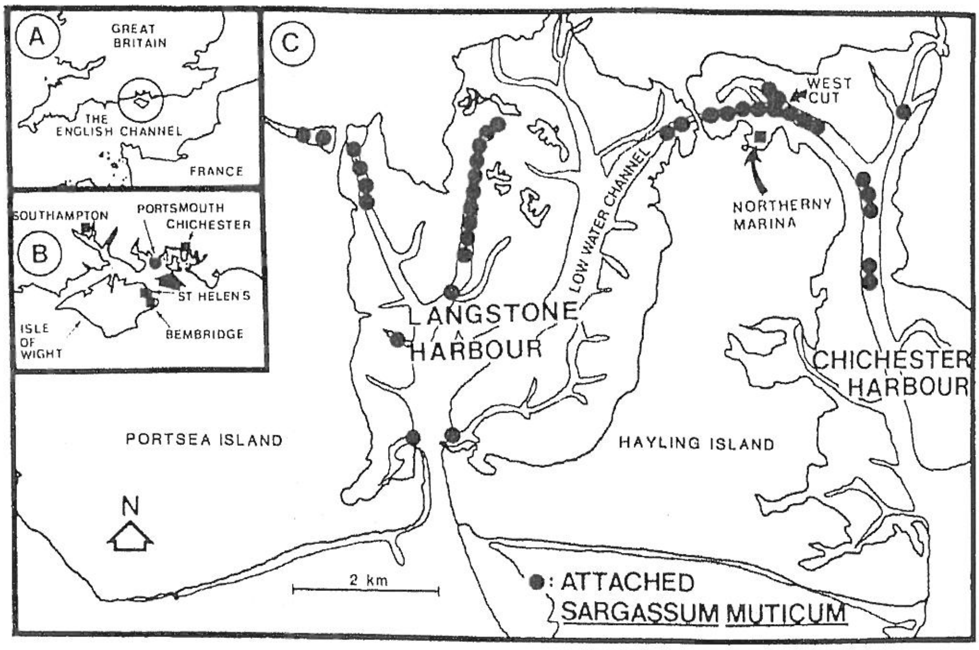

Fig. 1. (A) Circle indicates position of Isle of Wight in relation to southern England. (B) The Solent area of southern England; large arrow indicates Hayling Island. (C) Langstone and Chichester Harbours, showing the distribution of *Sargassum muticum* (1980) within the low water channels of the harbours and the positions of Northerny Marina and West Cut channel.

Engineering and Naval Architecture at Portsmouth Polytechnic undertook the task of developing machinery suitable for the clearance of *Sargassum*. The design objectives proposed by the Polytechnic team were that the machinery should be simple and safe to handle from conventional inshore fishing boats and effective in removing weed from small areas. The 'hardware' should also be cheap to manufacture and cause minimal damage to the sea-bed and unnecessary removal of other marine species.

Mechanical clearance became important in ensuring access, during the summer months, to Northerny Marina, through the West Cut channel at the northern end of Langstone Harbour, near Portsmouth (Fig. 1).

The research and development programme carried out by the Polytechnic began with initial phases of identifying the mechanical characteristics of the weed, to building prototype hardware which could be handled from an inshore fishing boat. Later the purpose-built research vessel *Toriki* (Japanese for harvester; see Fig. 2) was constructed to carry out sea trials of machinery designed and constructed for the removal of *Sargassum*.

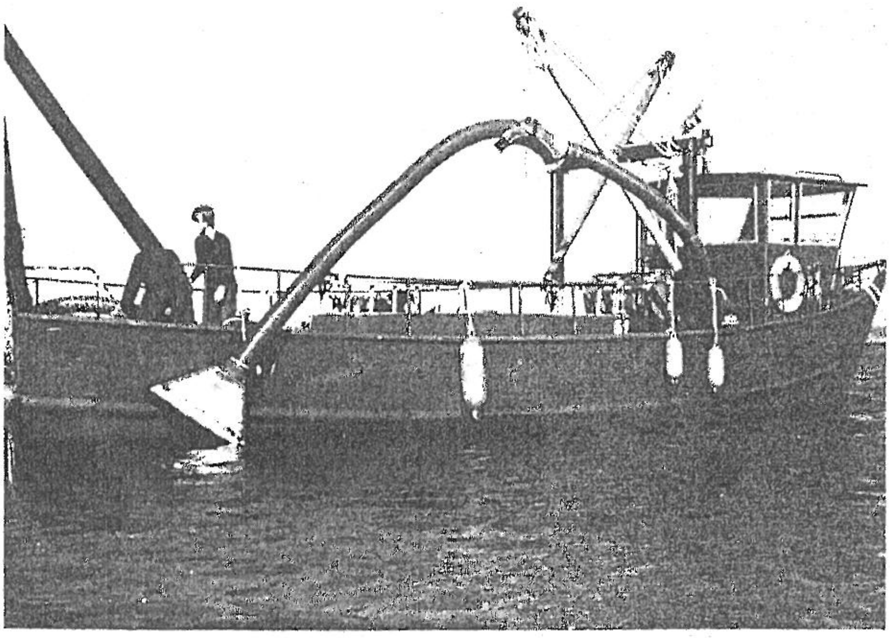

Fig. 2. *Toriki*, a purpose-built research vessel constructed to test prototype clearance machinery. The vessel has a large working area at the rear, where a trawl and net are just visible. Attached to the side of the vessel is a trial suction-head, used to lift *Sargassum muticum* from its substratum.

Initial observations upon *S. muticum*, relevant to clearance procedures, were as follows:

(1) Frond length and plant density were found to vary in different areas according to substrata type and the age of populations.
(2) The weed floats upright in still water only; in moving water the fronds incline sharply with the current.
(3) Plant statistics.

Maximum length of frond (May–July)	6 m
Maximum diameter of axis of retrieved frond	2 mm
Maximum number of fronds on one stone	25
Maximum density of plants (plants > 1 m in length)	$18\ m^{-2}$
Maximum tensile strength of frond (measured mid-summer with lower values earlier and later in the year)	$5,5\ MN\ m^{-2}$
Weight of unit volume of wet weed as retrieved.	$800\ kg\ m^{-3}$

The three main techniques developed for the mechanical removal of *Sargassum* were: (a) trawling, (b) cutting, and (c) suction clearance. These are discussed below.

Trawling methods

The trawling technique was based upon a modified oyster dredge, raised upon shoes, which operated 50 cm above the sea bed, following the sea-bed contours. Operation required a crew of three. The combination of operating skills and the expertise of fishermen with cheap and simple hardware formed an attractive proposition for the removal of *S. muticum*.

The design team found that some method of engaging *Sargassum* was required along the front of the trawl (termed 'bar weed-head'), with a net for the collection of weed at the rear. A prototype trawl with serrated teeth and circular bars was used to compare the effectiveness of the two different teeth.

In operation of the trawl, *Sargassum* is not cut but pulled away together with attached substrata (stones, flints, shells, etc.). The quantities of weed which are not retained by the net are small. Field trials showed that the trawl shoes caused little damage to the sea-bed. Some environmental damage occurred by the removal of marine species associated with *S. muticum* and the bottom substrata; mainly crabs *Carcinus maenus* (L.) elvers *Anguilla anguilla* (L.) and some oysters to which the alga was attached.

A fully loaded trawl had to be off-loaded into the hold of the boat, or a waiting hopper-vessel. The overall efficiency of this method was found to be limited by the time taken to retrieve and store the collected weed and then restream the trawl for further collection of *S. muticum*.

In a final trial of the trawl, a 2·8 m bar weed-head with a staggered teeth configuration and a central tow removed 8 tonnes of *S. muticum* in less than 1·5 h operation from an area of dense long weed (>1 m length). An efficiency rate of 90% was achieved, with the removal of long weed.

The costs of *Sargassum* removal are variable, but the following figures have been obtained:

Weight of weed removed in 6 h	6 tonnes
Area of weed cleared	3000 m^2
Cost of removal (disposal not included)	£20 per tonne (wet weight)

Hurley (1981) separately costed the use of the trawl at £22·38 per tonne (including disposal). This is only a crude indication of costs, which may vary with plant length, density, trawl size, tide, weather, crew efficiency and site changes, i.e. short weed clearance of low-density would lead to higher costs per tonne of weed removed but a lower cost per unit area.

Cutting methods

This approach may be necessary where it is desirable to minimise disturbance of the sea-bed and avoid removal of attached substrata. The cutting method was worthy of investigation if the commercial harvesting of *S. muticum* was to be considered.

The cutting technique required the following three mechanical assemblies: a power source (boat-housed), a form of power transmission and, finally, the cutter. An early prototype machine, converted from an agricultural corn-cutting implement, was powered by either a pneumatic or hydraulic energy source. The framework for the cutting head was similar to that of the trawl and housed both cutters and underwater drive units. Again the implement was mounted upon shoes and could be operated from the boat by a central tow; the head following the contours of the sea bed.

The research and development programme investigated various reciprocating blade configurations (using triangular and rectangular bar teeth) on differing spans, with adjustable longstroke (up to 150 mm) and slow speed (400 rev min^{-1}) characteristics. The parameters could be adjusted and tested to obtain optimum cutting characteristics during field trials.

Field operations have shown that the sea-bed following cutters can be satisfactorily operated and controlled from the vessel. The primary performance restraints were the tooth blade shape of the cutter and clearance of the weed from the cutter head. Again, the major limitation in overall effectiveness was found to be retention and handling of cut *Sargassum*. There are three options for weed handling when using the cutters:

(1) The weed can be restrained behind the cutters, as with the trawl (Fig. 3). However, the net requires frequent emptying and the cutter can be difficult to restream behind the boat for continued operation.
(2) One vessel could be used to cut, using a head free of restrictions from a net, with a support vessel to collect cut *Sargassum*. However, efficiency in collecting all material is not high and some loss of the alga must be accepted.
(3) The weed is cut and allowed to drift freely. This would be a cheap and effective method of *Sargassum* clearance, but could result in increased spread if the fronds floating away are (or become) fertile.

Although the prototype cutters suffered from some blockages in dense stands of *Sargassum*, in a final trial (1980) within an area of low weed density, using a 1·5 m wide cutting head, a strip 1 m wide was cut at approximately 3 knots, leaving behind cut weed of 0·3 m in length. As the cutting heads were all at developmental stages, cost analysis was difficult. Hurley (1981) costed the use of air-driven cutters with a retention cage and disposal of collected weed at £24·08 $tonne^{-1}$. It is thought that the use of the cutting technique should be restricted to ecologically sensitive areas, where use of the trawl would be unacceptable due to environmental damage.

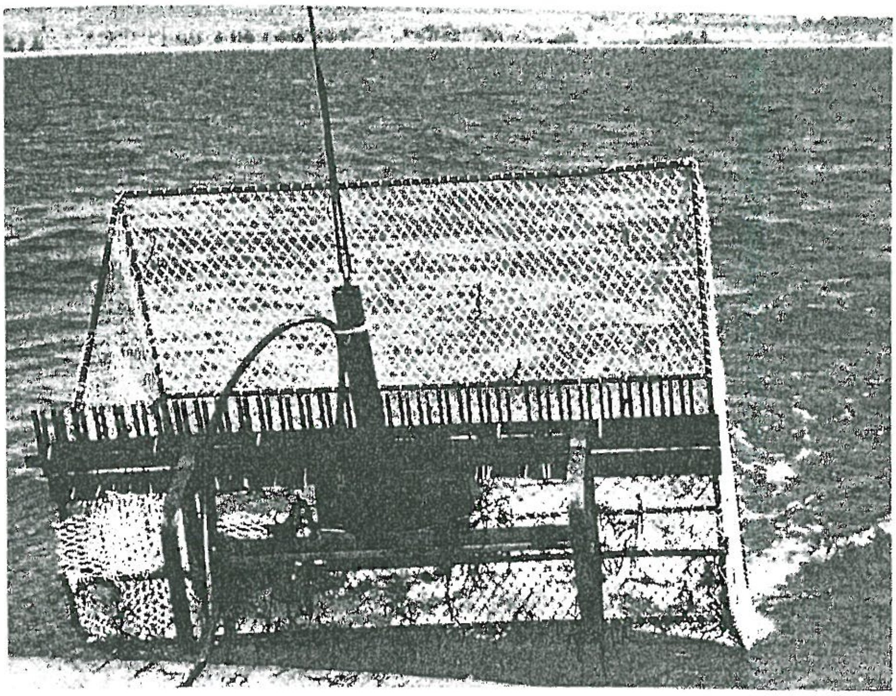

Fig. 3. Purpose-built cutters (square-peg teeth configuration), with retaining net for cut weed.

Suction methods

Suction techniques have been used as effective methods of dredging sea-beds comprising materials of low cohesive characteristics (e.g. silt and mud). It has to be accepted that any suction system must cause changes in the sea-bed configuration. Any material alive or inanimate (below a limiting mass which cannot be lifted) in the path of the suction head will be removed. This system could only be considered appropriate for specific areas where commercial or amenity interests were of primary importance. Such areas include marinas, harbour channels and amenities and areas surrounding building structures or work zones, etc.

The most suitable suction head (Fig. 2) was designed to operate on the 'jet-lift' principle, using air or water to the detail design stage, and a 'torque-flow' principle was developed to a viable working system. This has been shown to be very efficient for *Sargassum* removal in particular conditions. With algal frond lengths of up to 1·5 m, of medium density, and attached to substrata of less than 100 mm diameter, a swathe of 1·5 m wide could be cleared at 2 knots, with the suction head some 1 m above the sea-bed. However, high densities of long *Sargassum* (> 1·5 m) and large diameter substrata (> 100 mm) were found to block the suction head and tube. All collected material was captured in a net cage at the rear of the suction discharge nozzle. Again, retention of all *S. muticum* fragments was a major problem, as forces within the water column tended to break the weed into small pieces, which were then able to escape from the 50 mm mesh net. The operation of the suction method has been costed at £22·56 $tonne^{-1}$ of disposed *S. muticum* (Hurley, 1981).

DISPOSAL OF COLLECTED *Sargassum muticum*

With all methods of *Sargassum* clearance so far mentioned, the collection and disposal of the weed formed a major limitation in overall efficiency. The major problem was to prevent the dispersal of weed after removal. Any free-floating material would only act as a further source of drifting material and possibly enhance the spread of the alga (Critchley *et al.*, 1983). Therefore, the cut weed had to be constrained, retrieved and removed at an off-loading point. It could not be assumed that good quality concrete slips or quayside cranes were available, or even existed, near to the most troublesome *Sargassum* beds. Furthermore, disposal of *Sargassum* demanded handling the weed on land to transporters and subsequent removal to a point of disposal.

At present, *S. muticum* has no commercial value, either to farmers as fertilizer or as a source of alginic acid (which is poor both in yield and quality from the alga). It is possible that renewable sources of this brown seaweed could be used in the production of paper (see Kiran *et al.*, 1980), or biogas (see Rao *et al.*, 1980), but considerable research is still required to determine the suitability of *S. muticum* for such purposes. At present, the weed must merely be disposed of at a suitable site on land.

THE EFFECTS OF REMOVAL UPON *Sargassum* POPULATIONS

Mechanical clearance must be considered as an annual undertaking (Farnham *et al.*, 1981; Morrell & Farnham, 1981), with clearance operations taking place between April and June. This early summer period is at a time when the alga is at its greatest length, but before the plants have become fully fertile. Monitoring of experimental areas has demonstrated that mechanical clearance rapidly decreases the length of fronds, but during the following growth season elongation of primary laterals in cleared and non-cleared areas is similar (Morrell & Farnham, 1981). It has been noted that surviving *Sargassum* plants, developing in a previously cleared region, become fertile sooner, presumably in response to damage of their apical meristems. Furthermore, clearance of a mature *Sargassum* stand results in the effective removal of many of the older plants, allowing regeneration of the population from an increased density of juvenile plants. Therefore, re-growth may actually be at a greater density than prior to its clearance (Morell, unpublished).

FORMULATION OF POLICY ON THE MECHANICAL REMOVAL OF *Sargassum muticum*

As a guide to the use of mechanical methods to control *S. muticum* populations, the model in Fig. 4 has been proposed. It will be seen that unless there is considerable input of complaints from water users the best policy may be to allow the *Sargassum* population to develop under natural influences. However, if opinion is such that the weed should be removed, an assessment of local parameters and ecological importance is required. A policy of monitoring the affected sites should also be implemented to discern the long-term effects of the mechanical operation.

DISCUSSION

The *Sargassum* clearance programme was a novel venture in that the extensive control of an unwanted 'marine weed' had not been tried before, even though problem seaweeds have been previously encountered (Ridout, 1956; Dunn, 1972). The whole experience provided a useful exercise in dealing with other potentially troublesome introduced seaweeds, should they occur. Farnham (1980) gave an account of other exotic algae occurring within the Solent area of southern Britain. These algae have remained relatively confined and are now considered to add to the algal diversity, rather than present any potential threat to the ecology of the area. Notwithstanding this, it will be interesting to follow

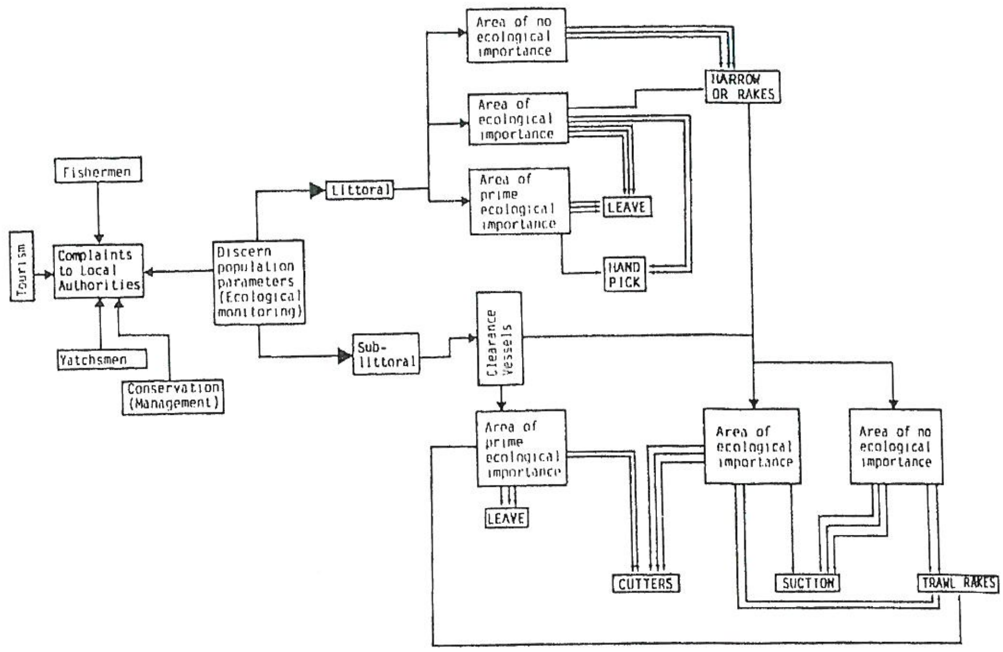

Fig. 4. A model for the proposed control of *Sargassum muticum*, with reference to the ecological sensitivity of affected areas. After a decision on the ecological value of the site has been made, connecting lines leading to available courses of action are indicative of the desirability of various methods of clearance. ≡ = most desirable; = = intermediate; — = least desirable.

the distributions of *Laminaria japonica* Aresch, *Undaria pinnatifida* (Harvey) Sur. and *Spaerotrichia divaricata* (C. Ag.) Kylin, which have been introduced to the Mediterranean waters of southern France (L'Étang de Thau) presumably with the importation of Japanese oysters (Pérez *et al.*, 1981; Riouall, 1985).

Furthermore, a candidate with a high potential to become a troublesome imported alga is the giant kelp *Macrocystis pyrifera* (L.) C. Ag. The French alginate industry have already cultivated this alga, introduced from California, for a trial period in the open sea off the coast of France (Pérez, 1973; Dizerbo & Floc'h, 1974; Franklin, 1974; Boalch, 1981, 1985). Should this alga 'escape' from cultivation and grow uncontrolled along the European coastline, in a similar manner to *S. muticum*, then methods of mechanical control would certainly be necessary. The Wildlife and Countryside Act (1981) of Great Britain prohibited, for the first time, the importation of alien marine species, including algae. Unfortunately, as pointed out by Critchley & Dijkema (1984), invasive biota show no regard for international boundaries.

CONCLUSIONS

Sargassum muticum has increased its European range considerably, expanding its distribution to occupy many new localities and different habitat types (Farnham *et al.*, 1981). Because of the alga's size potential, rapid growth rate and high density/standing stock, the presence of *S. muticum*, at certain sites, causes environmental problems.

The occurrence of *S. muticum* in European waters has caused a reduction to the recreational usage of marine waters, in particular, the Bembridge Lagoons (Isle of Wight) and the low water channels of Langstone Harbour (see Critchley, 1983*b*). The ecology of areas colonised by *S. muticum* has changed noticeably, with the presence of a large standing stock of alga, and its associated epibionts (Withers *et al.*, 1975), in areas where few macrophytes were found, prior to the introduction of *Sargassum* (Farnham *et al.*, 1981; Critchley 1983*b*; Critchley *et al.*, 1983).

In the absence of long-term (permanent) control measures viz. chemical/biological control, mechanical clearance is proposed as palliative. A decision as to which method of mechanical clearance is applicable to a particular problem area requires ecological investigation and continued monitoring for impact assessment.

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