National Institute of Water & Atmospheric Research Ltd
Te Tari Taihoro Nukurangi

NIWAR

Research directed towards the management of sea lettuce in Bay of Plenty coastal waters

by

Taupo Research Laboratory
National Institute of Water and Atmospheric Research Ltd
P O Box 415
Taupo, New Zealand

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Contributors:

I Hawes *
J Hall†
R D Pridmore †

* NIWAR Freshwater
P O Box 8602
Christchurch

† NIWAR Ecosystems
P O Box 11-115
Hamilton

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Executive Summary

The processes which need to be studied in order to effectively manage sea lettuce populations in Bay of Plenty coastal waters are identified in this report. Each process is reviewed in terms of existing knowledge and required information and recommendations for research programmes are given and prioritised in the summary section.

Aim

The aim of this report is to identify research directions required to understand the environmental controls on sea lettuce growth and how these may be manipulated to manage problem growth.

Introduction

Sea lettuce is the collective name given to algae of the genus *Ulva*. Sea lettuce has a world-wide distribution and under some conditions can grow to great size and abundance (e.g. Sawyer 1965). Once considered an opportunist (ruderal) plant, there is now growing appreciation of the resilience and flexibility of the plant in withstanding adverse conditions and low light levels (Vermaat and Sand-Jensen 1987; Sand-Jensen, 1988). It is now best thought of as a persistent plant which is capable of rapid growth responses to favourable conditions rather than simply as an ephemeral "weed".

Biology of Ulva

Sea lettuce is a leafy green alga, formed of a 2 cell thick blade (the thallus) which is initially attached to the substratum by a simple holdfast. Parts of or entire blades may become detached and continue to grow, forming loose-lying communities. While the thalli are typically annual, the holdfast is frequently perennial and gives rise to new blades during each growing season (Fritsch, 1971).

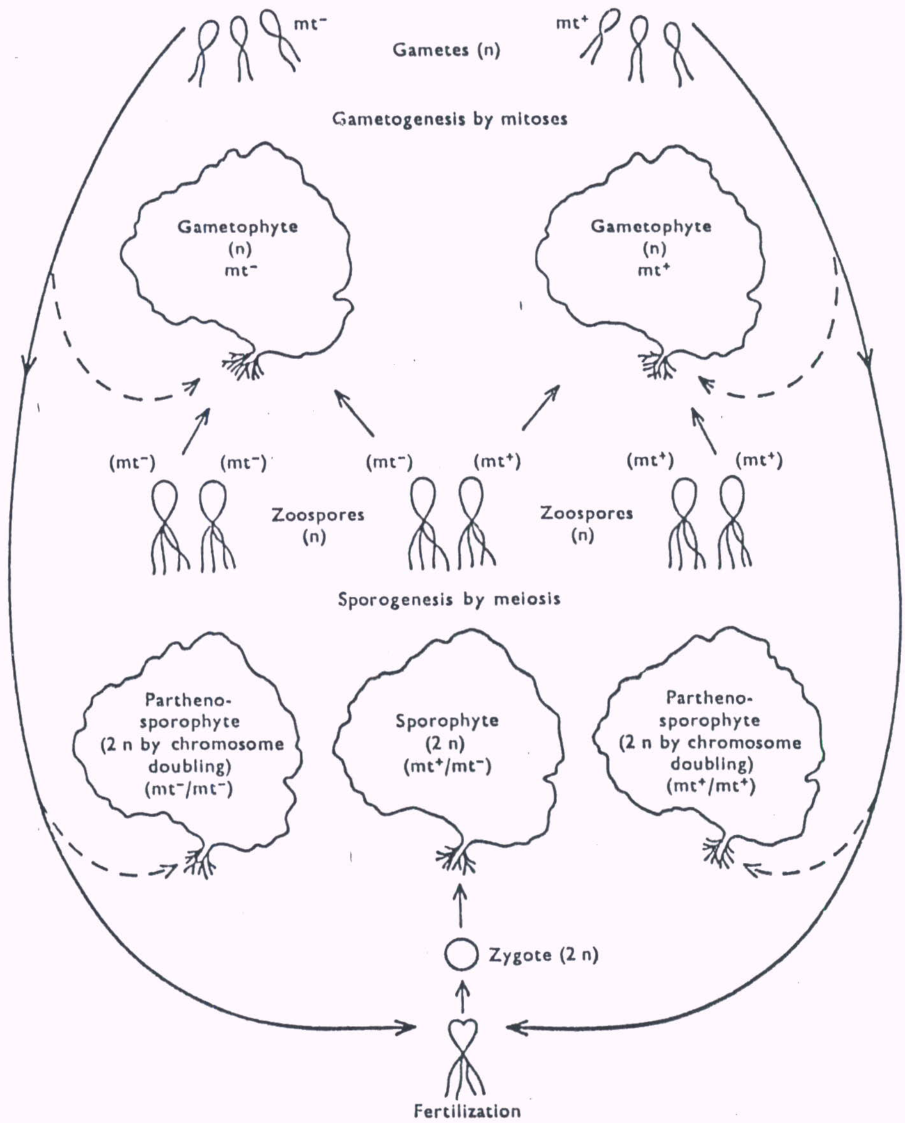

Figure 1. The life cycle of sea lettuce, mg^+ and mt^- indicate mating type (sex) of the plant. Solid lines indicate "normal" life cycle, dotted lines "abnormal" cycle. See text for details.

The life cycle is traditionally viewed as an alternation of haploid and diploid generations. Haploid thalli (gametophytes) release motile gametes, which fuse and give rise to diploid thalli (sporophytes) morphologically identical to the gametophytes (Figure 1). Sporophytes release motile zoospores which give rise to new gametophytes (Solid lines in Figure 1). This simple reproductive cycle is complicated by the capacity of gametes to give rise to gametophytes or to sporophytes without undergoing fertilisation (Dotted lines in Figure 1 - Field, 1970; Philips, 1990). Following germination approximately 2-3 months is required for plants to reach maturity and commence sporulation (Phillips, 1990). Sporulation usually commences at the edges, and may involve the whole plant. Areas of plants which have undergone sporulation are devoid of cell contents and white.

<u>Blooms of sea lettuce</u>

Species of *Ulva* are recognised as natural components of the low to mid shore zones of many littoral ecosystems world-wide (e.g. Round 1981). Profuse growths of *Ulva*, and other green algae, in response to nutrient enrichment from sewage discharges, have also been widely recognised for many years, (e.g. Cotton, 1910; Sawyer, 1965; Reise, 1983; Soulsby *et al.* 1985). Indeed, sea lettuce is so responsive to nitrogen and phosphorus enrichment that it can be used as a monitor of localised enrichment (Levine, 1984; Ho, 1987). Blooms of sea lettuce and similar algae are not only of considerable aesthetic and economic importance (Sawyer, 1965), but also have adverse impacts on other benthic biota, including commercially important species (Reise, 1983; Thrush, 1986; Olafsson, 1988).

Accumulation of sea lettuce has been clearly linked overseas with sewage pollution. This, however, may not be the single most important factor involved in Bay of Plenty coastal waters, where the plant grows to nuisance proportions. Biomass accumulates when growth rates exceed loss rates. Growth may be affected by a wide range of factors, including availability of spores in addition to nutrient concentrations. There are few data on loss processes of sea lettuce but Owens and Stewart (1983) estimated total monthly losses of up to 700% of a population of *Enteromorpha* (an alga similar to sea lettuce) from a small Scottish estuary. Loss processes include grazing, advection, washout, sporulation and burial. Many of these processes are interactive and in some cases there is not a clear distinction between losses and gains. The aim of research directed at managing sea lettuce in Bay of Plenty coastal waters should be as far as possible to quantify these processes in terms of their effects on population dynamics and to identify how management decisions can then be made to directly or indirectly control biomass. This report briefly reviews information on sea lettuce from the international literature and identifies areas where research is required to understand existing problems.

Factors affecting growth and loss processes

Nutrients

There is no doubt that growth of sea lettuce, and related algae, is stimulated by nutrient enrichment. Even very small increase in NO_3-N or NH_4-N can cause massive increases in growth (e.g. from 1.4 to 2.8 mg m^{-3} NO_3-N led to a many-fold biomass - Harlin and Thorne-Miller, 1981). N and P status of sea lettuce can be related to ambient concentrations (Ho, 1987), but its ability to take up and store nutrients received in pulsed supply (Rosenburg and Ramus, 1984; Ramus, and Venable, 1987; Fujita *et al.* 1988, 1989) means that spot measurements of concentrations in water should be interpreted with care.

A first priority for research should be to determine whether populations of sea lettuce are limited by nutrients, and if so, which ones.

This would be best accomplished by analysis of the nutrient content of plants and the use of physiological indicators of nutrient deficiency rather than relyiung on water chemistry data. The N:P ratio in Tauranga harbour (close to 10) suggest that either N or P are likely to be limiting. Fujita *et al.* (1989) report critical N tissue contents of >3% dry weight for *Ulva rigida* when grown on NH_4-N and >2.4% when grown on NO_3-N as indicating the onset of N sufficiency, with minimal tissue (subsistence) content of 1.2% . Nitrogen saturated growth rate was 10-15% day^{-1}. Critical internal concentrations for sea lettuce in the Bay of Plenty area should be determined and applied to field data on plant nutrient status. The major source of nitrogen (NH_4 or NO_3) should also be determined though plants may simultaneously take up both species of nitrogen (Rosenburg and Ramus, 1984). Specific uptake assays will provide information on both critical tissue N contents and the likely source of nitrogen and hence most likely effective management regime. Sewage disposal is likely to provide mostly ammonium-N while river drainage will supply mostly nitrate-N. Critical tissue phosphorus concentrations of 0.1-0.2% are likely to result in the onset of phosphorus limitation. If Bay of Plenty populations are nutrient limited (either by N or P), control of nutrient-rich discharges may have a rapid effect on population size.

Dense populations of sea lettuce can reduce CO_2 concentrations in sea water, causing a correlated increase in pH (Frost-Christensen and Sand-Jensen 1990). These authors argue that in dense stands of sea lettuce , in stagnant water, limitation of growth due to low dissolved inorganic carbon (DIC) concentration may be as much as 80%. However, they suggest that under normal field conditions, DIC limitation is unlikely. We suggest that pH or DIC concentration are unlikely to be serious controls of sea lettuce growth in Bay of Plenty waters, except where extensive areas of stagnant water occur with large populations of sea lettuce.

Temperature

Sea lettuce is tolerant of low temperatures and even freezing (Vermaat and Sand-Jensen, 1987), but maximum biomass in Puget Sound, USA, can be correlated with maximum temperature (Thorn and Albright, 1990). Maximum summer water temperature in the Puget Sound study area was 15-16°C. These data are consistent with the temperature-growth relationship determined for a population of sea lettuce in Christchurch, New Zealand, where growth rate increased with increasing temperature to a maximum of 16-20°C (Steffensen, 1976). Above 20°C, growth rate in the Christchurch population fell rapidly, reaching zero at 25°C. *Temperature in Bay of Plenty coastal habitats may therefore be an important determinant of growth rates and should be monitored. Any historical records linking water temperature and algal growth should also* *be examined. The relationship between temperature and growth in Bay of Plenty populations of sea lettuce should be ascertained as this may vary with latitude.*

Light

The importance of light in controlling growth rates of sea lettuce is not clear. While temperature was identified as the major factor determining growth rate of sea lettuce in Puget Sound, 48°N, increasing irradiance in spring above a surface daily average of 46 µmol photons m^{-2} s^{-1} initiated the annual increase (Thom and Albright, 1990). The compensation light intensity for *Ulva lactuca* is much lower than this, at <1 µmol photons m^{-2} s^{-1} (Henley and Ramus, 1989), though this value varies with previous history of light exposure (Sand-Jensen, 1988). Light saturation of photosynthesis in *Ulva curvata* is also variable according to previous light history but occurred at high light intensities, up to 910 µmol photons m^{-2} s^{-1} (Ramus, 1983). Adaptation to low light in *Ulva lactuca* can reduce saturating radiation flux to <50 µmol m^{-2} s^{-1}. Adaptation to the type of fluctuating light experienced in tidal waters is likely to be to optimise production rate (Henley and Ramus, 1989) and will be site-specific. These data suggest that light will have a significant influence on growth of sea lettuce, particularly where attenuation is occurring by suspended solids in overlying water.

In relation to light two factors need to be determined for Bay of Plenty waters, firstly what are the in situ light fields encountered by sea lettuce and secondly the response of the plants in terms of growth.

Sporulation

The production of spores is both a loss and a growth-related process. While spore settlement is an essential prerequisite to blade formation, spore production involves the loss of cell contents and may result in complete tissue loss from a plant.

The stimulus for spore production in sea lettuce is not clearly understood. In cultures it can be induced by a change of medium. In the field, in Port Phillip, Southern Australia, spores are produced year round, except for late March-early June (Phillips, 1990), with plants taking 2½-3 months to reach maturity. Cotton (1911) quotes several sources in support of the view that sporulation only occurs in attached plants (not in loose blades). Other authors have suggested that nutrient rich conditions delay the onset of sporulation and hence enhance vegetative growth. The issue of location, timing, quantity and trigger of sporulation is clearly of critical concern as it represents a significant potential loss of tissue, and the first stage in colonisation. *The sporulation process needs to be investigated in Bay of Plenty waters, particularly to answer the questions; is biomass accumulation due to the absence of sporulation as a growth stopping mechanism, and when and where are new innoccula produced.*

Desiccation

Sea lettuce is able to withstand desiccation when exposed to air at low tides and to maintain net photosynthesis down to 35% water content (Beer and Eshel, 1983). Rate of photosynthesis is lower in air than in water and the balance between rate of desiccation, period of exposure and net growth is likely to determine the maximum vertical extent of the plant in the intertidal zone (Beer and Eshel, 1983). Protection from desiccation, either by waterlogged substrata or by persistent flows of water may therefore enhance the potential area for colonisation of sea lettuce in Bay of Plenty harbours. *The extent to which desiccation governs distribution and growth rate should be examined by determining critical water contents for mortality and for net growth. The desiccation rates of field plants should be examined in areas of high and low biomass.*

Grazing

Grazing can be a very important control on population size and structure in intertidal algae. Browsing animals, such as sea urchins and snails, can reduce sea lettuce to a short turf or eliminate it altogether (Round, 1981). Some fish, particularly mullet, eat sea lettuce and related algae.

Most information on grazing of intertidal algae has been gained from rocky shores, where removal of grazers promotes rapid growth of algae. Indirect evidence for grazer control is also gained from the rich growth of fast growing algae, including sea lettuce, following removal of grazers by toxic pollutants (Round, 1981). There is little quantitative information on grazer control of sea lettuce on soft shores. *Grazer manipulation experiments, which normally take the form of exclusion or enclusion cages, in areas of high and low density of sea lettuce, would be an appropriate method to investigate the role of this process in population dynamics.*

Burial

There is little information on the incorporation of sea lettuce into sediments. Owens and Stewart (1983) estimated monthly loss rates of 700% from an *Enteromorpha* population (related to sea lettuce) in a small estuary to be mostly due to burial.

Sea lettuce is likely to be tolerant of extended periods of burial, as it survives exposure to extremely low radiation fluxes, anoxia and sulphide for up to two months (Vermaat and Sand-Jensen, 1987). This may be due to heterotrophic uptake of organic substrates (Markagar and Sand-Jensen 1990). However, prolonged burial is likely to relate in decomposition, which may represent a significant local source of recycled nutrients (*cf* Birch *et al.* 1981).

Advection, washout and hydrodynamics

The close linking of these three processes means that they are best discussed together. The rate and extent to which plants are moved around in estuaries and washed out to sea will depend on the movement of water and meteorological conditions. Hydrodynamics will also determine the distribution of localised nutrient inputs and any pulses of spore production. Influx of coastal water may act as a nutrient dilution (or possible concentration if upwelling is occurring) and the degree of tidal flushing will determine residence times. An understanding of water movement in coastal waters, at coarse and fine scale for sensitive areas, together with the effect of these movements on nutrients and mobile sea lettuce will be needed to understand the dynamics of the populations.

Where changes in water movement, either natural of anthropogenic, result in physical changes in habitats these may affect the development of sea lettuce. Lowthion *et al.* (1985), attributed expansion of sea lettuce in Langstone Harbour, UK, more to conversion of marsh to favourable habitat than to sewage pollution.

Investigation of movement and burial of adult plants should be part of the population dynamics study. The most appropriate technique for this would be a mark recapture programme (using a fluorescent stain, e.g. calcofluor) or repeated biomass mapping.

Management options

Once the complex of factors which control the dynamics of population of sea lettuce in Bay of Plenty waters has been quantified, management decisiions aimed at reducing nuisance accumulation can be made. If, for example, nitrogen concentations are limiting growth, measures targeting reduction of phosphorus loading will be of little value. If nitrogen is not limiting to growth, it may not be appropriate to consider reducing nitrogen loadings unless they can be reduced to a level which will limit growth. While economic harvesting of sea lettuce may be a possible control option (Frederiksen 1987) environmental manipulation, either to increase flushing, reduce areas of stagnation, reduce nturient loadings or enhance grazer activity are possible options which may be identified by the research programme.

Summary

To effectively manage sea lettuce growth in Bay of Plenty coastal waters, studies on nutrient limitation, temperature, light, sporulation, desiccation, grazing, burial and hydrodynamics need to be undertaken . We believe that this will be best achieved using an hierarchal approach, based on the likely importance of a process and its potential value in management, as outlined below.

Highest Priority	**Major Questions**
Nutrients	- do nutrients limit growth
	- which nutrient
	- what are the major sources of this nutrient
Temperature	- what is the long-term record of temperature
	- can this be related to biomass
Sporulation	- when and where are spores produced
	- how are they distributed
	- is high biomass due to absence of sporulation
Advection, washout, hydrodynamics	- how are loose plants moved around and out of harbours
Desiccation	- what are rates of desiccation
	- how does desiccation affect distribution
Grazing	- how does grazing affect growth at high and low plant densities

Light	-	what are light fields encountered by sea lettuce
	-	how does light affect growth
Burial	-	how much biomass is lost to burial and where does this occur

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