

STUDIES ON THE AUTECOLOGY OF
MYRIOPHYLLUM AQUATICUM IN THE
SOUTH - WESTERN CAPE PROVINCE

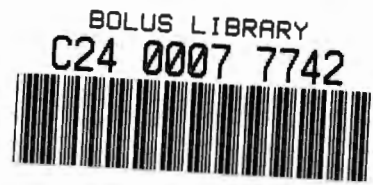
Terrance Pieter Flach

A Thesis Submitted to the Faculty of Science,
University of Cape Town, for the Degree
of Master of Science.

Cape Town 1977

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.



ABSTRACT

The distribution in the South-Western Cape Province of Myriophyllum aquaticum, which occurs as a weed on many rivers and dams, is given. Winter flood waters remove large quantities of the weed annually. Very small fragments can regenerate into new plants. Plants can survive dry summers rooted in clay, but can only survive for a few days in a desiccator. In culture, increased nitrate nitrogen in the culture solution resulted in increased growth, whereas ammonium nitrogen inhibited growth at high concentrations ($10 \mu\text{g.ml}^{-1}$). A dense colony of M. aquaticum resulted in a water loss due to evapotranspiration approximately double that of an open water surface. The salinity tolerance of the plant is decreased in alkaline media.

ACKNOWLEDGMENTS

My grateful thanks are due to my supervisor, Prof. E.A. Schelpe for his encouragement and interest. I am also grateful for the advice and interest shown by Prof. O.A.M. Lewis who supervised some of the physiological work. I would also like to thank Mr. Santer of the South African Bureau of Standards for analysing all the water samples. I wish to thank D. McLachlan for assisting in the drawing of the maps and diagrams, and Miss L. Boehmke for typing the manuscript.

Finally I wish to thank my wife for her continual encouragement and support. Without it, this thesis might never have been completed.

<u>CONTENTS</u>	<u>PAGE</u>
1. INTRODUCTION.....	1
2. TAXONOMY AND MORPHOLOGY OF <u>M. AQUATICUM</u> AND <u>M. SPICATUM</u>	5
3. DISTRIBUTION.....	17
4. VEGETATIVE PROPAGATION.....	29
5. SHADE TOLERANCE.....	31
6. DROUGHT RESISTANCE.....	32
7. NITROGEN UTILIZATION.....	34
8. EVAPOTRANSPIRATION.....	41
9. SALINITY TOLERANCE.....	44
10. CHEMICAL COMPOSITION.....	54
11. DISCUSSION AND CONCLUSIONS.....	57
12. REFERENCES.....	63

STUDIES ON THE AUTECOLOGY OF
MYRIOPHYLLUM AQUATICUM IN THE
SOUTH - WESTERN CAPE PROVINCE

1. INTRODUCTION

Aquatic macrophytes are an integral part of any freshwater ecosystem. In addition to being primary producers, they assist in nutrient circulation and provide shelter and spawning areas for many other forms of associated animal life (Nichols and Keeney, 1973; De Marte and Hartman, 1974). However, with the rapidly growing human population, an increase in the use of natural water sources is causing extensive problems due to the disturbance of the natural freshwater ecosystem. The effects on natural waterways include firstly, the construction of dams and impoundments which restrict the water flow, and secondly, the addition of large amounts of nutrients to the system through various forms of pollution. These include sewage effluent, fertilizer leaching from agricultural areas and industrial wastes. This restricted flow and increased eutrophication enables aquatic macrophytes to experience a much more rapid growth rate than in an oligotrophic system and the problems associated with this rapid proliferation are manifesting themselves more frequently in many places all over the world.

A dense bank to bank growth of aquatic weed has deleterious effects on the associated animal life as it drastically reduces light penetration and oxygen concentration in the underlying water (Schelpe, 1961; Grace and Tilly, 1976; Nichols and Keeney, 1976a). Man's utilization of the water is also seriously affected as the large mass of plant material results in increased water loss due to evapotranspiration. Waterways also become blocked with the weed thus choking irrigation canals, hydroelectric turbine inlets and adversely affecting recreational use of the water for boating and fishing (Steenis,

1967; Holm, Weldon and Blackburn, 1969; Chapman, Brown, Hill and Carr, 1974). The author has also observed that the large mass of plant material on the Eerste River can assist in causing floods during the rainy season.

This problem of excessive aquatic weed growth is at present manifesting itself in many of the natural and man-made water bodies of the South-Western Cape. One of the major species causing concern is Myriophyllum aquaticum (Vell.) Verd., commonly called "parrot feather" or "emersed watermilfoil". Excessive aquatic weed growth is a particularly important threat in South Africa, as the country is generally poorly provided with natural water bodies. In addition this is often accompanied by a relatively low rainfall and a high evaporation rate.

This species was first collected at Paarl in the 1920's according to Jacot Guillarmod (1977), although Harrison (1958) makes no mention of it on the Berg River. However it was collected before 1950 in the Black River at Observatory (Adamson and Salter, 1950). The danger that this species presented was only realized very recently and the first survey in the South-Western Cape was by Piaget and Schliemann (1973 a).

This study was initiated to determine the magnitude of the M. aquaticum infestation in the water bodies of the South-Western Cape and also to investigate the autecology of this species with a view to controlling its spread, its possible eradication and predicting future sites of infestation.

A preliminary survey showed large stretches of river infested with M. aquaticum in the South-Western Cape. Particular areas along the major rivers were visited regularly to monitor the degree of infestation. Water analysis data from the most important rivers was obtained from the South African Bureau of Standards.

The initial survey also indicated that M. aquaticum was not tolerant of dense shade and this appeared to be a controlling factor resulting in its absence in the heavily shaded upper reaches of the Krom River at Wellington. Where ponds and dams are periodically drained to eliminate M. aquaticum, the drought resistance of the species is of importance. With this in mind an experiment was devised to determine the period that plants could survive on drying. In the field, plants appeared to be able to survive for considerable periods when rooted in soil.

As M. aquaticum appeared to thrive in water bodies where there was thought to be large amounts of fertilizer leaching or sewage effluent, the response of this plant to various concentrations of nitrate and ammonia nitrogen in an aqueous medium was investigated.

When a body of water is covered with waterweed, a certain amount of water must be lost through transpiration by the plant. In various studies on aquatic macrophytes, workers have shown that evapotranspiration from an area covered in weed is many times higher than from an equivalent clear area of water (Bokorny, 1890; Holm et al., 1969; Piaget and Schliemann, 1973b). With the possibility of M. aquaticum finding its way into major water reservoirs, the water loss from an area covered in M. aquaticum compared with an equivalent open area was estimated.

In many areas it was apparent that the distribution of M. aquaticum was restricted by some factor thought to be the salinity levels in the water. This was apparent in the lower reaches of the Berg River and at the junction of the Keysers River and Sandvlei. In an attempt to determine the actual factor limiting its spread, various experiments using differing salinity concentrations as well as varying the pH levels, were designed.

With the ultimate possibility of having to remove large amounts of M. aquaticum from dams or rivers, it was decided to determine its chemical composition as this would indicate its potential as either compost or fodder. The possibility of use as fodder was suggested after receiving reports and observing cattle grazing the plant. However it later transpired that the high tannin content (Boyd, 1966) caused animals to soon tire of it (Jacot Guillarmod, 1977). At the present moment legislation also forbids the transport of aquatic weeds from rivers for any purpose.

Another *Myriophyllum* species, M. spicatum L. also occurs in the South-Western Cape. However, the nearest location was found to be at Verloren Vlei, 250 km away from Cape Town. Thus, due to the large amount of travelling involved, as well as the fact that this species is believed to be indigenous and unlikely to cause any major problems, research undertaken on this species was minimal.

2. TAXONOMY AND MORPHOLOGY OF *M. AQUATICUM* AND *M. SPICATUM*

Myriophyllum aquaticum was originally introduced from South America, where it occurs in Brazil, Peru, Chile, Uruguay and Argentina (Adamson and Salter, 1950; Teles and Pinto da Silva, 1975; Jacot Guillarmod, 1977). Although the taxonomy of the species is at present being investigated, it is believed that *M. aquaticum* is synonymous with *M. brasiliense* Canbess. and *M. proserpinacoides* Hook and Arn. (Van der Meijden, 1969; Teles and Pinto da Silva, 1975).

This species roots in river or dam banks and grows out over the water surface. These horizontal stems, which are shallowly submerged, can exceed 6 m in length and have a diameter of approximately 6 mm. The sub-surface nodes can give rise to between one and four adventitious roots which can reach a length of nearly 90 cm in deep water (Fig. 1). The roots are much shorter when they occur in soil.

The main photosynthetic regions of the plant are the aerial portions, which protude 3 to 14 cm above the water surface. Each node gives rise to a whorl of six or occasionally five leaves (Plate 1). Many small enations (outgrowths) occur between and just above the leaf stalks and are considerably larger than those found in *M. spicatum*.

Only female specimens of *M. aquaticum* have been found in the South-Western Cape, the flowers occurring in the axils of the aerial leaves and consisting of a white calyx and two bifurcate or trifurcate bracts. The flowering season is believed to be between May and November in the field, however in culture ponds, flowers were found in March. Reproduction is believed to be purely vegetative in the South-Western Cape due to the absence of male plants.

One of the unusual features of this species is its ability to survive in a terrestrial habitat on river banks (Plates 2,3 and 4). The only noticeable difference in its appearance

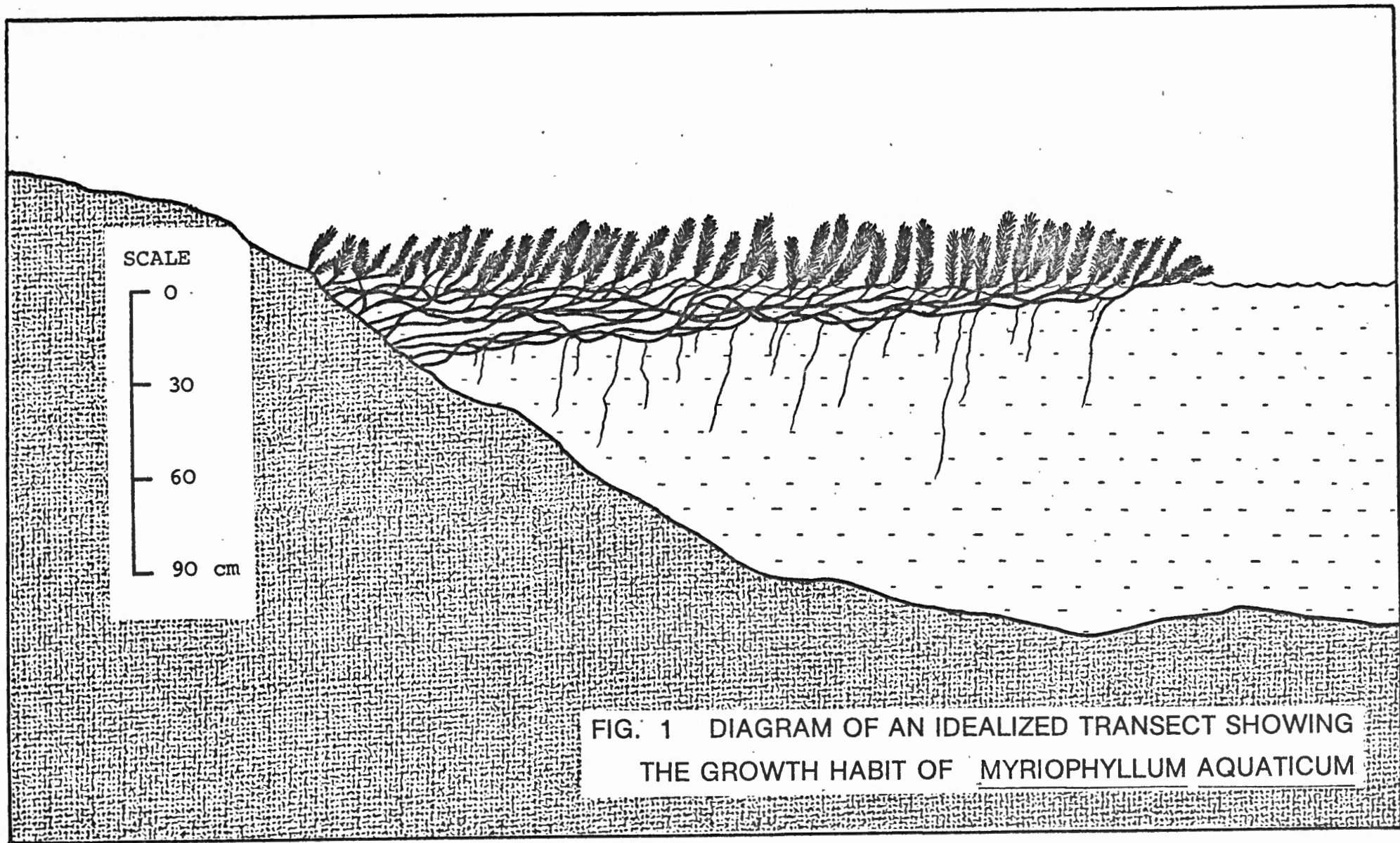


FIG. 1 DIAGRAM OF AN IDEALIZED TRANSECT SHOWING THE GROWTH HABIT OF MYRIOPHYLLUM AQUATICUM



PLATE 1: Close-up of M. aquaticum showing foliage appearance.



PLATES 2, 3 and 4: M. aquaticum flourishing in a terrestrial habit on the banks of the Berg River at Lady Loch bridge, Wellington. (January, 1977)

compared with its aquatic counterpart, is a reddish colour which develops in the stems.

In rivers in the South-Western Cape it is a noticeable feature that each year a considerable amount of M. aquaticum is removed by winter floods. This is clearly shown by a comparison of Plates 5 and 6, 7 and 8, 9 and 10, 11 and 12. Large amounts of dead material of M. aquaticum can be found on river banks and washed up against the piers of bridges (Plate 13). However small remnants which survive flooding, usually rooted in the substrate, give rise to new colonies when the water level subsides. This, in conjunction with the fact that M. aquaticum does not tolerate shade, results in the characteristic semi-circular colonies which form along some of the deeper stretches of river e.g. Eerste River just above the Faure weir (Plates 7 and 9). Each colony presumably arises from a fragment which survived the winter floods in a part of the river bank not in dense shade.

Myriophyllum spicatum L. is apparently an indigenous species which is totally submerged (Plate 14), except for the inflorescences. This species roots in much deeper water than M. aquaticum and was found rooted in over 2 m of water at Verloren Vlei. The leaves of this species are much more finely branched and only three to four occur at a node, never more. M. aquaticum is known to produce sub-surface leaves which closely resemble those of M. spicatum. This heterophyllous habit in species of Myriophyllum (Woltereck, 1928; England and Tolbert, 1964; Allsopp, 1965) has led some workers to believe that hybridization might have occurred between M. spicatum and M. aquaticum, but this is unlikely as they appear to have different flowering periods (M. spicatum flowers between September and February) and they occur too far apart for the pollination agent, which is believed to be wind to be effective (Jacot Guillarmod, 1976). No trace of turion development has been found in M. aquaticum, although this is known to occur in other species of Myriophyllum (Weber



PLATE 5: The Berg River at Lady Loch bridge prior to winter flooding. (March, 1976)



PLATE 6: The Berg River at Lady Loch bridge after winter flooding. (November, 1976)



PLATE 7: The Faure Weir on the Eerste River before winter floods showing semi-circular colonies. (April, 1976)



PLATE 8: The Faure Weir on the Eerste River after winter floods. (October, 1976)



PLATE 9: The Eerste River at Faure prior to winter flooding.
(April, 1977)



PLATE 10: The Eerste River at Faure after winter flooding.
(November, 1977)



PLATE 11: Sedgewicks Weir along the Berg River before winter flooding. (March, 1977)



PLATE 12: Sedgewicks Weir after winter flooding. (November, 1977)



PLATE 13: An accumulation of dead M. aquaticum washed up by winter flooding, on one of the pillars of the Lady Loch bridge.



PLATE 14: Close-up of M. spicatum showing submerged foliage.

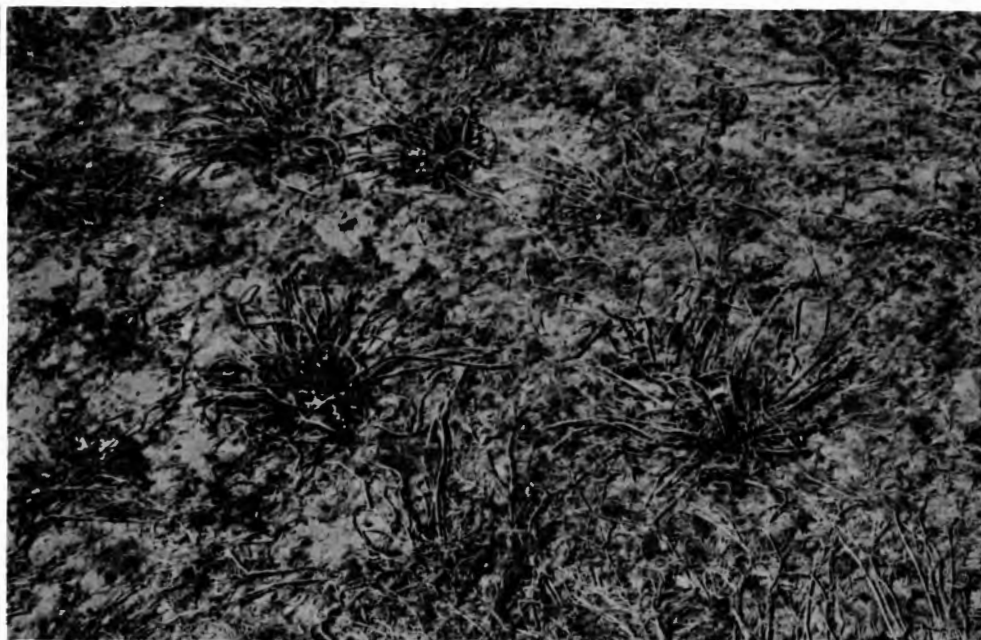


PLATE 15: Exposed M. spicatum plants during summer at Verloren Vlei.



PLATE 16: Verloren Vlei during summer showing vast quantities of exposed M. spicatum.



PLATE 17: Verloren Vlei during winter showing the extent of M. spicatum colonies.

and Nooden, 1976).

As previously stated, M. spicatum has microscopic enations at the nodes. The flowers occur on an emergent aerial spike usually several centimetres in length, with the flowers arranged in whorls along the axis.

M. spicatum may be left exposed to the atmosphere when the water level recedes during the dry season (Plates 15 and 16), but as the level rises during winter, the plant appears to give rise to shoots which increase in length as the water depth increases (Plate 17). This is probably a response to light (Gibbs-Russel, 1975), although turbulence and competition are also regarded as being important factors controlling the depth of water in which aquatic macrophytes can root (Spence, Campbell and Chrystal, 1973).

3. DISTRIBUTION

Myriophyllum aquaticum is believed to be indigenous to South America, although it also occurs in Australia, New Zealand, Malesia, Japan, South-East and North-West North America (Van der Meijden and Caspers, 1971; Jacot Guillarmod, 1977).

The Southern African distribution of M. aquaticum is shown in Fig. 2. This was compiled by Jacot Guillarmod (1977) from herbarium specimens, live collections and references in literature. The main areas of infestation appear to be the Western Cape, the Vaal River system between the Vaal dam and the barrage, the Tugela river system and in parts of Rhodesia, notably the Hunyani River.

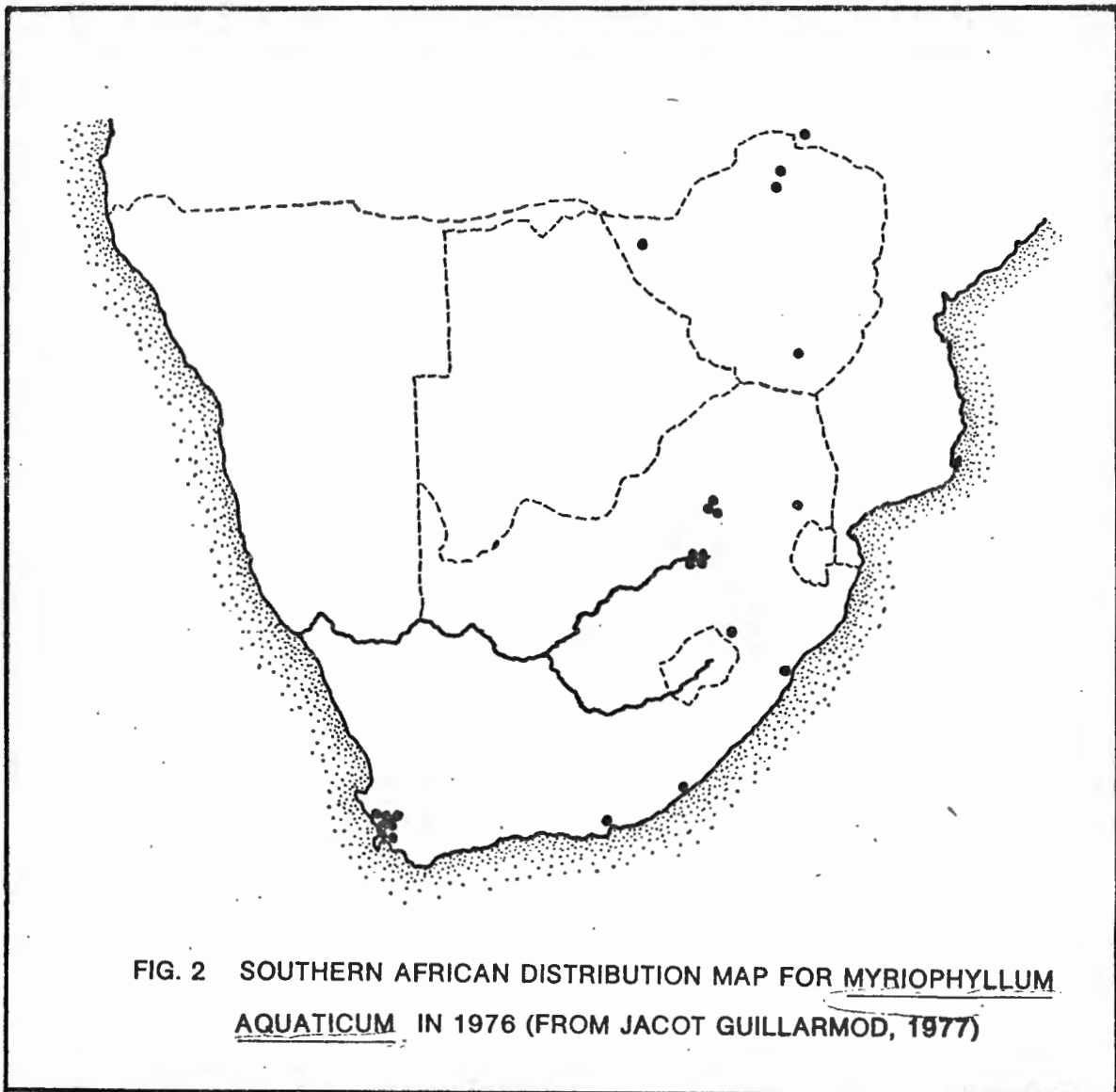


FIG. 2 SOUTHERN AFRICAN DISTRIBUTION MAP FOR MYRIOPHYLLUM
AQUATICUM IN 1976 (FROM JACOT GUILLARMOD, 1977)

Although no voucher specimen exists, the first record of M. aquaticum in the South-Western Cape was from Paarl in the 1920's according to Jacot Guillarmod (1977). Harrison (1958) makes no reference to the weed and photographs which he took near Wellington show no infestation, where a large stand now exists. The distribution in the Berg River, as described by Piaget and Schliemann (1973a) is still accurate and the plant does not appear to have spread to any extent in this area, although the degree of the infestation within the area described might well have increased.

A general map showing all the occurrences of both M. spicatum and M. aquaticum in the South-Western Cape is given in Fig. 3. In the Berg River, which is shown in detail in Fig. 4, M. aquaticum covers a stretch of approximately 25 km from Paarl to nearly 5 km upstream from Hermon. A point of interest is that the stand at the National Road at Paarl is at least 3 km above the sewage outlet, although other industrial outlets do occur along this stretch of river. This would seem to indicate that the plants obtain their nutrients from fertilizer leaching, as the upper reaches of the river pass through areas of intensive agriculture. The Krom River which joins the Berg River at Wellington, is also infested for a distance of approximately 10 km from the farm Goede Hoop to its junction with the Berg River.

M. aquaticum is present in the Eerste River from Vlottenburg to the river mouth at Macassar, a distance of nearly 20 km. Dams along the river, for example, the farm dam at Spier (Plate 18), also contains large amounts of M. aquaticum, probably due to the fact that these dams are supplied by an aqueduct from the Eerste River. An aqueduct would result in nutrient rich water and small fragments of M. aquaticum from the Eerste River finding their way into the dam. The Jonkershoek Fish Hatchery and Klawervlei at Faure both are infested. The Eerste River system is shown in Fig. 5.

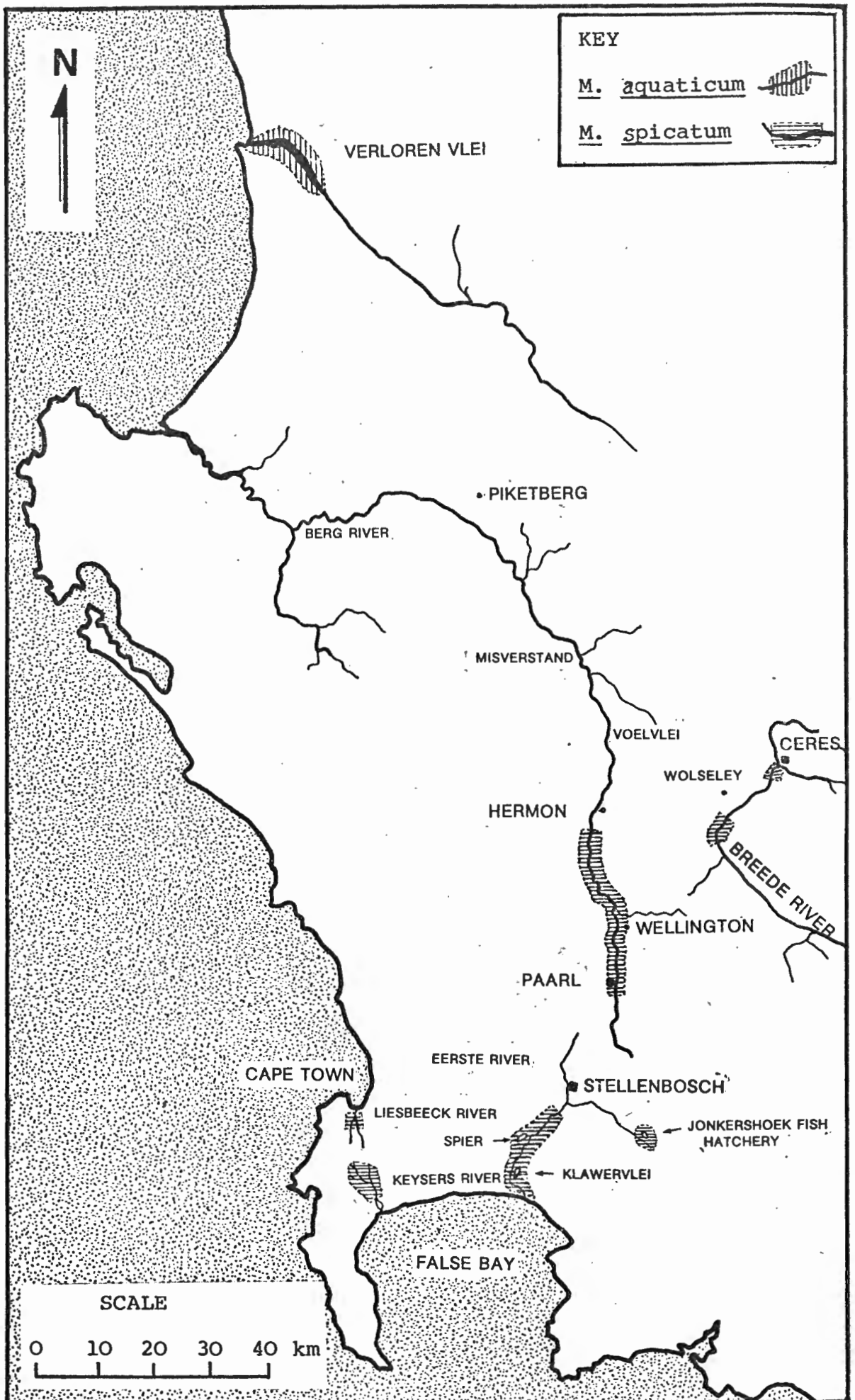


FIG. 3 DISTRIBUTION OF MYRIOPHYLLUM SPECIES IN THE SOUTH WESTERN CAPE

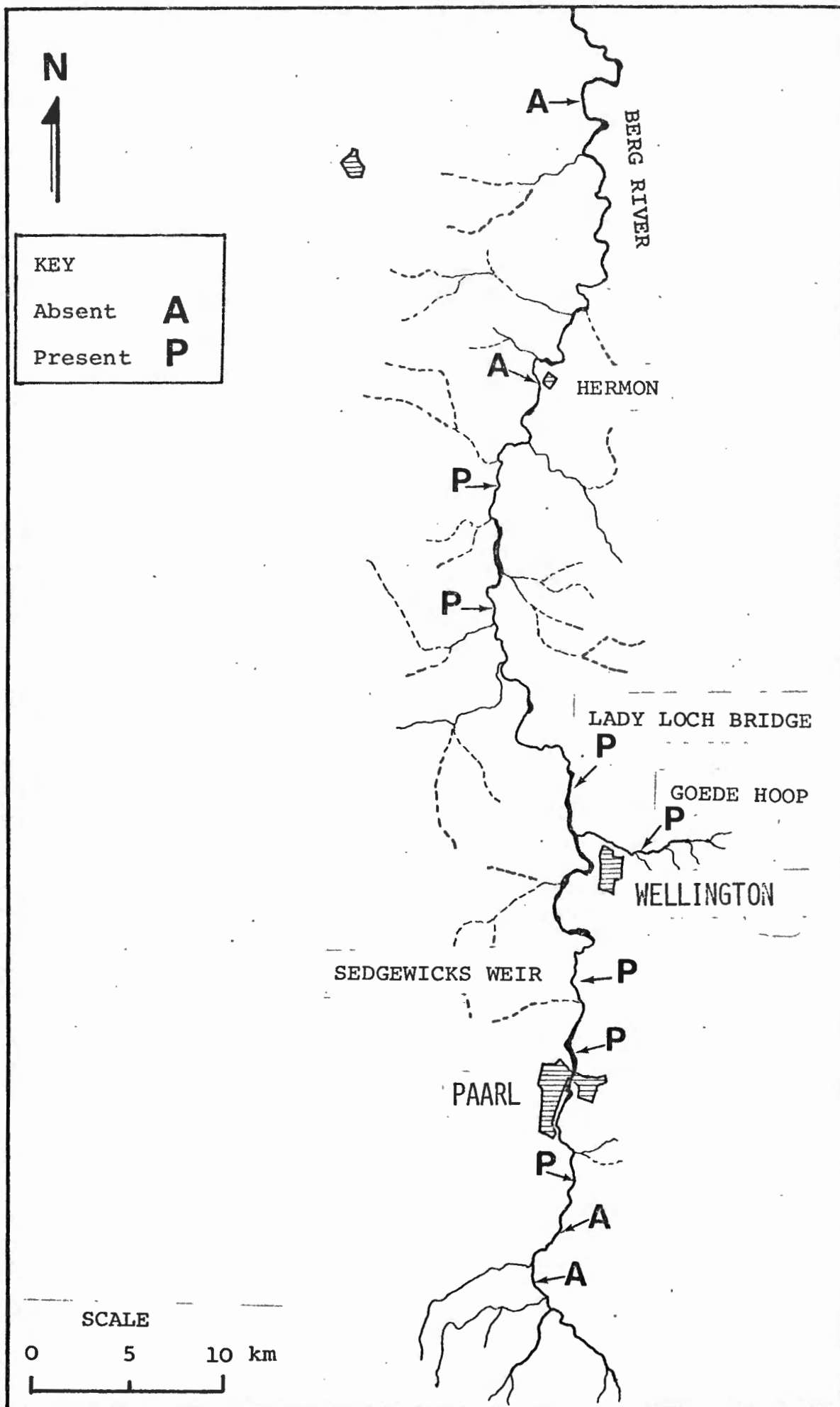


FIG. 4 DISTRIBUTION OF *MYRIOPHYLLUM AQUATICUM* IN THE BERG RIVER

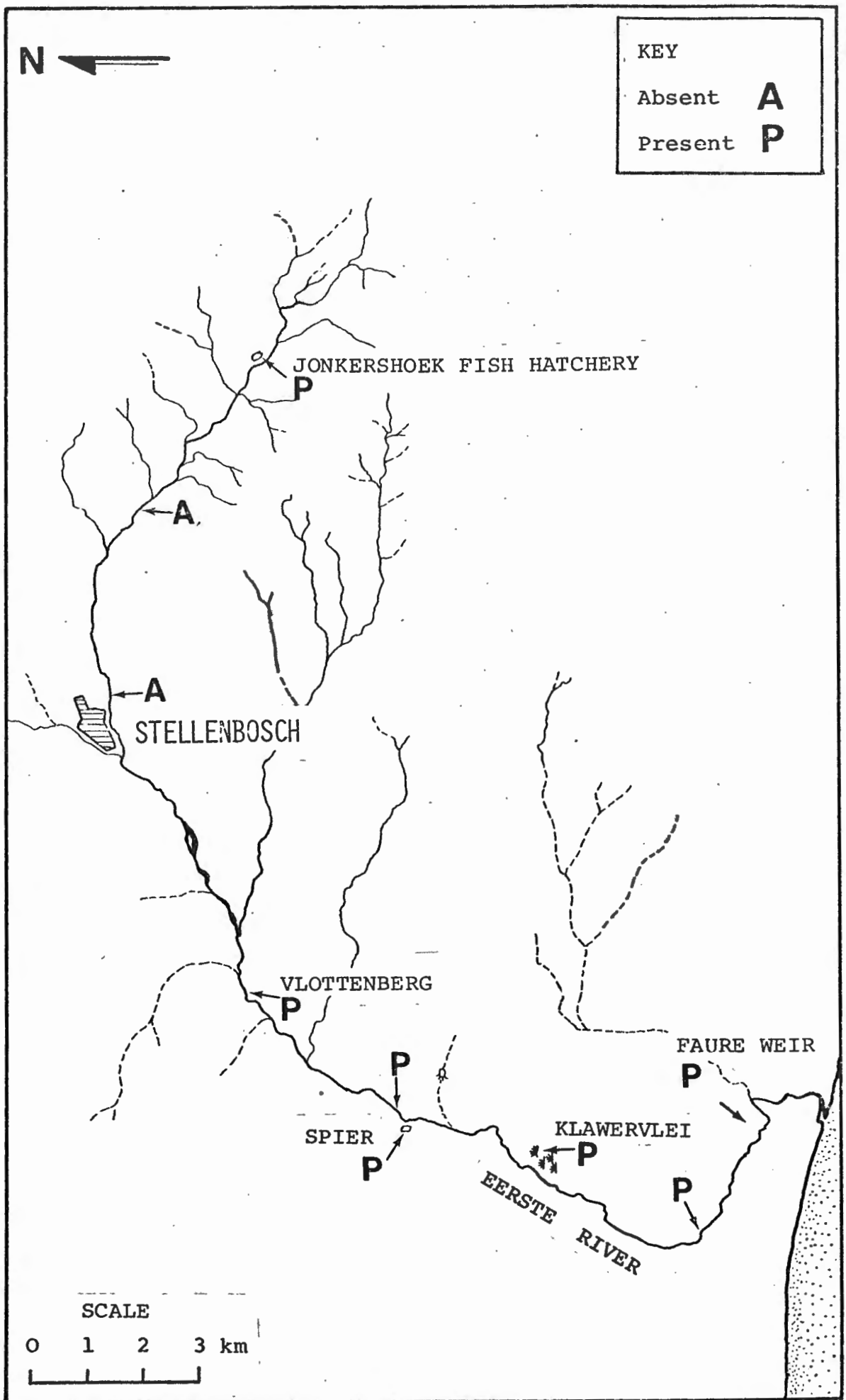


FIG. 5 DISTRIBUTION OF MYRIOPHYLLUM AQUATICUM IN THE EERSTE RIVER



PLATE 18: Spier farm dam at Stellenbosch, colonized bank
to bank with M. aquaticum.

At Ceres, the Dwars River is infested for 5 km. Piaget and Schliemann (1973a) reported the presence of M. aquaticum at Witbrug on the Breede River. However, this infestation could not be located and its possible that recent winter floods have removed all of the colony. A few isolated colonies are known to occur lower down the Breede River (Jarman, pers comm.). The infested part of the river is shown in Fig. 6.

On the Cape Peninsula, M. aquaticum is found on the Keyzers River from just above the Wynberg intersection on the Blue Route Freeway to its mouth at Sandvlei, a distance of over 15 km (Fig. 7). Many of its tributaries and adjoining irrigation canals also contain dense colonies. The Liesbeeck River is infested for 1 km from Observatory to its junction with the Black River. Adamson and Salter (1950) reported the presence of M. proserpinacoides in the Black River at Observatory. However, this location could not be verified and it is probable that the plant has been eliminated from this area due to regular spraying of the banks of the river with herbicide. The Black River also contains large amounts of suspended solids from sewage, which results in excessive colonization by filamentous sewage bacteria and fungi, which submerged species of Myriophyllum are reported to be unable to tolerate (Sculthorpe, 1967). This probably accounts for its absence below the junction of the Black and Liesbeeck Rivers where herbicide spraying does not occur. This river system is shown in Fig. 8.

The distribution of M. aquaticum in the South-Western Cape would seem to be associated with its introduction to the Jonkershoek Fish Hatchery and subsequent escape into the Eerste River. The other infestations might be either as a result of small fragments being introduced with fish fingerlings or as an escape from other sources, due to its past popularity as an ornamental aquatic plant.

In contrast, Myriophyllum spicatum is believed to be indigenous as it occurs in remote locations such as Lake Sibaya,

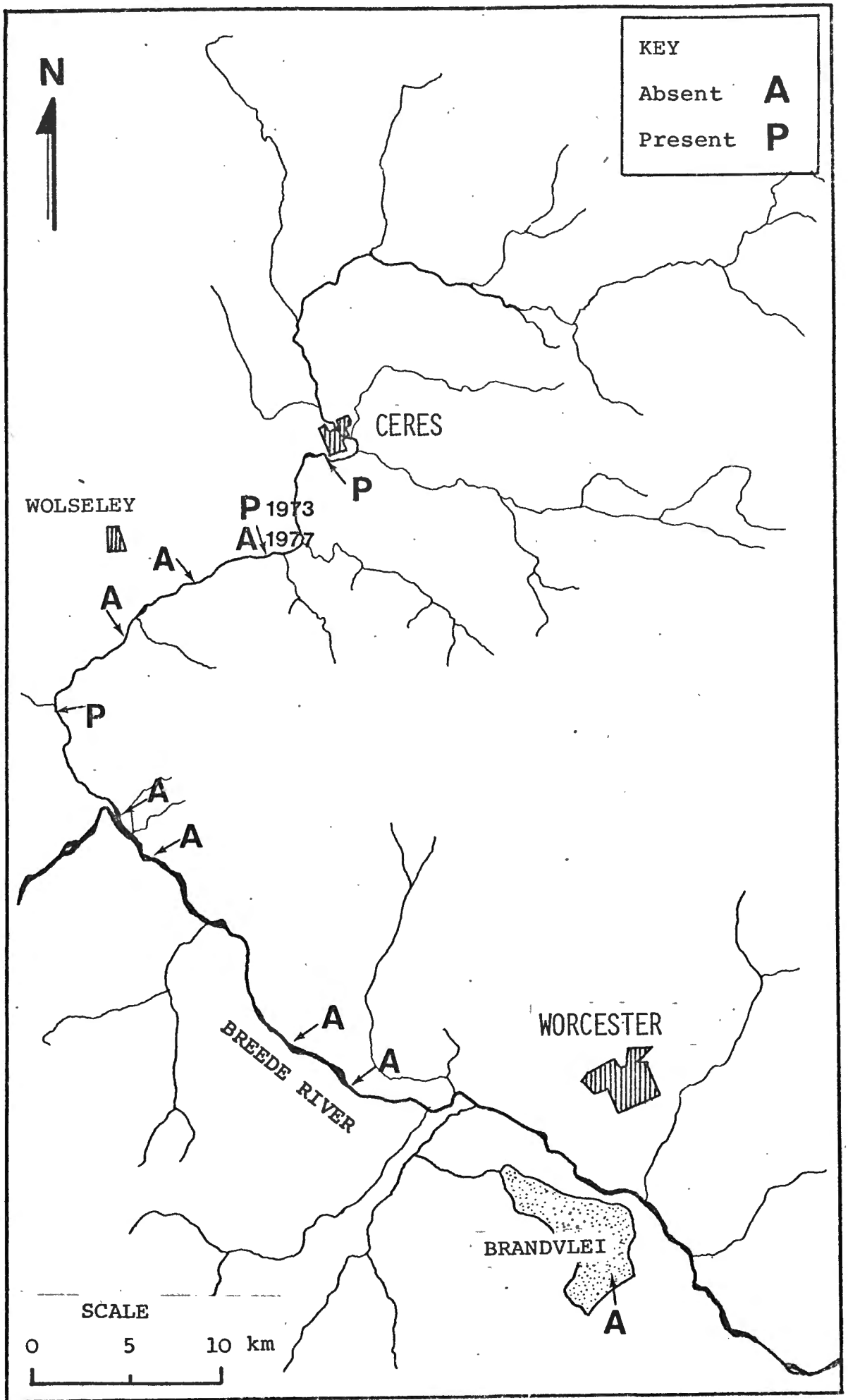


FIG. 6

DISTRIBUTION OF MYRIOPHYLLUM AQUATICUM
 IN THE BREDE RIVER

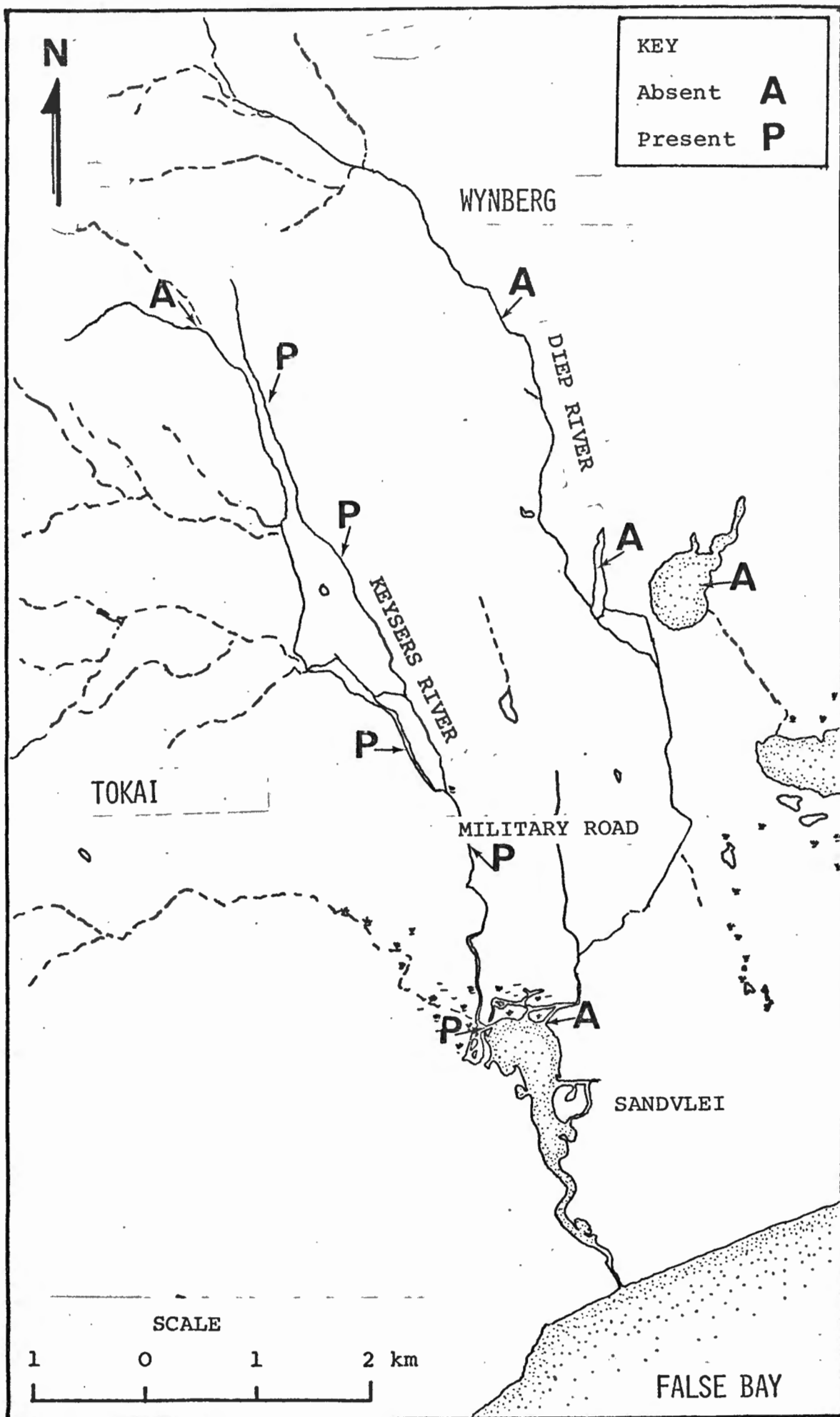


FIG. 7

DISTRIBUTION OF MYRIOPHYLLUM AQUATICUM IN THE KEYSERS RIVER

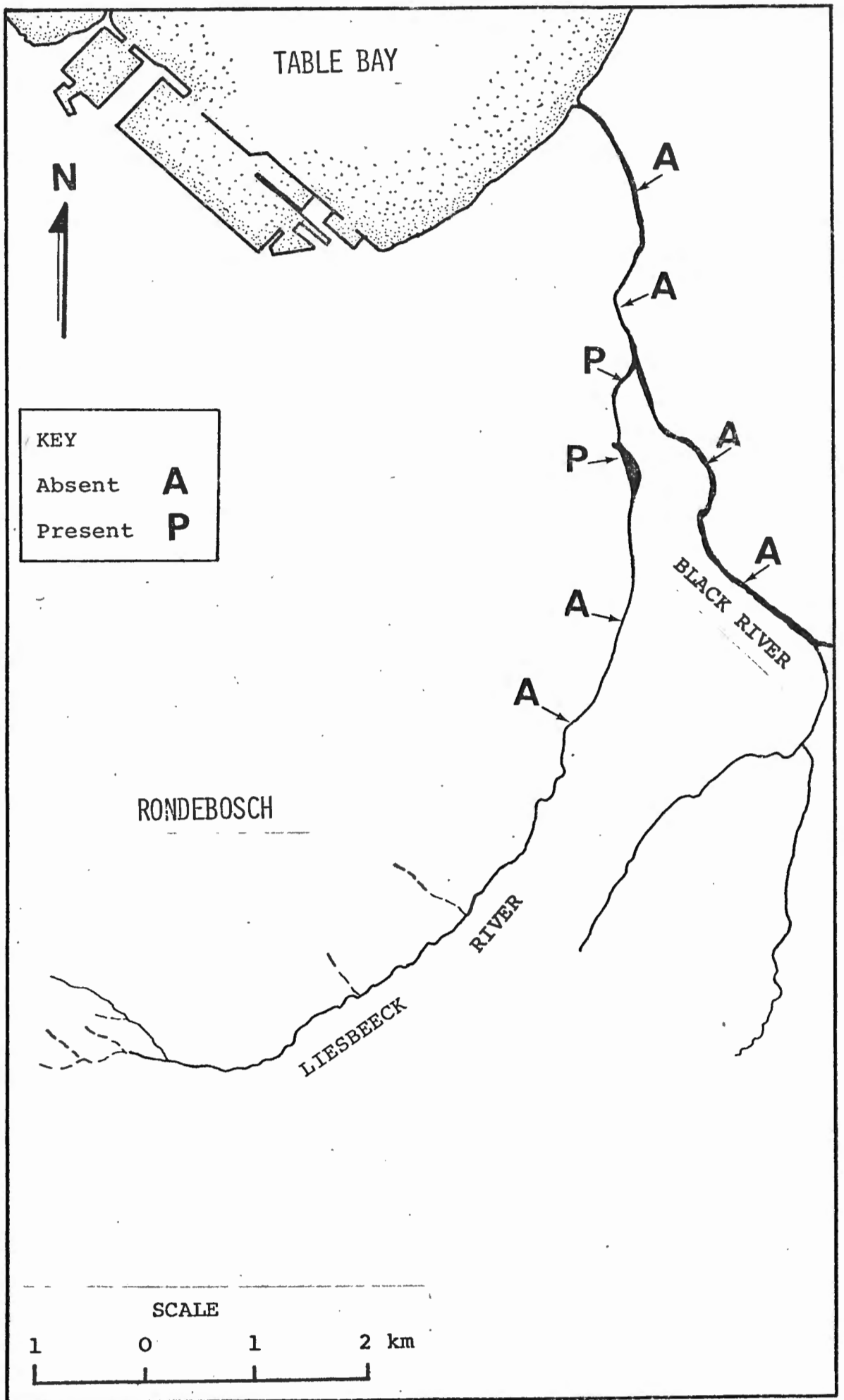


FIG. 8

DISTRIBUTION OF *MYRIOPHYLLUM AQUATICUM* IN THE LIESBEECK RIVER

where it is impossible for it to have been distributed by mans activities (Jacot Guillarmod, 1977). This species has a wide distribution in the northern hemisphere, including Malesia, Philippines and West and Southern Africa (Van der Meijden, 1969). The Southern African distribution is shown in Fig. 9. The closest locality to Cape Town where the plant occurs is at Verloren Vlei at Elandsbaai, where the species covers the vlei for a distance of about 6 km upstream from the mouth.

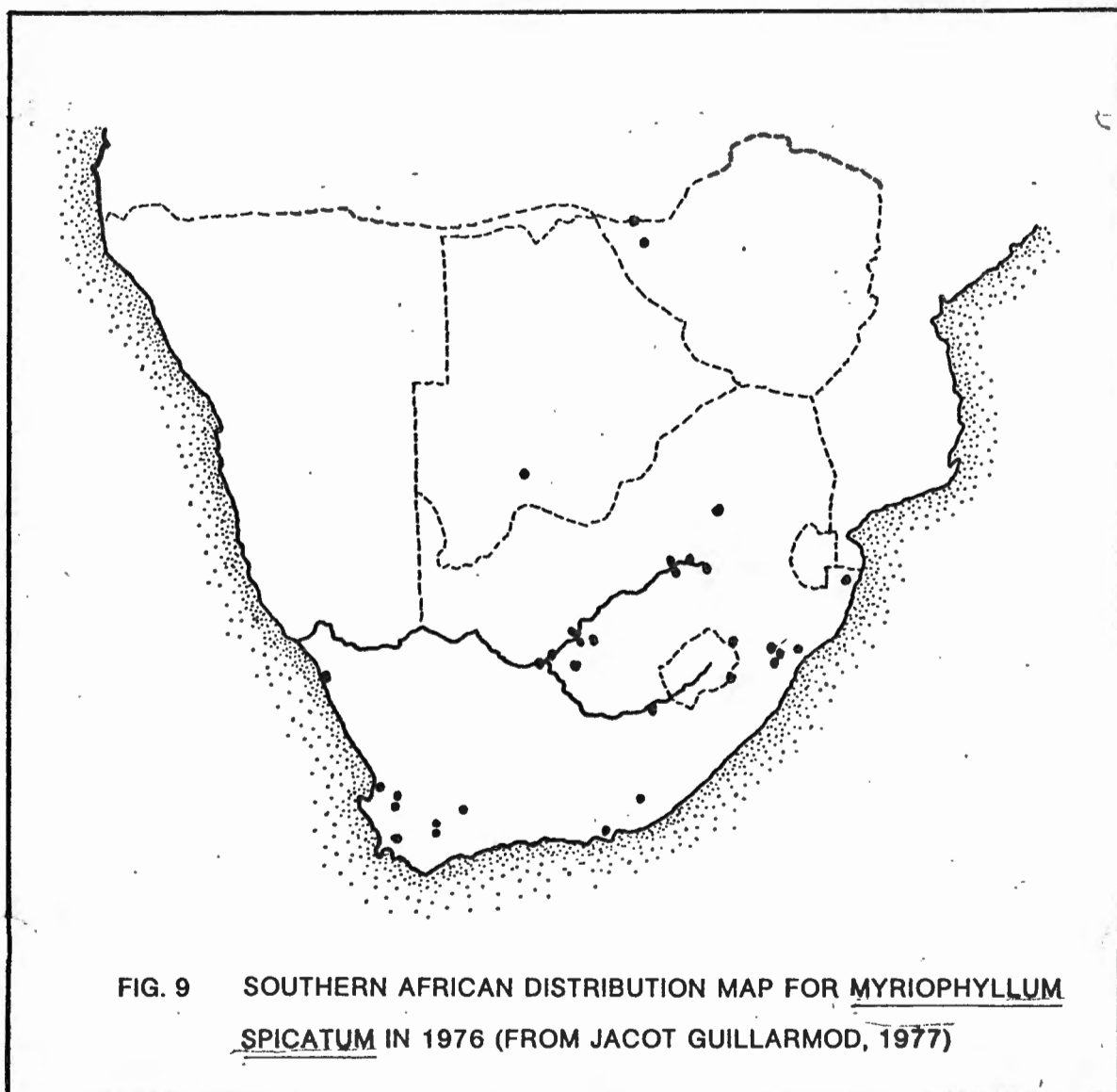


FIG. 9 SOUTHERN AFRICAN DISTRIBUTION MAP FOR MYRIOPHYLLUM
SPICATUM IN 1976 (FROM JACOT GUILLARMOD, 1977)

Although the two species, M. aquaticum and M. spicatum, do not occur in the same water bodies in the South-Western Cape, they do in other parts of Southern Africa. However, Jacot Guillarmod (1977) feels it is unlikely that any form of competition will occur between these two species as M. spicatum roots in much deeper water than M. aquaticum. The author however believes that M. aquaticum, once rooted in river banks would be capable of growing over and shading out established colonies of M. spicatum.

4. VEGETATIVE PROPAGATION

A fact that emerged very early on in the investigation was that only female plants of M. aquaticum occurred in the South-Western Cape. This phenomenon has also been reported from other parts of the world (Van der Meijden, 1969). This meant that propagation has been purely vegetative. It was clear at the outset that the plant was capable of very rapid growth under optimal conditions. This was verified by the owner of Speir farm at Faure, who revealed that a dam on the farm was ostensibly cleared of M. aquaticum two years previously, and is now completely covered from bank to bank. This dam is connected by an aqueduct with the Eerste River and it is likely that this is the source from which the dam originally obtained its infestation. On the other hand, M. aquaticum is absent from nearby dams, downstream from the Stellenbosch sewage farm which are not supplied by an aqueduct. This is one of the complex problems that occur along riverways like the Eerste River, with adjoining dams, as an interlinked system is found where if the river is cleared, infestation will reoccur from adjoining dams and vice versa, making total eradication virtually impossible.

With the knowledge that no fertile seeds are being produced, it was decided to determine the minimum size fragment which was capable of initiating an infestation.

Shoots of M. aquaticum were obtained from material grown in ponds on the University campus, which were stocked originally with plants obtained from the Keyzers River at Tokai. Portions were cut from these shoots in such a manner that fragments consisting of just a node, a node with 1 mm of stem on either side and a node with 3 mm of stem on either side were obtained. In addition to these, the apices were also tested using the apical portion with 1 mm, 2 mm, 3 mm and 4 mm of stem.

Three portions of each size described above were placed in two litres of dilute (one tenth normal strength) Knops solution which provides $12, 5 \mu\text{g}.\text{ml}^{-1}\text{N}$, $4,5 \mu\text{g}.\text{ml}^{-1}\text{P}$, $13, 6 \mu\text{g}.\text{ml}^{-1}$ $13, 6 \mu\text{g}.\text{ml}^{-1}\text{Ca}$ and $2 \mu\text{g}.\text{ml}^{-1}\text{Mg}$ (Harris 1966).

The plants and solutions were placed in containers in a glasshouse, where the maximum and minimum temperatures were recorded. The experiment was run for fourteen days, the solutions being renewed after the first seven days.

It was found that a stem segment containing a node with 2 mm or more of stem on either side was capable of growth. Smaller pieces were not viable. Stem segments which did not include a node, when placed in the nutrient solution were not capable of producing shoots, as in all cases the production of shoots and roots occurred at the nodes. Roots were produced within seven days.

The smallest apical portion (i.e. 1 mm of stem) was found to be capable of developing into a plant. During the course of the experiment average maximum and minimum temperatures recorded were 35°C and 22°C respectively.

Anderson, Brown and Rappleye (1966) working on M. spicatum, found that a node with 1 mm of stem on either side was viable. It therefore appears that very small pieces of both species are capable of growth.

This means that during winter flooding, while the mats of M. aquaticum formed during the summer season are broken down, small pieces which are washed downstream are capable of giving rise to new colonies lower down the river. Also during mechanical removal, a certain amount of fragmentation is unavoidable and small pieces, which are not removed, will give rise to further infestations. Also to achieve total eradication every fragment rooted in the bank would have to be removed. In addition, when water is being pumped from infested rivers, care will have to be taken that fragments are not conveyed to areas where they can give rise to new infestations.

5. SHADE TOLERANCE

Initial observations revealed that on the Eerste River at the Faure Weir, new colonies of M. aquaticum that developed after winter floods, had a characteristic semi-circular form (plates 7 and 9). It was apparent that fragments rooted in the river bank, which had survived the winter floods, only developed into colonies from foci which were not densely shaded.

Also, it was observed in the upper reaches of the Eerste and Krom Rivers that M. aquaticum was absent in shaded areas. To determine the shade tolerance of the plant a 2 x 2 m pond covered in a dense stand of M. aquaticum was screened by successively thicker shade cloth. The cloths shaded out 30%, 50%, 70% and 80% of the incoming sunlight.

It was found that with 80% shading the plants were becoming slightly elongated, growing up towards the screen. However, the plants still had a healthy appearance. This proved that an established colony of M. aquaticum could survive under shaded conditions in the short term. However it must be realized that in the field, the plants have to establish themselves and actively grow to enable a colony to be formed and it would seem that they are incapable of such establishment under heavily shaded conditions.

6. DROUGHT RESISTANCE

On a preliminary survey it was noted that M. aquaticum could survive in a pond at the Jonkershoek Fish Hatchery which had been drained over the summer period. In this case the plant was rooted in clay. However at the Lady Loch bridge on the Berg River, plants rooted in sand banks well above the water level, were observed to turn brown and eventually die. It was decided to investigate the drought resistance of the plant under controlled experimental conditions to determine how these results would compare with those observed in the field.

Pieces of plant material approximately 5 cm long were placed in desiccators containing dehydrated silica gel. The humidity in these was less than 10%. Daily samples of ten pieces were removed from the desiccators and placed in 2 l of one tenth normal strength Knops solution and the containers were placed in the glasshouse.

For the first eleven days of drying the portions remained fully viable. By this stage the foliage was turning brown. After twelve days 80% of the fragments were viable and after thirteen days only 40% were capable of growth. The stems were now turning brown and after fourteen days only 20% were viable. At periods longer than fourteen days none of the fragments were found to be viable.

During the course of the experiment an average maximum temperature of 37°C and an average minimum temperature of 23°C were recorded.

A similar experiment was done on M. spicatum and it was found that the portions were all fully viable after the first three days. After four days of desiccation 90% were viable and after five days only 40% were capable of growth. At this stage the leaves were turning brown. Only 10% were viable after six days of drying and thereafter none of the pieces were

capable of growth and the stems were completely brown.

As the experiments were run concurrently the temperature regime for the M. spicatum experiment was identical to the range obtained during the M. aquaticum experiment.

From these results it would seem that M. aquaticum has a much higher drought resistance than M. spicatum. The main point of interest however is the large difference between observed occurrences in the field and experimental results. In the field M. aquaticum was seen viable after five months drought, whereas just over two weeks of desiccation in the laboratory proved fatal. However one must consider the fact that rooted portions remaining in clay would still experience a high water availability due to water retention by the clay, which could prevent rapid dehydration of the plant material. It has been observed on many occasions that M. aquaticum can colonize a moist terrestrial habitat.

In the case of M. spicatum experimental data again did not agree with the observed situation. At Verloren Vlei, the plants are exposed for at least a five month period and still remain viable, whereas they could not withstand five days of desiccation under experimental conditions. This can also probably be explained by the fact that a much higher humidity almost certainly occurs below the soil surface. However it must be remembered that the experimental plants were unrooted as opposed to being rooted in the normal environment. In both species the subterranean rhizomes and roots can remain viable even though the vegetative portions become brown.

This data is of particular importance if M. aquaticum is to be removed from dams and rivers and used as compost. It is obvious that a very efficient composting method would have to be used as the high humidity encountered in many composting methods without high temperatures, could still leave some of the plant material viable over considerable periods of time. The use of the plant as a wet mulch is also not recommended

as small portions would obviously still remain viable and grow.

From the results it would appear that draining a dam over the dry summer period is not a reliable method of M. aquaticum eradication, particularly if the substrate has a high clay content.

7. NITROGEN UTILIZATION

From the outset of the investigation it was believed that the high growth rate of M. aquaticum in the South-Western Cape rivers was due to high nutrient levels resulting from fertilizer leaching or sewage effluent. Results from water analyses done by the South African Bureau of Standards on the Berg and Eerste Rivers showed maximum nitrate nitrogen values of 6 and 11, 2 $\mu\text{g. ml}^{-1}$ respectively. During winter the additional rain water caused this value to drop to 0,1 and 0,2 $\mu\text{g. ml}^{-1}$ respectively as shown in Figs. 10 and 11.

With these figures as guidelines it was decided to conduct an experiment aimed at determining the growth response of M. aquaticum to various nitrate nitrogen and ammonia nitrogen concentrations in an aqueous medium.

Three 5 cm long portions of M. aquaticum were placed in each of three 2 l beakers containing Knop's solution modified to contain 10 $\mu\text{g. ml}^{-1}$, 4 $\mu\text{g. ml}^{-1}$ and 0,2 $\mu\text{g. ml}^{-1}$ nitrate nitrogen. A duplicate experiment was run concurrently. These feeding levels were chosen as they corresponded to maximum and minimum levels found in the rivers. Similarly six 2 l beakers were set up containing 10 $\mu\text{g. ml}^{-1}$, 4 $\mu\text{g. ml}^{-1}$ and 0,2 $\mu\text{g. ml}^{-1}$ ammonium nitrogen. All the beakers were enclosed in matt black paper in an attempt to minimize the growth of algae within the solutions. The experiment was run in a Conviron growth chamber set at 30,000 lux (provided by Sylvania (USA) fluorescent lamps and incandescent lamps), 75% relative humidity, 22°C and a 14 hour day.

FIG 10. FLUCTUATION OF NITRATE NITROGEN CONCENTRATION IN THE BERG RIVER WITH TIME OF YEAR

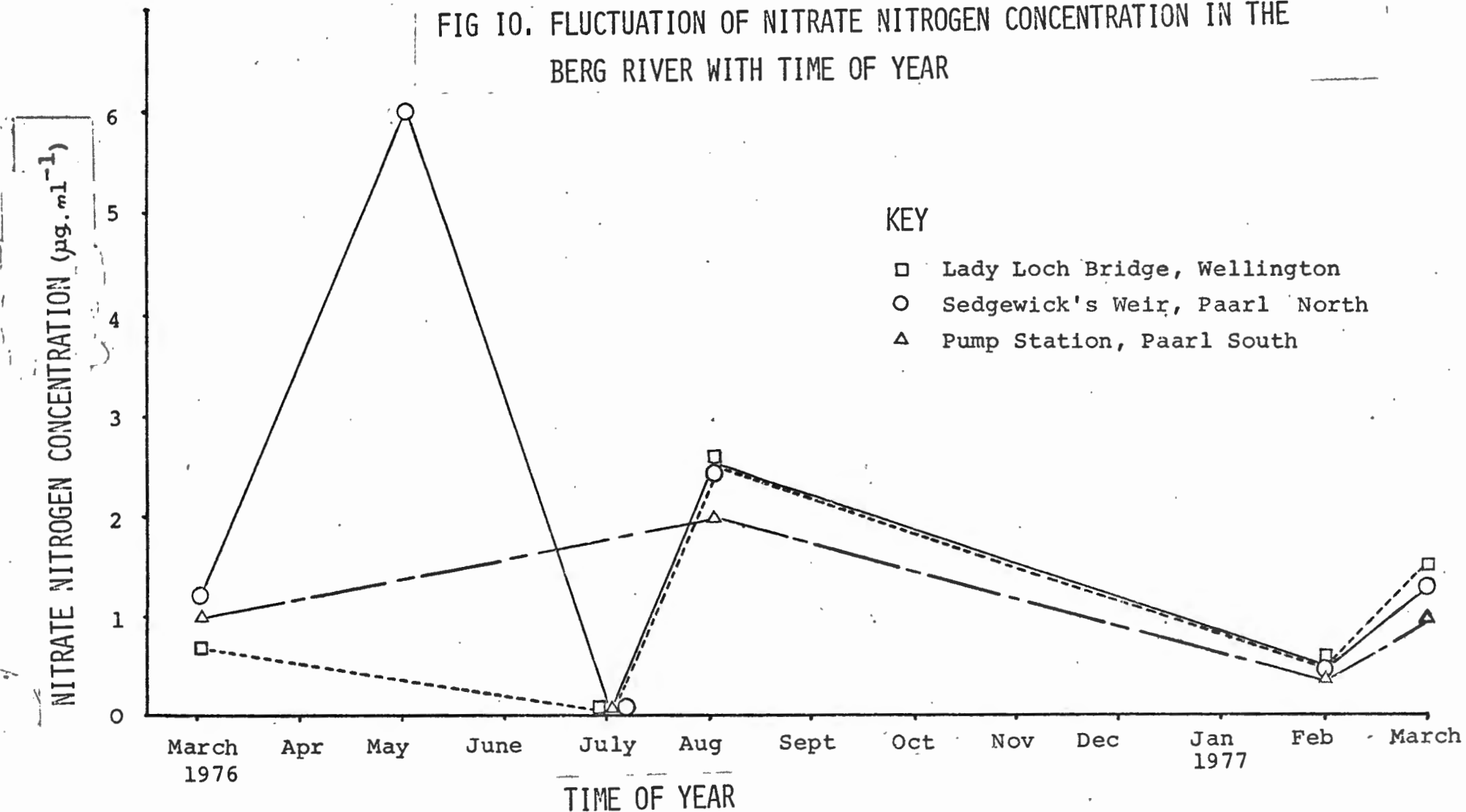
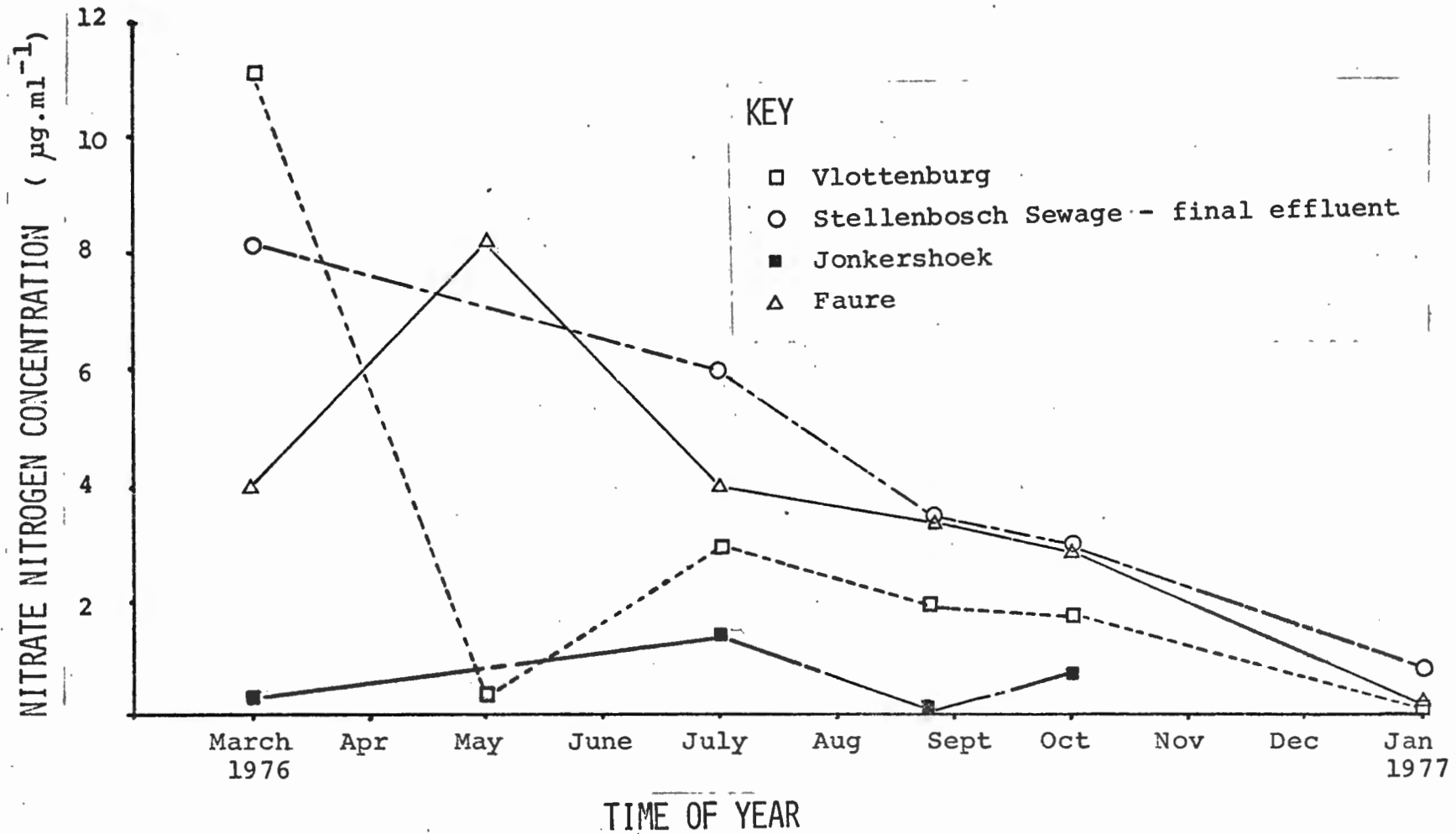


FIG II. FLUCTUATION OF NITRATE NITROGEN CONCENTRATION IN THE
EERSTE RIVER WITH TIME OF YEAR



The initial weight of the plant material was determined to two decimal places after blotting the excess water from the roots. During the course of the experiment the plants were weighed at seven day intervals.

The nutrient solutions were replaced weekly and a sample from each beaker was tested prior to being renewed, using a nitrate electrode and a HACH test kit to determine the nitrate nitrogen and ammonium nitrogen levels.

The results obtained are given in Table I and Figs. 12 and 13, and show the average % increase in weight with time.

From these results it would appear that M. aquaticum shows a positive growth reaction to nitrate nitrogen with maximum increase in weight occurring in $10 \mu\text{g. ml}^{-1}$ nitrate nitrogen feeding solution. In contrast a negative response to ammonium nitrogen was obtained, where maximum growth occurred in the $0,2 \mu\text{g. ml}^{-1}$ ammonium nitrogen feeding solution and minimum increase in weight occurred in the $10 \mu\text{g. ml}^{-1}$ ammonium nitrogen solution. The growth at the $10 \mu\text{g. ml}^{-1}$ ammonium nitrogen feeding level was slightly less than at the $0,2 \mu\text{g. ml}^{-1}$ nitrate nitrogen feeding level which indicates that ammonium nitrogen actually inhibits growth to a certain extent, at the feeding levels used in this experiment. Thus, high levels of ammonium nitrogen in a river could possibly lead to a restriction of M. aquaticum growth.

Analyses done on water samples taken from the beakers prior to the solutions being renewed indicate that only minimal amounts of ammonium were taken up by the plant material. However, from the nitrate samples considerable quantities were lost, notably towards the end of the eight week period when the biomass of the M. aquaticum in the higher nitrate nitrogen solution was quite high. At this stage by the week end the $10 \mu\text{g. ml}^{-1}$ nitrate nitrogen levels had dropped to approximately $6,5 \mu\text{g. ml}^{-1}$, the $4 \mu\text{g. ml}^{-1}$ samples had dropped to $2,7 \mu\text{g. ml}^{-1}$ and the $0,2 \mu\text{g. ml}^{-1}$ samples also indicated a decrease, although

TABLE 1 : The growth rates of M. aquaticum as measured by % increase in fresh weight, growing in nitrate nitrogen and ammonium nitrogen solutions of various concentrations.

	% INCREASE AT WEEK 1	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 2	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 3	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 4	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 5	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 6	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 7	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 8	MEAN % INCREASE AND DEVIATION FROM MEAN
10 $\mu\text{g. ml}^{-1}$ NITRATE NITROGEN	46,72		53,28		65,37		81,35		103,69		135,65		165,57		199,79	
	35,13	40,92 $\pm 5,79$	43,84	48,56 $\pm 4,72$	63,96	64,66 $\pm 0,70$	74,92	78,13 $\pm 3,21$	86,64	95,16 $\pm 8,50$	92,19	113,92 $\pm 21,73$	98,19	131,88 $\pm 33,69$	105,10	152,44 $\pm 47,34$
4 $\mu\text{g. ml}^{-1}$ NITRATE NITROGEN	30,06		41,74		56,54		57,32		57,63		59,81		62,15		64,64	
	23,64	26,85 $\pm 3,21$	44,03	42,88 $\pm 1,14$	57,91	57,22 $\pm 0,68$	58,35	57,83 $\pm 0,51$	60,73	59,18 $\pm 1,55$	65,51	62,66 $\pm 2,85$	72,67	67,41 $\pm 5,26$	82,86	73,75 $\pm 9,11$
0.2 $\mu\text{g. ml}^{-1}$ NITRATE NITROGEN	23,24		38,01		46,68		47,60		49,45		51,29		51,64		51,66	
	18,11	20,67 $\pm 2,56$	24,25	31,13 $\pm 6,88$	29,76	38,22 $\pm 8,46$	30,86	39,23 $\pm 8,37$	31,18	40,31 $\pm 9,13$	32,44	41,86 $\pm 9,42$	32,44	42,05 $\pm 9,61$	33,23	42,44 $\pm 9,21$
10 $\mu\text{g. ml}^{-1}$ AMMONIUM NITROGEN	24,38		27,00		31,59		32,24		32,24		32,57		32,57		33,22	
	35,03	29,70 $\pm 5,32$	38,53	32,76 $\pm 5,76$	38,53	35,06 $\pm 3,47$	42,03	37,13 $\pm 4,89$	42,73	37,48 $\pm 5,24$	42,73	37,65 $\pm 5,08$	43,08	37,82 $\pm 5,25$	43,43	38,32 $\pm 5,10$
4 $\mu\text{g. ml}^{-1}$ AMMONIUM NITROGEN	29,90		40,57		54,47		56,57		59,05		61,52		70,09		75,05	
	20,88	25,39 $\pm 4,51$	26,32	33,44 $\pm 7,12$	32,76	43,61 $\pm 10,85$	34,05	45,31 $\pm 11,26$	36,05	47,55 $\pm 11,50$	39,91	50,71 $\pm 10,81$	42,63	56,36 $\pm 13,73$	44,63	59,84 $\pm 15,21$
0.2 $\mu\text{g. ml}^{-1}$ AMMONIUM NITROGEN	16,02		19,15		39,59		49,54		66,29		79,19		88,03		96,13	
	13,17	14,59 $\pm 1,42$	21,17	20,16 $\pm 1,01$	32,56	36,07 $\pm 3,51$	46,62	48,08 $\pm 1,46$	63,35	64,82 $\pm 1,47$	74,73	76,96 $\pm 2,23$	86,29	87,16 $\pm 0,87$	93,95	93,04 $\pm 1,09$

FIG 12. GROWTH RESPONSE OF M. AQUATICUM AT VARIOUS CONCENTRATIONS OF NITRATE NITROGEN

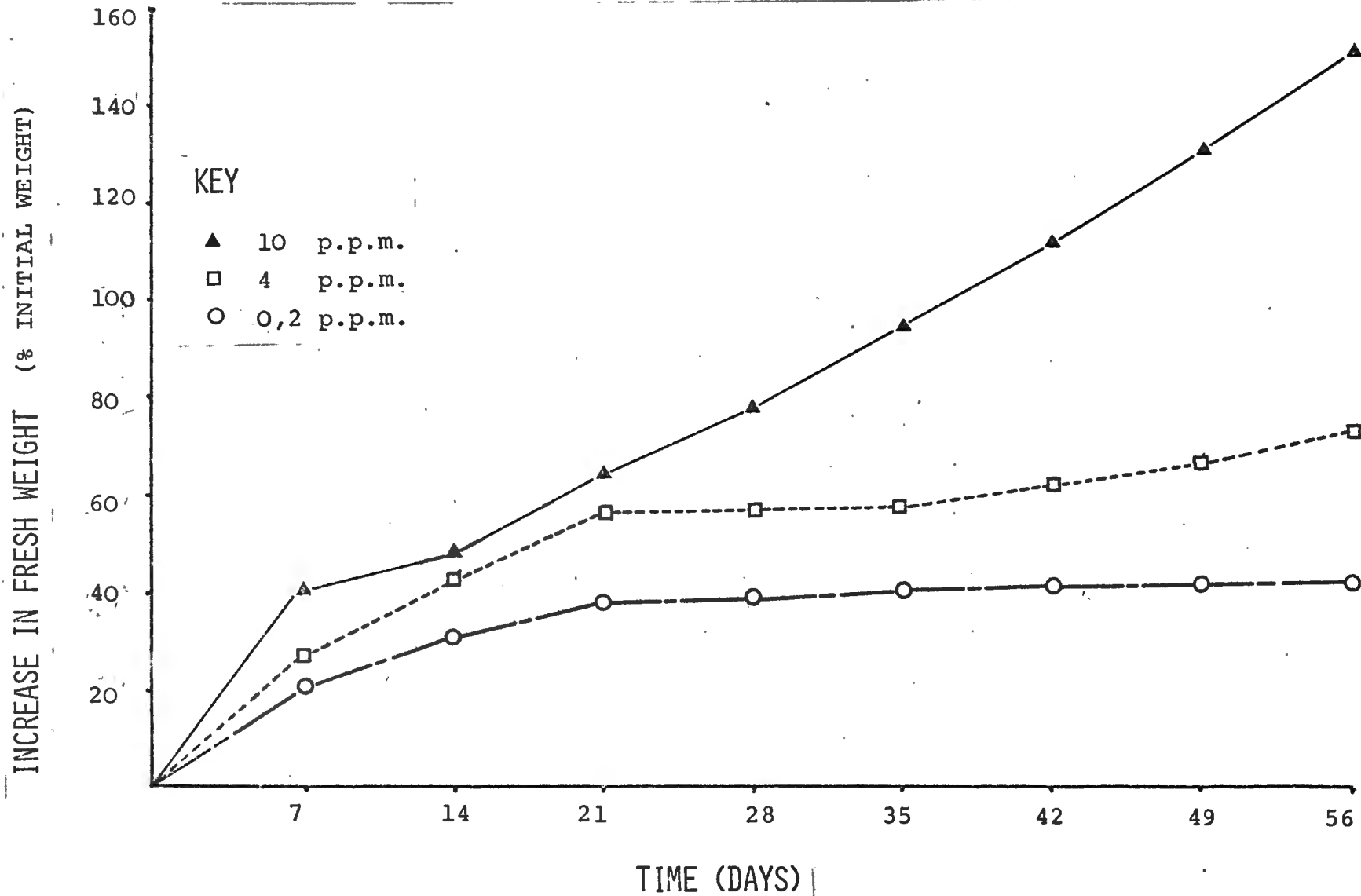
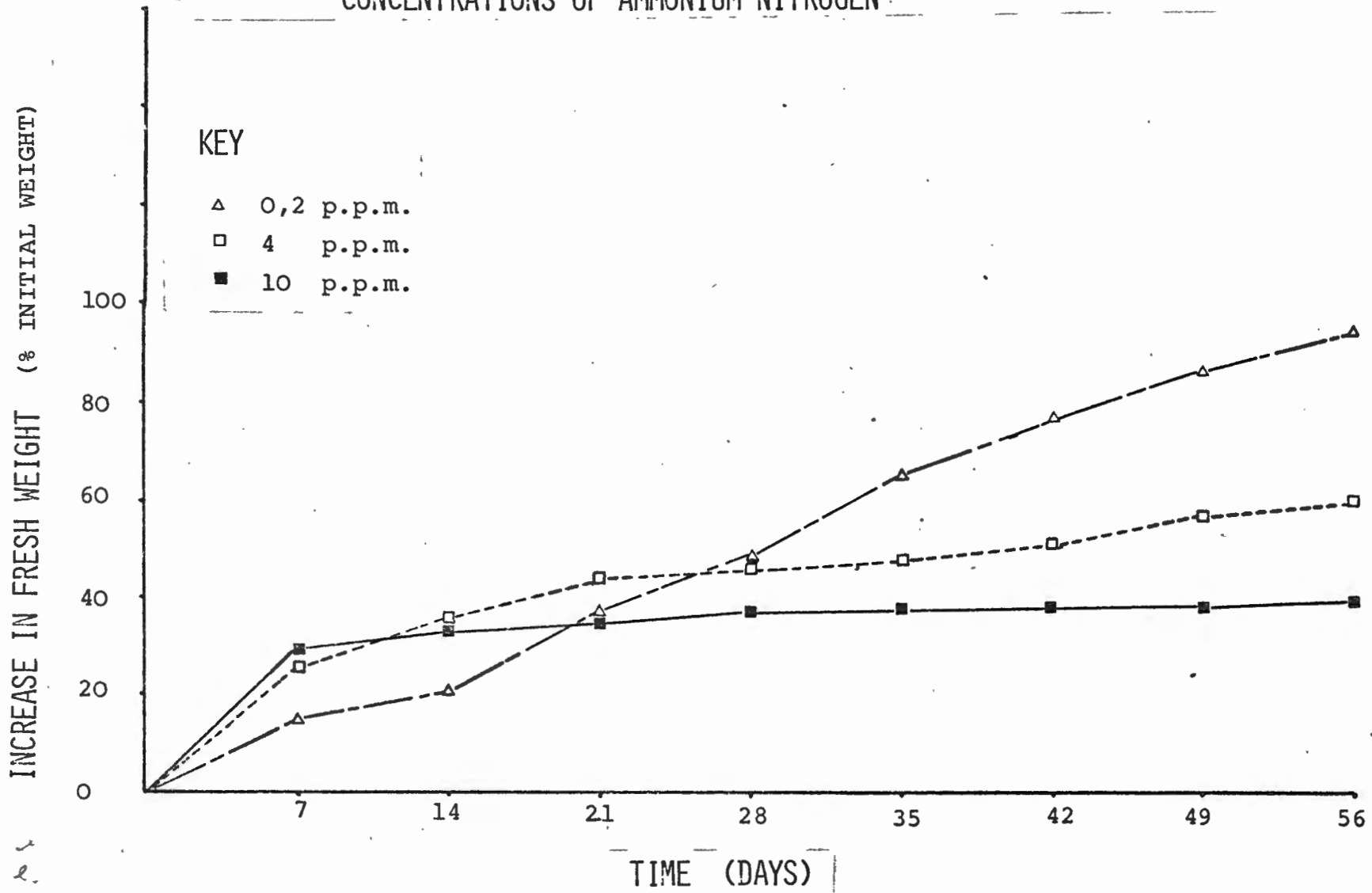


FIG 13. GROWTH RESPONSE OF M. AQUATICUM AT VARIOUS CONCENTRATIONS OF AMMONIUM NITROGEN.



43
24

although this could not be determined with any accuracy.

From the results in Table I it is clear that when a river contains $10 \mu\text{g. ml}^{-1}$ nitrate nitrogen, as occurs in the Berg River during the summer months, the growth of M. aquaticum will be very rapid, nearly doubling its weight over a two month period. The summer months are also the growing period for M. aquaticum, as during the winter months when the nitrate nitrogen levels are low, most of the M. aquaticum is washed away by the floods. Water analysis data from the South African Bureau of Standards indicates that ammonium nitrogen levels seldom exceed $2,0 \mu\text{g. ml}^{-1}$ and are usually in the region of $0,1 \mu\text{g. ml}^{-1}$. It appears as if these levels are not high enough to have an inhibitory effect on M. aquaticum. It is obvious from data obtained over the past two years that there has been a marked increase in the levels of nitrate nitrogen in the Berg River, as Harrison (1958), in his survey, obtained a maximum nitrate nitrogen level of $0,57 \mu\text{g. ml}^{-1}$. This shows clearly the effect of fertilizer leaching and sewage effluent on the river, and this appears to be an important factor assisting in the rapid growth of M. aquaticum in the Berg River and the other infested water bodies of the South-Western Cape.

8. EVAPOTRANSPIRATION

For many years it has been known that a certain amount of water is lost through evapotranspiration by aquatic macrophytes. Bokorny (1890) demonstrated free transpiration by the emergent leaves of M. brasiliense (from Sculthorpe, 1967). In the western U.S.A. it is estimated that over \$39 million is lost in irrigation water through transpiration by aquatic weeds (Holm, Weldon and Blackburn, 1969). These authors also reported that a dense stand of Eichhornia crassipes loses 3,2 to 3,7 times more water than an open surface. However, in drier atmospheres this value can rise as high as 7,8 times, as was found in India. As no reference to the rate of transpiration by M. aquaticum

could be found, an experiment was devised which would give a rough estimate of how much water was lost from a surface covered by this plant. This information would be of importance, as the possibility exists that M. aquaticum could establish itself in some of the shallower water reservoirs of the South-Western Cape.

For this purpose two 2 m x 2 m x 25 cm ponds were established, one stocked with a dense stand of M. aquaticum which gave 100% cover (Plate 19). A known amount of water was added to both ponds and the water levels were checked every 48 hours and losses replaced when necessary. Throughout the duration of the experiment a record of the minimum and maximum temperatures was kept. The M. aquaticum shoots were trimmed so that they did not overlap the edges of the pond.

The experiment was run over two rainless five day periods in April, 1977. At the conclusion of the experiment the number of shoots per square metre were counted and this was found to be approximately 2200 shoots/m².

During the initial five day period it was found that the control pond lost 2,97 l/m²/day whereas the pond covered in M. aquaticum lost 5,82 l/m²/day. This means that M. aquaticum caused a 95, 95% increase in water loss. The average minimum and maximum temperatures over the period were 5,6°C and 21,4°C respectively.

Over the second five day period the control pond lost 3,27 l/m²/day and the experimental pond lost 7,06 l/m²/day with the average maximum and minimum temperatures being 26,6°C and 11,2°C respectively. This 115,9% increase in water loss is somewhat higher than that recorded for the first period, probably as a result of the higher average temperatures recorded over this period.

The results thus indicate that a surface covered in

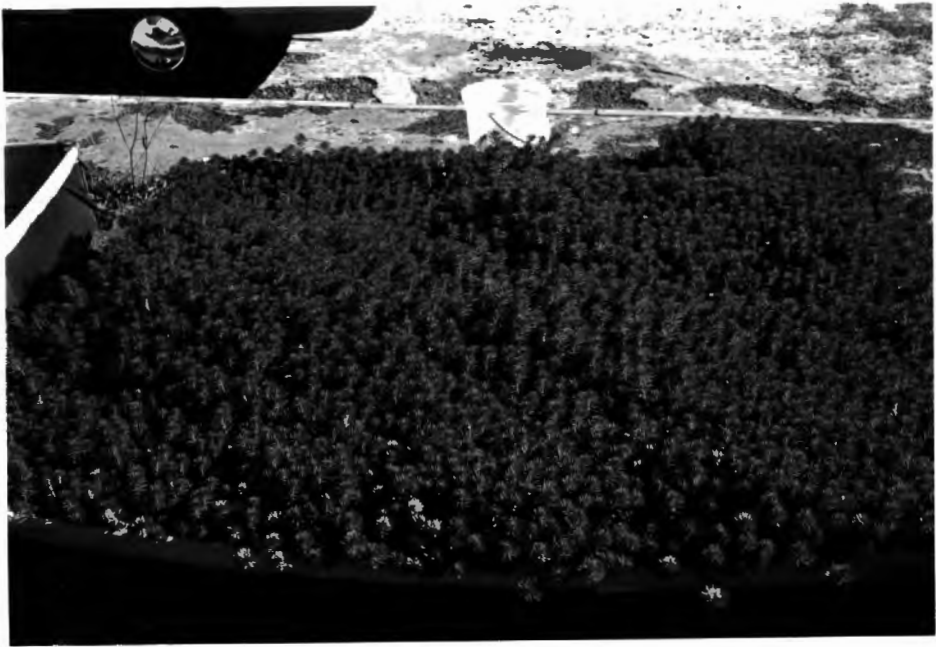


PLATE 19: The pond with M. aquaticum used to determine the rate of evapotranspiration.

M. aquaticum would loose approximately twice as much water through evapotranspiration than an equivalent open surface of water in summer. The fact that this is somewhat lower than values found in other species could possibly be attributed to the fairly low ambient temperatures over both periods for which the experiment was run. It is clear from the results that within the observed limits an increase in temperature increases the amount of water lost by M. aquaticum by comparison with the open water surface.

Consequently a water body or dam covered in M. aquaticum could be expected to loose water at least twice as rapidly as an equivalent open stretch of water.

9. SALINITY TOLERANCE

Initial observations revealed that at the mouth of the Keyzers River and on the lower reaches of the Berg River some factor was inhibiting the growth of M. aquaticum.

In the Keyzers River situation it was thought that salinity would be an important controlling factor as Sandvlei is known to be very saline. Results of water analyses done by the South African Bureau of Standards on three water samples taken from the lower Keyzers River are given in Table II.

TABLE II: Water analyses results of three samples taken from the Keyzers River on 4th March, 1977.

	SITE 1 (Military Rd.)	SITE 2 (River Mouth)	SITE 3 (Sandvlei)
pH	7,1	7,8	7,6
Ammonium N ($\mu\text{g. ml}^{-1}$)	5,0	0,3	0,2
Nitrate N ($\mu\text{g. ml}^{-1}$)	2,0	4,0	8,0
Chloride ($\mu\text{g. ml}^{-1}$)	145	490	1410
Sodium ($\mu\text{g. ml}^{-1}$)	86	340	1020

The three sites are shown in Plates 20, 21 and 22.

M. aquaticum was abundant at Site 1, in an unhealthy, yellowish condition at Site 2, and absent at Site 3. Similar analyses were done at two sites on the lower Berg River and these results are given in Table III.



PLATES 20, 21 and 22: Three photographs taken near the mouth of the Keyzers River showing the effect of salinity. They represent Sites 1, 2 and 3 as given in Table II.

TABLE III: Water analyses data from two sites on the Berg River (late 1976).

	SITE 1 (Daljosphat)	SITE 2 (Drieheuwels)
Chloride ($\mu\text{g. ml}^{-1}$)	8-44	50-154
Sodium ($\mu\text{g. ml}^{-1}$)	4-6	23-47
pH	7,2	8,0

M. aquaticum was present at Site 1 and was absent at Site 2. The increase of nutrient levels at Site 2 has been attributed to a change in farming practice in the area from a 4-camp system (1 standing crop : 1 stubble : 2 fallow) to a contoured 2-camp system (1 standing : 1 stubble) which results in less run-off and an increase in the mineralisation of the sub-soil water which finds its way into the Berg River.

Two water samples taken from the Berg River at Wellington and Hermon were stocked with three shoots of M. aquaticum and the experiment was run as described in Chapter 7. The solutions were renewed weekly and the % change in weight after three weeks in each solution is shown in Table IV.

TABLE IV: The % increase in weight of M. aquaticum grown in the sample described above, over a three week period.

	WEEK 1	WEEK 2	WEEK 3
Sample 1 - Hermon	2,4	3,6	4,7
Sample 2 - Wellington	19,6	32,5	46,2

The shoots in the water sample from Hermon only experienced a 4.7% increase in weight while those in the water sample from Wellington increased by 46.1% over a three week period. As large amounts of M. aquaticum are known to be washed downstream during winter flooding, it was assumed that conditions must be unfavourable for growth and the above experiment indicated that the factor restricting growth was probably in the water.

With these results in mind an experiment to determine the salinity tolerance of M. aquaticum was devised. A range of beakers containing different salinity concentrations was set up in duplicate. Successive dilutions of full strength sea water ($19,000 \mu\text{g. ml}^{-1} \text{Cl}^{-}$) were used, resulting in a range as follows:- $19,000 \mu\text{g. ml}^{-1} \text{Cl}^{-}$, $9500 \mu\text{g. ml}^{-1} \text{Cl}^{-}$, $4750 \mu\text{g. ml}^{-1} \text{Cl}^{-}$, $2375 \mu\text{g. ml}^{-1} \text{Cl}^{-}$, $1180 \mu\text{g. ml}^{-1} \text{Cl}^{-}$, $590 \mu\text{g. ml}^{-1} \text{Cl}^{-}$ and $295 \mu\text{g. ml}^{-1} \text{Cl}^{-}$. The beakers, each containing three portions of M. aquaticum of known weight, were placed in the Conviron growth chamber. Growth conditions were identical to those described in Chapter 7. The weights were taken at seven day periods, the solutions being renewed at the same time. The results obtained are given below in Table V.

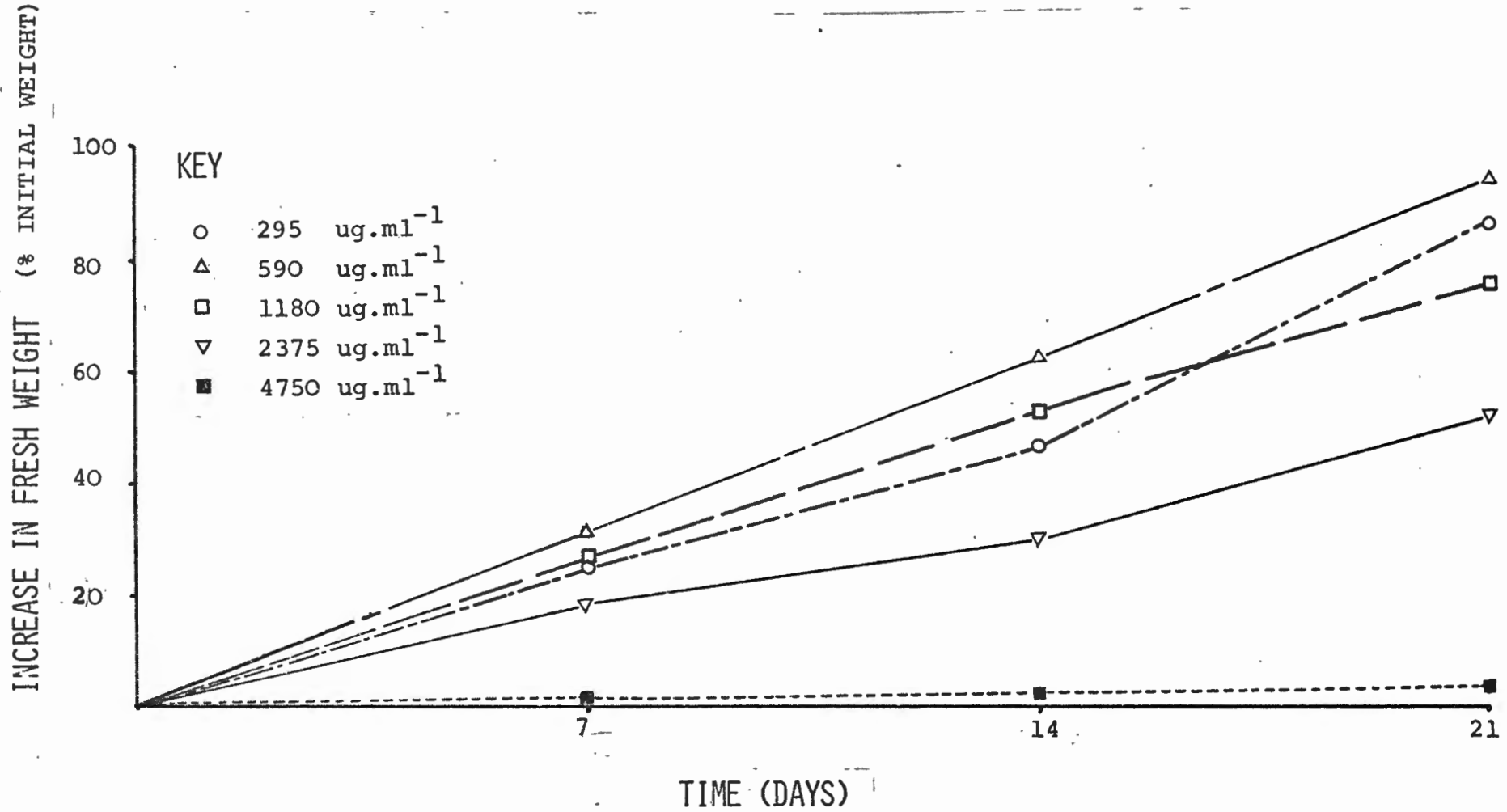
The two highest salinities i.e. $19000 \mu\text{g. ml}^{-1} \text{Cl}^{-}$ and $9500 \mu\text{g. ml}^{-1} \text{Cl}^{-}$ proved fatal and the plants had died after the first seven day period.

TABLE V : The % increase in weight of M. aquaticum grown in decreasing salinities of a three week period

	% INCREASE IN WEIGHT AFTER WEEK 1	% INCREASE IN WEIGHT AFTER WEEK 2	% INCREASE IN WEIGHT AFTER WEEK 3
4750 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	2,05	2,37	2,37
	0,00	1,92	2,45
2375 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	14,38	25,58	44,15
	27,49	35,03	61,30
1180 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	27,64	56,40	79,78
	25,25	49,50	72,92
590 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	31,49	70,04	103,52
	29,67	56,07	85,35
295 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	23,71	53,04	85,80
	28,04	40,54	87,33

The % increase in weight of M. aquaticum with passage of time is shown in Fig. 14.

FIG 14. THE PERCENTAGE INCREASE IN FRESH WEIGHT OF M. AQUATICUM GROWN AT VARIOUS SALINITIES



It is obvious from these results that M. aquaticum can tolerate a salinity of up to and including $4750 \mu\text{g. ml}^{-1} \text{Cl}^{-}$. These results did not verify observations in the field, as in both the Keyzers and Berg Rivers the plants were found to be restricted by a much lower concentration of Cl^{-} . This indicated that some other factor must be controlling the distribution. Further inspection of the data given in Tables II and III revealed that pH is higher in the areas where M. aquaticum is absent. With this in mind an experiment was set up which included the relevant pH and salinity values as found in both the Keyzers and lower Berg River systems. A pH range from 6,5 to 9 was used and salinity values of 100, 500 and $1400 \mu\text{g. ml}^{-1} \text{Cl}^{-}$ were selected. The experiment was run for three weeks as described in Chapter 7 with weekly weighings and solution replacement. Three shoots were placed in each solution. The results obtained are given in Table VI. Fig. 15 shows the % increase over the three week period for which the experiment was run.

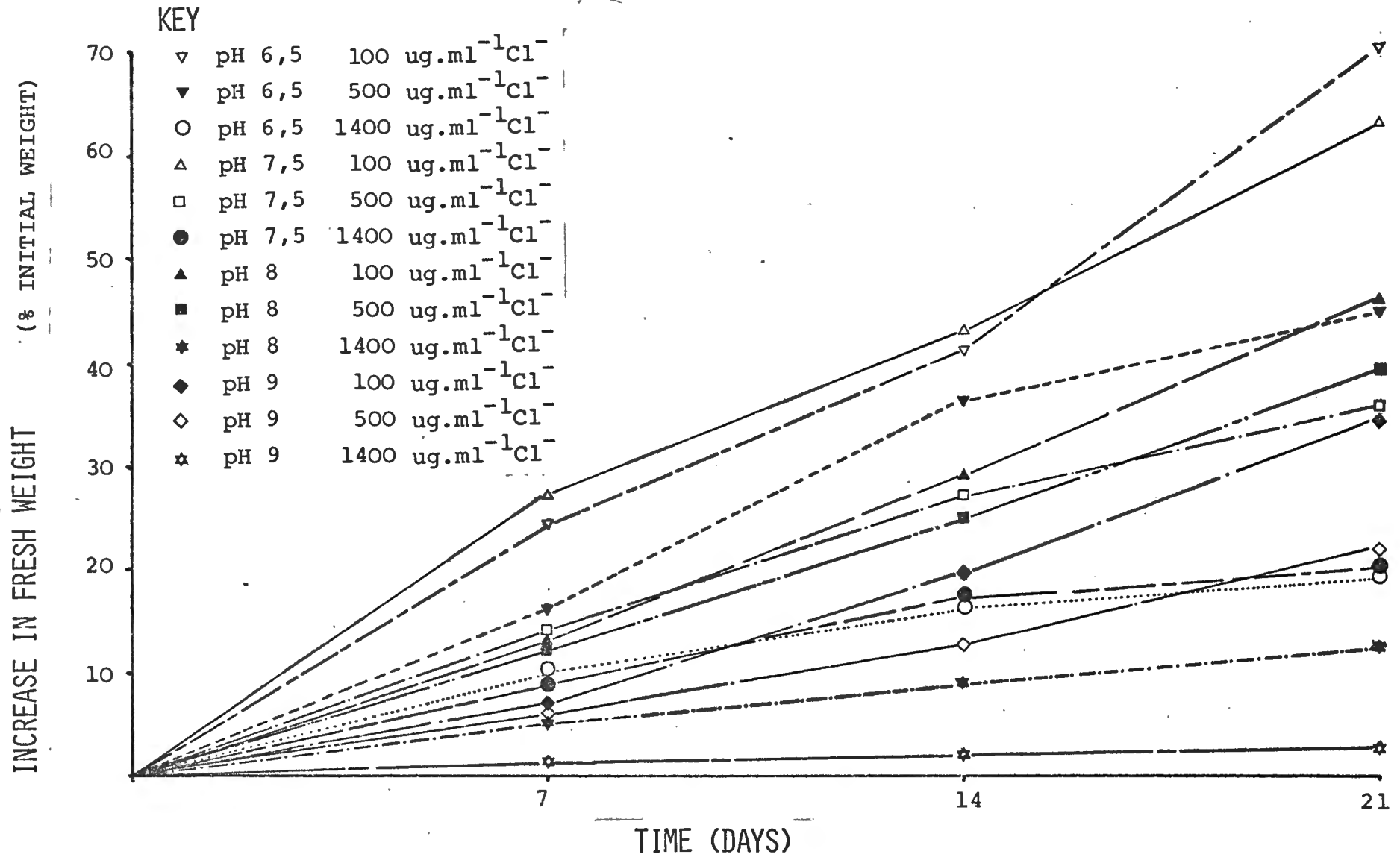
The results indicate that M. aquaticum shows a decreased growth rate with a combined increase in pH and salinity. This would seem to satisfactorily explain the unhealthy appearance of M. aquaticum at the Keyzers River mouth (pH 7.8, $490 \mu\text{g. ml}^{-1} \text{Cl}^{-}$) and the absence of the plant in the Berg River below Hermon (pH 8, $50-150 \mu\text{g. ml}^{-1} \text{Cl}^{-}$) because at these levels M. aquaticum shows a much reduced growth rate and exhibits slight chlorosis.

Thus it was determined that a combination of pH and salinity levels were probably responsible for the limiting of the spread of M. aquaticum in the lower reaches of the Keyzers and Berg Rivers. This knowledge could be put to good use when considering future control measures. For example it might be postulated that M. spicatum which flourishes in Lake Wingra in a pH range of 7,5 to 10,3 (Titus et al., 1976) would probably be more suited to colonizing the Henrick Verwoed Dam, which has a pH range of 7,5 to 9,8 (Ashton, 1974).

TABLE VI : The % increase in fresh weight of M. aquaticum at various salinity and pH levels over a three week period.

	% INCREASE AT WEEK 1	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 2	MEAN % INCREASE AND DEVIATION FROM MEAN	% INCREASE AT WEEK 3	MEAN % INCREASE AND DEVIATION FROM MEAN
pH 6,5 100 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	27,01 22,39	24,70 $\pm 2,31$	44,53 38,99	41,76 $\pm 2,77$	74,23 67,75	70,99 $\pm 3,24$
pH 6,5 500 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	17,55 15,07	16,31 $\pm 1,24$	37,74 35,72	36,73 $\pm 1,01$	48,96 42,02	45,49 $\pm 3,47$
pH 6,5 1400 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	10,93 9,35	10,14 $\pm 0,79$	18,54 15,42	16,98 $\pm 1,56$	23,32 15,72	19,52 $\pm 3,80$
pH 7,5 100 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	32,40 22,38	27,39 $\pm 5,01$	49,58 41,12	45,35 $\pm 4,23$	69,83 57,70	63,81 $\pm 6,02$
pH 7,5 500 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	15,43 12,23	13,83 $\pm 1,60$	29,57 25,21	27,39 $\pm 2,18$	37,79 34,27	36,03 $\pm 1,76$
pH 7,5 1400 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	8,08 5,60	6,84 $\pm 1,24$	13,75 12,23	12,90 $\pm 0,76$	24,08 20,24	22,16 $\pm 1,92$
pH 8 100 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	16,89 9,55	13,22 $\pm 3,67$	33,22 24,96	29,09 $\pm 4,13$	51,88 40,66	46,27 $\pm 5,61$
pH 8 500 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	16,88 8,66	12,77 $\pm 4,11$	28,36 21,48	24,90 $\pm 3,44$	42,72 36,40	39,56 $\pm 3,16$
pH 8 1400 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	8,05 3,01	5,53 $\pm 2,52$	10,87 7,75	9,31 $\pm 1,56$	14,36 10,68	12,52 $\pm 1,84$
pH 9 100 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	10,45 3,53	6,99 $\pm 3,46$	24,00 15,68	19,84 $\pm 4,16$	39,46 30,50	34,98 $\pm 4,48$
pH 9 500 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	13,54 4,30	8,92 $\pm 4,62$	20,23 13,74	17,03 $\pm 3,29$	24,40 16,06	20,23 $\pm 4,17$
pH 9 1400 $\mu\text{g. ml}^{-1} \text{Cl}^{-}$	2,55 0,43	1,49 $\pm 1,06$	3,35 0,87	2,11 $\pm 1,24$	3,48 1,74	2,61 $\pm 0,87$

FIG 15. THE PERCENTAGE INCREASE IN FRESH WEIGHT OF M. AQUATICUM GROWN AT VARIOUS pH AND SALINITY LEVELS



If the salinity levels were also fairly high, the growth of M. aquaticum would be adversely affected. The fact that at various pH values inorganic carbon exists as either CO_3^{2-} , H_2CO_3 , HCO_3^- (Lowenhaupt, 1956; Van, Haller and Bowes, 1976; Spence, 1967; Steeman-Nielsen, 1944-7), is unlikely to effect M. aquaticum to any marked extent as the greatest part of its photosynthetic area protrudes above the water surface.

10. CHEMICAL COMPOSITION OF M. AQUATICUM

With the possibility of having to remove large quantities of M. aquaticum from water bodies, it was decided to determine its chemical composition, as this would indicate its potential as either fodder or composting material.

A large quantity of fresh material was collected from the Keyzers River in May, 1976 and the chemical composition of the whole plant was analysed. The plant material contained flowers. The Kjeldahl method was used for total nitrogen determination and the extraction of other mineral nutrients was carried out according to the methods of Purvis, Collier and Walls (1966).

A known amount of material was oven-dried at 105°C for forty eight hours. The dried material was weighed and then ground in a mill so that it would pass through a 0,4 mm sieve. Carbon was removed by a wet digestion process. Five 1 g samples were transferred to Kjeldahl flasks and 5 ml of concentrated nitric acid was added. The temperature was gradually raised to approximately 200°C and left for forty-five minutes. After a cooling period 5 ml of ternary acid mixture was added, consisting of 100 parts concentrated AR nitric acid, 10 parts concentrated AR sulphuric acid and 40 parts concentrated AR perchloric acid. The samples were left at a temperature of 200°C until they had cleared. They were then made up to a known volume using 2,5 N hydrochloric

acid and aliquots of this were used for analysis.

The determinations of sodium and potassium were done by flame spectrophotometry, and calcium, magnesium, manganese, zinc, iron and copper were estimated by atomic absorption spectrophotometry. This process involved the making up of a series of standards of known concentrations and determining their atomic absorption on a Pye Unicam SP 1900 Atomic Absorption Spectrophotometer. The results of these determinations were used to draw up a calibration curve from which the concentration of the particular element in the five samples could be determined.

Total phosphate was determined by using the Molybdenum Blue Procedure (Jackson, 1958).

The analytical results of the above determinations on fresh whole plant material are shown in Table VII .

The controversy as to how aquatic macrophytes absorb their nutrients has been in progress for many years. Pond (1905) and Pearsall (1918) believed that the distribution of aquatic plants was related to the substrate, and uptake was mainly via the root system. Sutcliffe (1962) initially believed that uptake was via the foliage while Lundegarth (1966) contradicted this, believing that the root system was mainly responsible. Sculthorpe (1967) indicated that due to poorly developed vascular systems in the roots of most aquatic macrophytes, absorption was mainly via the leaves. Bristow and Whitcombe (1971) found a correlation between the root mass and the proportion of phosphate derived from the roots and showed that M. aquaticum would grow vigorously with a complete absence of mineral nutrients in the medium surrounding the growing region, proving that all its nutrients (except CO₂) were being derived via the roots and stem bases. The roots of M. aquaticum absorb 90% of the nutrients taken up by the plant, while roots of M. spicatum absorb only 59% of the total uptake.

TABLE VII : The average chemical composition of five samples of M. aquaticum.

ELEMENT	CHEMICAL COMPOSITION (mg. g^{-1} dry wt)	DEVIATION FROM MEAN
Nitrogen	33,16	$\pm 1,06$
Phosphate	3,03	$\pm 0,72$
Sodium	27,50	$\pm 2,31$
Potassium	4,75	$\pm 0,46$
Calcium	22,50	$\pm 0,17$
Magnesium	3,50	$\pm 0,53$
Manganese	0,10	$\pm 0,02$
Zinc	0,05	$\pm 0,02$
Iron	1,8	$\pm 0,50$
Copper	not detectable	-

This is feasible when one considers that all the foliage of M. spicatum is submerged whereas nearly all of the leaves of M. aquaticum are aerial. This is in agreement with the findings of Nichols and Keeney (1976 b) who proved that foliar uptake was the major pathway for nitrogen uptake in M. spicatum. Denny (1972) indicated that both methods could be used, depending on environmental conditions, and this seems feasible, provided that one takes into account the structural differences of the various species involved.

It must be realized that the values given in Table VII are approximations as the nutrient levels obviously fluctuate.

Although no data are available for M. aquaticum, it is known that M. spicatum accumulates phosphorus and potassium in its tissue after fertilization of the surrounding medium (Zdanowski, B et al, 1975). Adams and McCracken (1974) and Wilson (1972) also found large fluctuations in the phosphorus levels.

The levels for phosphorus and nitrogen obtained here are well within the critical growth levels given by Gerloff and Kromholtz (1966) who postulate levels of 13 mg. g^{-1} dry wt. N and $1,3 \text{ mg. g}^{-1}$ dry wt. P as the minimum content associated with maximum growth in aquatic macrophytes.

Sutton and Blackburn (1971) report that $2 \mu\text{g. ml}^{-1}$ Cu in the growth medium inhibits growth of M. aquaticum which possibly explains why no trace of copper could be found in the samples.

The rather high content of sodium can probably be attributed to the fact that many freshwater species actively accumulate sodium via their roots (Shepherd and Bowling, 1973), in contrast to studies which provide evidence for a sodium efflux pump in plant cells. The above authors also showed an active accumulation of potassium, while calcium and magnesium appear to be in electrochemical equilibrium with the external medium.

The results shown in Table VIII indicate that the nutrient levels are sufficiently high in M. aquaticum to enable it to be used as fodder or compost.

11. DISCUSSION AND CONCLUSIONS

At the outset of this study it was decided to investigate

- i) those aspects of the autecology of M. aquaticum which would assist in its control or eradication, as well as predicting possible future sites of infestation, and
- ii) the degree of natural control resulting from winter flooding.

It has been shown that draining a dam is not a reliable method of eradicating M. aquaticum, as the portions rooted in the substrate can remain viable over considerable periods. This drought resistance appears to be increased even further if the substrate has a high clay content.

As regards the prediction of possible future sites of infestation, the two major reservoirs which appear to be threatened by M. aquaticum are the Voëlvlei dam and the proposed Misverstand dam on the lower reaches of the Berg River. In the latter it has been shown that the pH and salinity levels are not suitable for the growth of M. aquaticum. If the levels do not change the plant should not prove to be a problem in this area.

At Voëlvlei dam however, the Department of Water Affairs are considering pumping water from the upper Berg River into the dam. This water is nutrient rich and it is unlikely that a fine enough filter could be used on the vast quantities of water involved, to prevent fragments of M. aquaticum passing through, which would result in the dam becoming infested. If this did occur one could postulate that the shallower areas of the dam would be most readily infested, considering the fact that M. aquaticum has only been found to root at a water depth of 30 cm.

The natural control by winter flooding has been clearly demonstrated on the Berg, Breede and Eerste rivers. The floods are obviously an important factor in regularly reducing the size of the colonies, washing large quantities of M. aquaticum out to sea or leaving it high and dry on river banks. Occasional summer floods also reduce the colonies which are establishing themselves, having survived the winter flooding.

It has also been observed that M. aquaticum cannot establish itself in densely shaded areas, and where the plant has been mostly removed by winter flooding, the remnants cannot give rise to further growth in dense shade.

Water analysis data revealed that the rapid growth of M. aquaticum in the South-Western Cape rivers was correlated to an increase in nutrient levels, as a result of fertilizer leaching in agricultural areas and sewage effluent in residential and industrial areas. Nitrogen utilization studies revealed that M. aquaticum showed a positive growth reaction to increased levels of nitrate nitrogen, but a negative response to an increase in ammonium nitrogen. This correlates with water analysis data which show high levels of nitrate nitrogen and low levels of ammonium nitrogen in the infested rivers.

As M. aquaticum is so well established in the rivers of the South-Western Cape, eradication is considered to be virtually impossible. Three methods of control of aquatic weeds exist, namely mechanical, chemical and biological control.

Mechanical control is one of the more widely used methods of control, specifically in areas where the water is being used for human or animal consumption or for irrigation purposes. This method is ten times more expensive than chemical control however (Holm et al., 1969). In Portugal agricultural equipment is being used to harvest M. aquaticum (Teles and Pinto da Silva, 1975). The mat is cut with a thresher and is pulled to the bank with a grapple. This grappling method has also been tried in South Africa at East London, and on the Vaal River by the Rand Water Board. However, this proved very labour intensive and as the pieces remaining in the mud and the fragments broken off remain behind and start new colonies, the operation must be repeated annually (Jacot Guillarmod, 1977). In addition, in South Africa it is illegal for water weeds to be transported. They must therefore be destroyed in situ.

Having removed the plant from the water, one is faced with the problem of how to utilize it. Aquatic macrophytes have been used for fodder (Zutchi, 1975), but the high tannin content of M. aquaticum (Boyd, 1970) make it unpalatable for cattle. Chemical analyses by the author have shown that the essential

nutrients are present should composting be contemplated, but with its extremely high water content (over 90%), the plant becomes very expensive to transport. The material would also have to be efficiently composted at a high enough temperature to ensure that no portions retain their viability, as this could lead to further spread. This is the reason why its use as a wet mulch is not recommended. The situation as regards the use of water weeds for fodder or compost is summed up by Tinker (1974), who states that no approach to the utilization of aquatic weeds has so far produced a product that can compete in the marketplace with similar products from other sources.

Another use to which the bulk of removed material can be put is the production of methane. This has proved very successful with Eichhornia crassipes where 374 litres of biogas are obtained per kilogram of dried plant material. This gas is composed of 60 to 80% methane (Wolverton and McDonald, 1976).

Although chemical control is widely used, care has to be taken that the application of the water and the other organisms associated with it.

In the U.S.A. 2,4 D (2,4 dichlorophenoxyacetic acid) has been applied to M. aquaticum with a wide range of results. The herbicide was found to be most effective in areas of slow water flow (Holm et al., 1969). However only temporary control was attained due to reinfestation by new fragments from untreated areas or by a few surviving plants (Nichols and Keeney, 1976 a). One must also consider the effect of a large mass of decomposing material that is left behind subsequent to herbicide application. This results in further depletion of the dissolved oxygen supply (Boyd, 1970) as well as resulting in obnoxious algal blooms (Nichols and Keeney, 1973). Success has been attained on other species, for example, diquat has proved effective in controlling Eichhornia crassipes (Holm et al., 1969). As previously stated, the use of herbicides in

the rivers of the South-Western Cape is not considered feasible due to the use of the water for overhead irrigation and animal and human consumption.

Biological control, like chemical control, requires extensive research prior to use as a control measure. Various species of insects and snails have been utilized in attempts to control Eichhornia crassipes and Salvinia molesta (Holm et al., 1969; Mitchell, 1968). It is believed that two species of nematodes have been responsible for the decrease of M. aquaticum in the U.S.A. (Teles and Pinto da Silva, 1975). A possible control measure in some dams could be the grass carp which is known to eat watermilfoil and has proved very successful in clearing Hydrilla verticillata in the U.S.A. One of the problems associated with the introduction of these fish would be the fact that they have a rather high optimum temperature of 26°C (National Academy of Sciences, 1976).

Consequently M. aquaticum control in the South-Western Cape would probably best be attempted by the removal of any new infestations by mechanical harvesting and composting. This method would be best applied in dams or reservoirs. In rivers of the South-Western Cape the winter floods appear to be controlling M. aquaticum by annually washing away most of the colonies formed during summer. The distribution of M. aquaticum has now been mapped and although eradication of most of the infestations is considered impossible, constant vigilance must be maintained on all major reservoirs and irrigation systems to prevent the establishment of further colonies.

M. spicatum, although declared a weed, is considered to be indigenous and the brief survey conducted indicates that it forms an integral part of the Verloren Vlei ecosystem. However, with the increase in human usage of the area as a result of planned development on the west coast, problems may be encountered.

It is believed that with vigilance and intelligent planning, the spread of M. aquaticum can be curtailed. However, if the threat it poses is ignored, there are other dams, rivers and irrigation schemes for it to invade, and wherever it occurs the control of it will prove very expensive.

12. REFERENCES

- ADAM, M.S. & McCRACKEN M.D. (1974).
Seasonal production of the Myriophyllum
component of the littoral of Lake Wingra, Wisconsin.
J. of Ecol., 62 (2) : 457-465.
- ADAMSON, R.S. & SALTER, T.M. (1950)
Flora of the Cape Peninsula.
Juta and Co. Johannesburg.
- ALLSOPP, A. (1965)
Land and Water Forms ; Physiological Aspects.
W. Ruhland (Ed.) Encyclopaedia of Plant Physiology 15.
Springer Verlag, Berlin.
- ANDERSON, R.R., BROWN, R.G. & RAPPLEYE, R.D. (1966)
The mineral content of Myriophyllum spicatum L.
in relation to its aquatic environment.
Ecology, 47 : 844-846.
- ASHTON, P.J. (1974)
The effect of some environmental factors on the
growth of Azolla filiculoides Lam.
The Orange River Progress Report, Inst. for Environmental
Sciences, University of O.F.S., Bloemfontein, S.A.
- BOYD, C.E. (1966)
Evaluation of some common aquatic weeds as possible feedstuffs,
Hyacinth. Cont. J., 7 : 26-27.
- BOYD, C.E. (1970)
Vascular aquatic plants for mineral nutrient
removal from polluted water,
Econ. Bot., 24 : 95;103.

BOKORNY, T. (1890)

Weitere Mitteilung ueber die wasserleitenden Gewebe.
Jhb. Wiss. Bol., 25 : 505-519.

BRISTOW, J.M. & WHITCOMBE, M. (1971)

The role of roots in the nutrition of aquatic vascular plants.
Am. J. Bot., 58 : 8-13.

CHAPMAN, V.J., BROWN, J.M.A., HILL, C.F. & CARR, J.L. (1974)

Biology of excessive weed growth in the hydroelectric
lakes of Waikato River, New Zealand.
Hydrobiologia 44 (4) : 349-364.

DEMARTE, J.A. & HARTMAN, R.T. (1974)

Studies on absorption of ^{32}P , ^{59}Fe and ^{45}Ca by watermilfoil.
(Myriophyllum exalbescens Fernold).
Ecology, 55 (1) : 188-194.

DENNY, P. (1972)

Sites of nutrient absorption in aquatic macrophytes.
J. Ecol., 60 : 819-829.

ENGLAND, W.H. & TOLBERT, R.J. (1964)

A Seasonal study of the vegetative shoot apex of
Myriophyllum heterophyllum.
Am. J. Bot., 51 : 349-353.

GERLOFF, G.C. & KROMHOLZ, P.H. (1966)

Tissue analysis as a measure of nutrient availability
for the growth of angiosperm aquatic plants.
Limnol. Oceanogr., 11 : 529-537.

GIBBS-RUSSELL, G.E. (1975)

Distribution of vascular aquatic plants in Rhodesia.
S. Afr. J. Sci., 71 : 270-272.

GRACE, J.B. & TILLY L.J. (1976)

Distribution and abundance of submerged macrophytes including Myriophyllum spicatum L. (Angiospermae) in a reactor cooling reservoir.

Arch. Hydrobiol., 77 : 4, 475-487.

HARRIS, D. (1966)

Hydroponics : The gardening without soil.

Purnell, Cape Town.

HARRISON, A.D. (1958)

Hydrobiological studies of the Great Berg River, Western Cape Province.

Trans. Royal Soc. of S.A. 35, 227-276.

HOLM, L., WELDON, L.E. & BLACKBURN, R.D. (1969)

Aquatic weeds.

Science, 166 : 699-709.

JACKSON, M.L. (1958)

Soil Chemical Analysis.

Prentice Hall.

JACOT GUILLARMOD, A. (1976)

Taxonomic and allied investigations on Myriophyllum species in Southern Africa. Interim Report for National Programme of Environmental Sciences. (Unpublished).

————— (1977)

Myriophyllum, an increasing water weed menace for South Africa.

S. Afr. J. Sci., 73 : 89-90.

LOWENHAUPT, B. (1956)

The transport of calcium and other cations in submerged aquatic plants.

Biol. Rev., 31, 371-395.

LUNDEGARTH, H. (1966)

Plant Physiology. Translated by F.M. Irvine.
American Elsevier, New York,

MITCHELL, D.S. (1968)

The ecology of vascular hydrophytes on Lake Kariba.
Hydrobiologia, 34 : 448-464,

NATIONAL ACADEMY OF SCIENCES (1976)

Making aquatic weeds useful ; Some perspectives
for developing countries.
Washington D.C.

NICHOLS, D.S. & KEENEY, D.R. (1973)

Nitrogen and phosphorous release from decaying
water milfoil,
Hydrobiologia, 42 : 509-525.

————— & ————— (1976 a)

Nitrogen nutrition of Myriophyllum spicatum:
Variation of plant tissue concentration with season
and site in Lake Wingra.
Freshwater Biol., 6 : 137-144.

————— & ————— (1976 b)

Nitrogen nutrition of Myriophyllum spicatum:
Uptake and translocation of ^{15}N by shoots and roots,
Freshwater Biol, 6 : 145-154.

PEARSALL, W.H. (1918)

On the classification of aquatic plant communities,
J. Ecol., 6 : 75-84.

PIAGET, J. & SCHLIEMANN, G. (1973 a)

Weeds choking Western Cape Rivers & appearance of
Myriophyllum spp. in the Boland.
The Deciduous Fruit Grower, 23 : 176-179.

_____ & _____ (1973 b)

Die verspreiding van die onkruid waterduisendblaar
en die gehalte van die water waarin die voorkom in
riviere van die Weskaapland.

Report to National Programme for Environmental
Sciences - Inland Water Section.

POND, R.H. (1905)

The biological relation of aquatic plants
to the substratum,

U.S. Commission of Fish and Fisheries,

Report for 1903, 485-526.

PURVIS, M.J., COLLIER, D.C. & WALLS, D. (1966)

Laboratory techniques in botany,

Butterworths, London.

SCHELPE, E.A.C.L.E. (1961)

The ecology of Salvinia auriculata and associated
vegetation on Kariba Lake,

Jl. S. Afr. Bot., 27 : 181-187.

SCULTHORPE, C.D. (1967)

The biology of aquatic vascular plants,

Edward Arnold, London.

SHEPHERD, U.H. & BOWLING, D.J.F. (1973)

Active accumulation of sodium by roots of
five aquatic plants.

New Phytol., 72 : 1075-1080.

SPENCE, D.H.N. (1967)

Factors controlling the distribution of freshwater
macrophytes with particular reference to the
Locks of Scotland.

J. Ecol., 55 : 147-70.

SPENCE, D.H.N., CAMPBELL, R.N. & CHRYSAL, J. (1973)
Specific leaf areas and zonation of fresh water macrophytes.
J. Ecol., 61 (2) : 317-328.

STEEMANN-NIELSEN, E. (1944)
Dependence of freshwater plants on the quantity
of carbon dioxide and hydrogen ion concentration.
Dansk. bot. Ark., 11 : 1-25.

STEENIS, J.H. (1967)
Eurasian watermilfoil, a rapidly spreading problem.
Hyacinth. Contr. J., 11 : 18-19.

SUTCLIFFE, J.F. (1962)
Mineral salt absorption in plants.
Pergamon, Oxford.

SUTTON, D.L. & BLACKBURN, R.D. (1971)
Uptake of copper by parrotfeather,
Weed Sci. 19, 282.

TELES, A.N. & PINTO DA SILVA, A.R. (1975)
A "Pinheirinha" (Myriophyllum aquaticum (Vell.) Verdc.)
uma agressiva infestante aquatica,
Agronomia Lusitana, 36 (3) : 307-323.

TINKER, J. (1974)
Waterweeds : Flies in the irrigation ointment.
New Scientist, 61 (890) 747-749.

TITUS, J. GOLDSTEIN, R.A., ADAMS, M.S., MANKIN, J.B.,
O'NEILL, R.V., WEILER, P.R., SHUGART, H.H. & BOOTH, R.S. (1976)
A production model for Myriophyllum spicatum L.
Ecology, 56 (5) : 1129-1138.

VAN, T.K., HALLER, W.T. & BOWER, G. (1976)
Comparison of the photosynthetic characteristics
of three submerged aquatic plants.
Plant Physiol., 58 : 761-768.

VAN DER MEIJDEN, R. (1969)
An annotated key to the South-East Asiatic,
Melesian, Mascarene and African species
of Myriophyllum (Haloragaceae).
Blumea, 17 : 303-311.

VAN DER MEIJDEN, R. & CASPERS, N. (1971)
Haloragaceae
In Flora Malesiana
Ser. I, 71 : 248-259.

WEBER, J.A. & NOODEN, L.D. (1976)
Environmental and hormonal control of turion
germination in Myriophyllum verticillatum.
Am. J. Bot., 63 (7) : 936-944.

WILSON, D.O. (1972)
Phosphate nutrition of the aquatic angiosperm
Myriophyllum exalbescens (Fern.).
Limnol. Oceanogr., 17 (4) : 606-611.

WOLTERECK, I. (1921)
Experimantelle Untersuchungen über die
Blattbildung amphibischer Pflanzen,
Flora, Jena, 123 : 30-61.

WOLVERTON, B. & McDONALD, R. (1976)
Don't waste waterweeds.
New Scientist, 17 (1013) : 318-320.

ZDANOWSKI, B., BRUNSKA, M., KORYCKA, A. & SOSNOWSKA, J. (1975)

The effect of mineral fertilization on ecosystem structure and functioning in lakes of different trophic type : I.

The effect of lake fertilization on changes in chemical composition of water and macrophytes, chlorophyll content and primary production of pelagic zone.

Polski Archiwien Hydrobiologii, 22 (2) : 217-232.

ZUTSHI, D.P. (1975)

Associations of macrophytic vegetation in Kashmir lakes.

Vegetatio, 30 (1) : 61-66.