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BIOLOGICAL CONTROL AGENTS OF
HYDRILLA VERTICILLATA; FINAL REPORT
ON SURVEYS IN EAST AFRICA,
1981-1984

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Since its introduction into Florida in the early 1960s, the submerged aquatic plant <i>Hydrilla verticillata</i> has become a serious weed problem in the waterways of the southern United States. Since East Africa forms part of the natural distribution of hydrilla, a search for potential biological control agents in the region was carried out by the Commonwealth Institute of Biological Control from 1981 to 1984. Hydrilla was found to have a wide but disjunct (Continued)		

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distribution in Uganda (Lake Kioga), Rwanda (Lake Bulera and Mukungwa River), and Burundi (Lake Tanganyika). In Kenya, despite an intensive search, only a single population, probably of exotic origin, was found. The range of the plant appears to have been reduced (especially in Lake Victoria), probably by man-made changes in the environment.

In East Africa hydrilla appears to be nonaggressive, and plants in most habitats are small in stature, forming mats on the hydrosol and rarely reaching the surface. Plant growth appears in general to be constrained by fish grazing, but in Lake Tanganyika hydrilla is seasonally attacked by larvae of a chironomid which destroys many of the apical meristems and curtails upward growth of the plant. This species was not successfully reared, but should be further studied for possible introduction into the United States as it is damaging to hydrilla and may be specific for hydrilla. Pyralid larvae were found on hydrilla at one site but these were not damaging, and the plant was not a preferred host in that region.

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Preface

This report presents the results of the search for potential biological control agents of *Hydrilla verticillata* in East Africa. Funds were provided by the Office, Chief of Engineers, under appropriation number 96X3122, Construction General, through the Aquatic Plant Control Research Program (APCRP) at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The principal investigator for this study was Dr. R. H. Markham, Commonwealth Institute of Biological Control (CIBC), Kenya Office.

The study reported here was funded through the USDA-SEA under Agreement No. 58-7B30-9-111. The author would like to thank Dr. T. D. Center who patiently guided the conduct of the project from a distance, and Dr. J. K. Balciunas who provided much useful advice on the spot.

Of the numerous people who assisted with the search for hydrilla in East Africa, the author would especially like to thank the following: in Kenya, the Director of Fisheries and staff of the Fisheries Department stations at Naivasha, Baringo, Kisumu, Port Bunyala, and Homa Bay; in Uganda, the Director and staff of the Uganda Freshwater Fisheries Research Organization, Jinja, and especially Mr. S. Mungoma; in Rwanda, Mr. V. Frank of the Pecherie Ihema; in Burundi, Mr. B. Nyakageni, the Director of the Departement des Eaux et Forets, and Dr. A. Autrique and Mr. P. Ndayiragije of ISABU; and in Malawi, the Fisheries Development Officer, Sengha Bay.

In Europe the author would like to thank Prof. C. D. K. Cook of the University of Zurich for his comments on the morphology of hydrilla samples and Dr. A. H. Pieterse of the Royal Tropical Institute of The Netherlands for his information on isoenzymes and much useful advice.

The research was monitored by Mr. Edwin A. Theriot, of the WES Environmental Laboratory (EL), Wetlands and Terrestrial Habitat Group (WTHG). The study was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Dr. Conrad J. Kirby, Jr. Chief, Environmental Resources Division; and the direct supervision of Dr. Hanley K. Smith, WTHG. Mr. J. Lewis Decell was Program Manager of the APCRP at WES. This report was edited by Ms. Jamie W. Leach of the WES Information Products Division.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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BIOLOGICAL CONTROL AGENTS OF *HYDRILLA VERTICILLATA*; FINAL REPORT ON
SURVEYS IN EAST AFRICA, 1981-1984

Introduction

1. The aquatic weed hydrilla (*Hydrilla verticillata*, Hydrocharitaceae) has a widespread but highly disjunct distribution throughout Europe, Africa, Asia, and Australasia. Throughout this range hydrilla rarely achieves the status of a serious weed and indeed is often highly restricted in distribution; reports of hydrilla pest problems in Asia and Australia almost invariably refer to man-made or disturbed aquatic systems. In contrast, hydrilla has become a widespread and highly aggressive aquatic weed in a variety of aquatic habitats throughout much of the southern United States. The precise origin of the US hydrilla infestation is not known, but the plant was first reported in the early 1960s from Florida, where it is thought to have been introduced via the aquarium trade. Considerable sums are spent annually on control by mechanical and chemical means, but these methods have proved expensive and nonpermanent. Literature on the botany, ecology, and control of hydrilla have been reviewed by Pieterse (1981).

2. As an exotic weed in the United States, hydrilla seems a promising candidate for classical biological control and the US Department of Agriculture (USDA) has coordinated an extensive search for suitable control agents. Exploration for natural enemies began in Asia, where long-term studies were conducted by the Commonwealth Institute of Biological Control (CIBC) Pakistan Station (Baloch, Sana-Ullah, and Ghani 1980), and more extensive surveys have recently been made by Balciunas (1981, 1982, 1983). A preliminary search in East Africa was made by Pemberton (1977) who explored lakes in Kenya and Tanzania but found hydrilla populations only in the area of Kigoma on Lake Tanganyika. Herbarium records of hydrilla also exist from Kenya, Uganda, and Burundi but Pemberton's findings indicated a very restricted plant distribution. It has been suggested by various workers that natural enemy activity may be contributing to its scarcity. Pemberton concluded that a chironomid midge (*Polypedium* sp.) and possibly herbivorous fish were the main control agents at his study sites in Lake Tanganyika.

3. Plans for the establishment of a new CIBC station in Kenya provided the opportunity for a more thorough survey of East Africa, and in 1979 an agreement was concluded between USDA and CIBC providing for a 1-year preliminary survey. Administrative difficulties initially delayed the posting of permanent CIBC staff to Kenya until 1981, and work on this project was begun during the latter part of that year. Unfortunately, further logistic problems associated with setting up the station and political obstacles to field work in several of the East African countries severely impeded progress on surveys; the project period was accordingly extended, initially into 1983 and then into 1984. By the end of this period, intensive searches had been made in Kenya, Rwanda, and Burundi and more limited ones in Uganda and Malawi. The results of this work are reported here, together with recommendations for further research.

Conduct of the Surveys

4. At the start of this project, hydrilla has been recorded in East Africa from Lake Victoria (Port Victoria in Kenya and Jinja in Uganda), Lake Kioga (Uganda), Lake Bunyoni (Uganda), and Lake Tanganyika (Burundi, Tanzania, Zaire, and Zambia), but few of these records were of recent finds. Uganda, with its extensive and varied systems of waterways, offered the most promise from a purely technical point of view; however, surveys in most of that country were precluded by the poor security situation. Accordingly, priority was given initially to a thorough exploration of lakes in Kenya; the country had only been treated cursorily by Pemberton. The variety of lakes within convenient reach of the CIBC laboratory offered the best opportunity for intensive study of natural enemies of hydrilla could be found.

5. Unfortunately, this effort failed to identify an extant population of hydrilla, and the search had to be extended to eastern Uganda, Rwanda, Burundi, and Malawi. Inevitably, the lack of a permanent base for research in any of these countries restricted the kind of studies which could be conducted. However, a number of varied hydrilla populations were identified and two or more collections made from each. Plant quarantine regulations initially prevented live material from being transferred to the CIBC laboratory in Kenya, but in due course permits were obtained and several shipments of hydrilla and associated insects brought back for further study.

6. Initially it proved difficult even to find hydrilla or obtain information about its occurrence in East Africa. Contact was established with fisheries projects and research stations in all the areas covered: Naivasha, Baringo, Kisumu, Port Victoria, and Homa Bay in Kenya; Jinja in Uganda; Kigali, Lac Ihema and Gisenyi in Rwanda; Bujumbura in Burundi; and Salima in Malawi. Color photographs and, later in the study, plant samples were shown to staff at these sites, but only in two cases (Jinja and Bujumbura) were researchers familiar with the plant and able to suggest collecting sites. Thereafter, local fishermen were usually the best source of information, though suspicion of the researcher's motives and lack of a common language were sometimes a barrier to good communication. Fragments of hydrilla in fishing nets or along the strand line sometimes provided the first clues to the existence of the plant in an area. One problem encountered in approaching local people for information was that the extreme morphological variation in hydrilla in East Africa made plants from one site unrecognizable even to those who were familiar with the species at another site. In many cases, the best guidance that could be obtained was to sites where submerged aquatics could be found. Thereafter, a patient search by boat was necessary, concentrating on sites which seemed from general topography and environment to be promising.

7. In Kenya boats for lake surveys were readily obtained from the nearest Fisheries Department station. Elsewhere it was usually necessary to hire canoes from local fishermen, but these craft were often highly unstable and difficult to work from. A weed drag was used in most cases to collect samples. Diving was a much more effective means of collecting plants in Lakes Tanganyika and Malawi but elsewhere the high risk of schistosomiasis infection and, in some localities, crocodile attacks precluded this possibility. Samples of 1 kg or more were collected in plastic bags from each stand found on each occasion; preliminary inspections of the material were always made on the spot and then a more thorough, stem-by-stem, search carried out back at the base. Laboratory facilities near to study sites were only available at Jinja and Bujumbura. Insulated "cool boxes" were usually used to transport samples, but rapid deterioration of samples in the typically high ambient temperatures was an ever-present problem.

8. Hydrilla samples were brought back to Nairobi from each collecting site and cultures established separately in small aquaria. These cultures

were used to feed phytophagous insects collected on subsequent trips. Only in Burundi, where laboratory facilities were made available by the Institut des Sciences Agronomiques du Burundi (ISABU), was it feasible to rear insects for a substantial period near the collecting site. In this case hydrilla samples were placed in 3- ℓ buckets, provided with aeration, and topped with cylinders of fine metal gauze from which emerging insects could be collected. The larvae of aquatic insects tend to be rather fragile (sensitive to changes in temperature, oxygen tension, and water quality) and high mortality was inevitably a problem in all attempts to bring material back to Nairobi.

9. Pressed specimens of hydrilla and associated aquatic plants were made at each site and are available for taxonomic investigation. Living plant material from most sites has been sent to Professor Cook of Zurich University (Botanic Garden and Institute for Systematic Botany) and to Dr. Pieterse of the Royal Tropical Institute of The Netherlands for morphological and isoenzyme studies, respectively.

Results of Hydrilla Distribution Surveys

10. An overview of the outcome of the surveys is given in the maps of East Africa (Figures 1-3) showing the sites searched and the presence or absence of hydrilla. The results are reviewed here briefly by the countries surveyed. A more complete and systematic account of the surveys, in the form of a list of the main sites visited with a brief description of the aquatic environments and of the plants found at each, is given as Appendix A to this report.

Kenya

11. The lakes of the eastern arm of the Rift Valley are mainly "soda" lakes (Magadi, Elmenteita, Nakuru, and Bogoria), which are too saline to support aquatic macrophytes. The largest of the Rift lakes, Turkana, is only moderately saline, but on brief visits to both the eastern and western shores submerged aquatics were found at only one site and there in weak stands. It was concluded that a more thorough search, for the purposes of this project, was not justified. Thorough surveys were, however, made of the two freshwater lakes, Naivasha and Baringo. The area of Baringo suffers from increasingly severe erosion and the lake itself carries a heavy sediment load, which

is deleterious to submerged plants. Only two species were found (*Ceratophyllum demersum* and *Najas pectinata*), and those were in limited stands. Naivasha is much clearer and supports a rich aquatic flora (dominated by *N. pectinata* and *Potamogeton* spp.), especially in the southern part of the lake, but here again hydrilla was not found.

12. The highlands on both sides of the Rift Valley have numerous streams, small natural ponds, and artificial reservoirs. A great many of these were inspected during the project period, including several with abundant aquatics, but none supported hydrilla. A somewhat similar plant, *Lagarosiphon hydrilloides*, was abundant in several lakes and streams in the Aberdares (Nyandarua Mountains). Water bodies in the semiarid lowlands are mainly seasonal and support few aquatics. Hydrilla was found in small artificial ponds on the coast south of Mombasa, but this population appeared to be naturalized from aquarium escapes.

13. A great deal of effort was invested in searches of the Kenya shore of Lake Victoria, including a brief aerial survey in the company of Dr. Balciunas, a project advisor from the University of Florida. Over 100 km of the coast was also covered in intensive searches by motorized canoe, beginning with Port Victoria (now Port Bunyala), the origin of the previous Kenyan records of hydrilla. Although the lake offers a great variety of aquatic habitats and, in places, a rich flora (dominated by *Potamogeton* spp.), no trace of hydrilla was found.

Uganda

14. The area west of the Nile was regarded as a poor security risk at the time of this work. Accordingly, no surveys were made in this area, which unfortunately includes Lake Bunyoni, the origin of many of the Ugandan hydrilla records. Attention was concentrated on two other sources of previous collections, Jinja on Lake Victoria and Lake Kioga immediately to the north.

15. The intensive Lake Victoria searches, carried out over three short visits by the project entomologist and continued by local collaborators from UFFRO (the Uganda Freshwater Fisheries Research Organization), drew a total blank. Indeed, virtually no aquatic macrophytes were found in this area of the lake, despite the clarity of the water and the great variety of shoreline habitats. Several fishermen claimed to have seen hydrilla occasionally brought up in nets from deeper water, but it was impossible to verify these reports.

16. An abundant growth of hydrilla (Figures 4 and 5) was, however, found in Lake Kioga, near Bukungu. Fisheries Department reports indicate that this lake was formerly shallower and carpeted with aquatic plants. Such growths are, however, now found only in a very limited area of shallow water, formerly an island, near the point at which the Nile flows into and crosses the lake. Hydrilla was a major component of stands of vegetation dominated by *Lagarosiphon* sp., and accompanied by *Potamogeton schweinfurthii*, *C. demersum*, *N. pectinata*, and *Vallisneria* sp.

Rwanda

17. Despite the small size of the country, Rwanda offers a great number and variety of aquatic habitats. The western Rift Valley forms the western border of the country and some 90 km of this consists of Lake Kivu. From the Rift watershed eastwards, the country is drained by a network of swamps, lakes, and rivers, referred to loosely as the "Nile drainage," all of which collect into the Akagera River and empty finally, via Tanzania, into Lake Victoria. Along the eastern frontier of the country the Akagera runs through a large area of swamps and lakes, of which the largest is Lake Ihema.

18. Most of the shore of Lake Kivu is very mountainous and access from the shore is difficult. The lake was visited at three points: Gisenyi in the north, Kibuye midway along the western shore, and Cyangugu in the south. At all points the water was very clear and shelved quite rapidly into deep water. At Gisenyi the shores were sandy and seemingly totally devoid of macrophytes. Elsewhere, sheltered bays and muddy inlets provided sites for aquatics, though these were very scarce. A single stand of one species of *Potamogeton* was found near Kibuye and around Cyangugu there were more extensive beds of an unfamiliar species, possibly a *Najas*. Neither fishermen nor fisheries specialists on the lake recognized hydrilla samples, and it seems unlikely that the plant occurs in Kivu.

19. Most of the rivers in the Akagera system are fast flowing and carry a very heavy sediment load, making them quite unsuitable for submersed aquatics. The many headwater lakes, which are fringed with papyrus swamps and therefore filter much of the sediment, appear more promising. Several lakes to the east and south of the country were visited, and boat searches were made of both Ihema and Muhazi, but without success. Indeed, these lakes are almost devoid of submerged aquatics. *Ceratophyllum demersum* and *Utricularia inflexa*

were the only species encountered, and these were encountered only rarely. Many fishermen reported that aquatics had formerly been more abundant, but it was impossible to verify this from official records or herbarium specimens.

20. Two lakes in the extreme north of the country, Lakes Ruhondo and Bulera (Figures 6 and 7), are in complete contrast to this pattern. Although technically part of the Akagera system, they lie in a very mountainous area near the Birunga Volcanoes and both are deep, clear, and support an abundant aquatic flora. In this they resemble the nearby Lake Bunyoni, across the frontier in Uganda, which is the source of numerous hydrilla records.

21. *Potamogeton schweinfurthii* and *P. pectinatus*, with smaller amounts of *C. demersum*, form an almost continuous fringe along much of the shore of both lakes. Hydrilla appear to be abundant in Lake Bulera as it was present in quantity at three of five points where drag-rake samples were collected along the northern shore. The hydrilla grows under, and in deeper water beyond, the fringe of more robust aquatics. Hydrilla was not found in Lake Ruhondo, though the habitat appears suitable and the plant is probably there. Hydrilla was, however, found in the stream below the hydroelectric dam leading out of Ruhondo. The main flow from the power station rejoins the natural riverbed some kilometres lower down the valley, leaving in the interval a series of shallow pools, almost choked with vegetation (Figures 8 and 9). This includes the same two species of *Potamogeton* found in the main lake, with patches of *C. demersum*, *Vallisneria* sp., and dense mats of hydrilla.

Burundi

22. Aquatic habitats in Burundi are very much more limited than in Rwanda. Apart from a 120-km stretch of the shore of Lake Tanganyika and two lakes (Cyohoha and Rweru) on the Rwanda frontier, most of the country is drained by small, fast-flowing rivers and streams, which become torrents during the wet season and support no submerged macrophytes. Lakes Rweru and Cyohoha were not visited because access is difficult and it was thought that they would probably be similar to the unproductive lakes of the southern part of the Akagera system in Rwanda. Attention was concentrated on finding and sampling hydrilla populations on Lake Tanganyika. The Lake Tanganyika populations are assumed to have an ecology similar to that found by Pemberton in the area of Kigoma on the Tanzania shore of the lake.

23. Boat searches in the immediate area of Bujumbura, carried out with the assistance of staff from the Departement des Eaux et Forets, yielded one large stand of hydrilla on a sheltered shore near the port area. Hydrilla was the dominant plant forming tangled beds with small amounts of *Potamogeton pectinatus* and *Vallisneria* sp. On later visits, additional hydrilla populations were found in three rather different localities further south along the lakeshore. The first was in shallow lagoons, cut off from the main lake by a sandbar, 12 km from Bujumbura. The second was on the exposed, gravelly shore of a sand spit projecting into the lake (Figure 10), 25 km from Bujumbura. The third was in a sheltered bay at Rumonge, 70 km from Bujumbura. In all these locations hydrilla was found growing in mixed stands with *Chara* sp., *Potamogeton* spp., and *Vallisneria* sp. In the latter two sites hydrilla was an abundant codominant.

Malawi

24. Interest in Lake Malawi stemmed from its striking similarity in general ecology to Lake Tanganyika. In the absence of existing records of hydrilla from the region, a full-scale survey was not felt to be justified. However, some exploration of the lakeshore was possible while visiting Malawi on other duties. Hydrilla was not found in a survey of the plants of the Shire River and Lake Malombe carried out by staff of the Biology Department, Chancellor College, University of Malawi (Osborne, Blackmore, and Dudley, unpublished data); therefore, this area was not searched.

25. Several points along the southwest sector of the Lake Malawi shore, the area thought most promising by local fisheries specialists, were visited. Aquatic macrophytes were abundant along sandy shores at Malembo, more sporadic at points between Cape Maclear and Mangochi, and very sparse in the area of Salima. At Malembo, especially, the habitat closely resembled the hydrilla sites on Lake Tanganyika with dense growths of *Potamogeton* spp., *Ceratophyllum*, and *Vallisneria* sp., but hydrilla was not found.

Control Agents of Hydrilla and Associated Plants

26. The status of each of the hydrilla populations sampled during this survey was quite different. There was certainly no sign of a predominant phytophagous organism, or group of organisms, which could be said to be responsible for the scarcity of hydrilla in East Africa.

27. The Ugandan population was the least studied, due to the logistic impossibility of working onsite and the deterioration of samples brought back from Bukungu to Jinja or Nairobi. No phytophagous insects were found on the hydrilla itself although *Parapoynx* sp. larvae were found in some abundance on the associated *Potamogeton*, *Najas*, and *Ceratophyllum*; a single *Parapoynx* larva was found on the abundant *Lagarosiphon* sp. which was growing with the hydrilla. A few stems of hydrilla showed damaged and aborted terminal buds, attributable to insect feeding, but no causative agent was found. Some stems had obviously been grazed by fish, probably *Tilapia zillii*, which is common in the lake, but the damage was not spectacular. Gastropods were abundant on all plant samples but probably were not damaging.

28. In Lake Bulera, Rwanda, no phytophagous insects and only very few gastropods were found on the hydrilla. The open structure of the hydrilla from this site (Figure 7) probably promotes fish predation and makes the plant a poor substrate for invertebrates. Most stems of hydrilla which grew upwards from the hydrosol were severely grazed by fish (Figure 12). There can be little doubt that this is the main restraining influence on hydrilla at this site.

29. The hydrilla in the stream below Lake Ruhondo was, in contrast, luxuriant in growth (Figures 9 and 12) and in this unstable habitat seemed to be growing opportunistically, constrained mainly by competition with other aquatics. *Parapoynx* larvae were again found in some numbers on both *Ceratophyllum* and *Potamogeton*; a single *Parapoynx* larva was found feeding on the hydrilla itself, but this was on a plant growing amongst *Ceratophyllum* and the pyralid may well have come originally from that host.

30. Only in Lake Tanganyika was substantial insect damage to the hydrilla apparent. This took the form of larval tunneling in the meristem of the terminal buds, which subsequently swelled slightly and then were cleanly aborted, leaving a characteristic cup-shaped tip. From 10 to 100 percent of the stems of particular plants were affected in this way. Usually a new shoot was produced just below the aborted tip but when plants were attacked repeatedly, their growth was considerably restrained and they showed a characteristic "layered" growth form (Figure 13). The form of the plants indicates that insect attack typically affects many stems simultaneously and then is followed by a period of regrowth; in other words, insect attack is strongly seasonal

rather than continuous. Fish damage was also apparent on some stems, but this appeared to be much less important in containing the growth of the hydrilla.

31. The plants showing this type of damage supported vast numbers of chironomid larvae, together with small nematodes, trichopterans, and various other less abundant insect larvae. However, most of these organisms were filter feeders or predators and were not feeding on the hydrilla. In all cases where responsibility for the damage could be attributed with confidence, the causative agent was a single type of chironomid larva, distinguishable by its larger size and characteristic color pattern (green streaked with red, in exact imitation of the coloration of the hydrilla buds). When placed in individual vials with undamaged tips of hydrilla, these larvae rapidly bored the terminal bud, causing the characteristic damage to the apical meristem. It is very likely, on the basis of the symptoms described, that this species of chironomid is the same as the *Polpedium* found by Pemberton in Tanzania. This form of damage was not found on any of the other submerged aquatics growing with the hydrilla, though admittedly in plants of markedly different growth form the symptoms might be difficult to identify.

32. Numerous samples of hydrilla were collected and searched in the course of four visits to the Lake Tanganyika sites, but at no time was the damaging chironomid abundant and no specimens of this species were successfully reared through to maturity. The characteristic damage symptoms are not at their most obvious until after the chironomid has completed its development, and clearly the symptoms persist for long periods thereafter. However, even when this is taken into account, the living insect populations found did not seem high enough to explain the damage; this again suggests that the incidence of the insect is markedly seasonal.

33. Bulk samples of hydrilla were brought back to Nairobi on two occasions in the hope that emerging insects could be brought into culture for study. Though both chironomids and trichopterans completed development in the laboratory, unfortunately no reproduction followed.

Environmental and Genetic Variability in Hydrilla

34. Field-collected specimens of hydrilla from the different East African populations varied spectacularly in appearance. Some idea of this variation may be gained by comparison of Figures 4-12.

35. Plants from Lake Tanganyika were typical of the African alkaline lake phenodeme described by Cook and Luond (1982) as having "short, leathery leaves which are ovate to widely ovate." The plants from Lake Kioga are similar in general form, having thick stems and short, broad leaves; however, in the Ugandan plants the leaves are somewhat keeled, sharply pointed at the tip, and bear stout, soft spines along the underside of the midrib.

36. Plants from Rwanda (Lakes Bulera and Ruhondo) resemble more closely hydrilla from Asia and the United States in having a more "bushy" growth form, relatively longer, narrower leaves and weaker stems. As collected, the plants from Bulera had a much more open structure than those from Ruhondo, with abruptly branching stems giving the whole plant an angular appearance (Figure 12). However, this form may represent a response to the lower light intensity to which the plant was subjected in the Lake Bulera habitat. Plants from other sources tended towards this form when grown in aquaria.

37. The hydrilla collected from freshwater ponds on the Kenya coast were quite different from all the others in having almost linear leaves, with distinct marginal serrations, and having a much larger number of leaves in each whorl. In these respects they resemble Asian forms, tending to confirm the suggestion that they are aquarium escapes.

38. Interestingly enough, considerable differences have persisted in hydrilla samples grown under standardized conditions in the laboratory. Indeed, plants from the various populations are still readily distinguishable after growing for many months in the same aquarium. The Lake Tanganyika samples have totally changed in appearance, producing narrow leaves and slender stems similar to the Rwandan plants. The Ugandan plants, on the other hand, have maintained their stout form and broad, short leaves.

39. After growing the plants under standard conditions in The Netherlands, Dr. Pieterse (personal communication, 6 February 1984) confirmed the above general comment that the Rwandan plants are similar in morphology to hydrilla from other parts of the world, but that the Lake Tanganyika and Lake

Kioga plants (with "short broad leaves, few in a whorl") are "very exceptional." He also notes from the isoenzyme patterns that the African plants seem to be closely related to one another, and that the Rwandan plants differ in one enzyme (out of eight tested) from the Tanganyika and Kioga plants. Interestingly, Pieterse remarks that "over the whole the isoenzyme patterns (of these African plants) are very similar to *Hydrilla* plants from Florida," though he notes that their chromosome number is 16, as compared with 24 for the Florida plants. Dr. Pieterse intends to publish the results of these investigations in due course.

Discussion

40. The extensive and intensive surveys carried out in the course of this study confirmed the impression that hydrilla in East Africa is a widespread but sporadically occurring plant which is not aggressive and has no pest status. The ecological tolerances of hydrilla were not studied as such, but consideration of the sites as a whole leaves a strong impression that in East Africa the plant has very particular requirements. These include water which is rich in minerals (probably neutral to alkaline in pH) but low in organic matter and free from suspended sediment and/or phytoplankton. In general, hydrilla occurs in stable natural habitats, rather than disturbed and man-made ones. In these respects the African populations appear to resemble those of European hydrilla (Cook and Luond 1982), rather than those in India, Australia, and the United States where the plant has sometimes been recorded as a noxious weed.

41. Both Pemberton's surveys and those carried out here, when compared with existing records, strongly suggest that hydrilla has disappeared from a number of localities where it previously occurred and in Lake Kioga its distribution has become much more restricted. It may be that in the case of Lakes Victoria and Kioga the plant failed to adapt to the relatively sudden increase in the water level which followed the closing of the Owen Falls dam at Jinja and the subsequent heavy rains of the early 1960s. The intentional dispersal of the phytophagous *Tilapia zillii* through much of the region may also have played a part in stressing the plant. However, it seems likely that more general, and possibly irreversible, changes in the environment in East

Africa have largely eliminated the plant's specific ecological niche and resulted in its decline. In particular, increasing population pressure and intensification of agriculture may be assumed to have had a considerable deleterious effect on African aquatic systems, with increased runoff and erosion leading to heavier sediment loads in rivers and to persistent turbidity and eutrophication of lakes. If this interpretation is correct, it would go a long way to explaining the present disjunct distribution of hydrilla in Africa, and would suggest that, in the long term at least, the plant is a threatened species rather than a potential pest.

42. The search for natural enemies strongly supports Pemberton's contention that fish grazing and, in Lake Tanganyika especially, damage to apical meristems by chironomid larvae are the two factors mainly responsible for containing hydrilla where it does occur. In general, this study also confirmed Pemberton's observation that the "surface guild" of phytophagous insects (including bagoine weevils, nymphuline moths, and agromyzids) is very poorly represented on, or absent from, hydrilla in East Africa. This was the case even for the three populations (Kioga, Ruhondo, and Bujumbura) where hydrilla was growing sufficiently vigorously to reach the surface in appreciable quantities, albeit probably only during the dry season. It may be noted that in these situations nymphuline larvae, presumably *Parapoynx* sp., were quite abundant on other submerged aquatics growing in association with the hydrilla but only in one case was a larva found feeding on the hydrilla itself. This would seem to imply a degree of nonpreference for hydrilla, which indeed is to be expected if the nymphuline strains have evolved in a situation where hydrilla is only rarely available for oviposition.

43. In the typical plant form of African hydrilla, procumbent stems creeping along the hydrosol often constitute the bulk of the plant, while vertical stems growing towards the surface may be sparse, usually not more than 50 cm long and little branched. The predominance of such forms, whether environmentally or genetically induced, strongly suggests that fish are a major influence on hydrilla growth in the region. These forms are very tolerant of grazing because fish tend mainly to browse from the upright shoots. *Tilapia zillii*, as mentioned above, may be important in containing the plant in Uganda and Rwanda, and this fish is known from studies elsewhere to feed readily on hydrilla (Pieterse 1981). However, it cannot be regarded as a

promising biological control agent for introduction to the United States because, apart from its lack of specificity, it breeds readily in a wide variety of situations and must be regarded as a significant and unmanageable threat to natural environments and other fisheries. On the other hand, the diverse cichlid fauna of Lake Tanganyika certainly deserves further investigation. At least 140 species of this family have been described from the lake and such research as has been done has indicated a remarkable degree of specialization, particularly in habitat selection and feeding habits. Since hydrilla is clearly a dominant component of the lake flora, it may well be that selective hydrilla feeders exist.

44. In this context, it may be noted that there exists a well-developed export trade in wild-collected fish and, to a much lesser extent, plants from Lake Tanganyika; some of this material passes directly into the US aquarium trade. Noting the overall similarity between the isoenzyme patterns of African and American hydrilla, it might just be possible that the original importation to the United States came from this source. In this case it would be necessary to postulate that diploid ($2n = 16$) plants were first introduced and that triploidy, possibly resulting in increased plant vigor and aggressiveness, arose subsequently.

45. Even if Africa is not the origin of the American hydrilla population, there is still an obvious need for further study of Lake Tanganyika's chironomid fauna. The phytophagous species found in this study, which is probably the *Polypedium* sp. identified by Pemberton, is definitely damaging to hydrilla and there is some evidence that it is adapted to, and possibly specific to, hydrilla. This study encountered the same problems noted by Pemberton in respect of this species: firstly, that it appears to be only seasonally abundant (and at other times cannot be collected in useful numbers); and, secondly, that it is difficult to rear through under field conditions. A researcher investigating this system would need to be able to sample on a regular basis and then to have a sufficiently flexible schedule to be able to spend longer periods at the lake at critical periods of high abundance.

46. Thus, in a further phase of this study, priority should be given to proper investigation of the Lake Tanganyika system. However, the possibility cannot be excluded that useful "surface guild" phytophagous insects remain to be discovered. These are most likely to be found in Uganda or Rwanda; Lake Kioga

especially deserves closer attention, if and when conditions permit. Accordingly, as far as possible without prejudicing the Tanganyika work, any available opportunity should be taken to visit the known Ugandan and Rwandan populations in search of new leads and to try to identify new sites where hydrilla may be growing in situations more similar to those encountered in the United States.

47. In planning a new phase of study, logistic considerations, as well as purely technical ones, will clearly be of crucial importance to the success of the project. The advantages and disadvantages of working at some of the possible sites were discussed in a previous trip report (Markham 1983a), and the main points set out there remain valid. Bujumbura would probably be the preferred base for operations as the Tanganyika hydrilla populations are within easy reach and adequate basic facilities already exist there. The need to provide support in some general way to local research efforts should be kept in mind, as well as the very high cost of living in Burundi.

48. Bujumbura also offers reasonably good access to other hydrilla sites; lake steamers provide connections to Lake Tanganyika ports in Tanzania, Zambia, and, though these are less well developed, to Zaire; and road access to Rwanda and thence to western Uganda is good, though it is hard to foresee any immediate improvement in the Ugandan situation which would allow easy field work there. The constraints on work in Tanzania described by Pemberton largely remain in force, though the recent opening of the Kenya-Tanzania border has to some extent eased problems of supply and transportation. Also still valid are the provisos that any researcher would need to be able to speak French and to be willing to learn some Swahili. Any program of intensive studies in the Bulera/Ruhondo area of Rwanda would need to take into account the exceptionally high rate of schistosomiasis endemic in the area.

49. In conclusion, it is recommended that a new phase of study be undertaken, giving priority to an intensive study of phytophagous fishes and chironomids attacking hydrilla in Lake Tanganyika. As a secondary objective, the search should be continued for "surface guild" hydrilla feeders at sites in northern Rwanda and Uganda. Funding should initially be sought for 1 year of evaluation work. This evaluation will cover ecological studies and preliminary feeding tests in the expectation that the project will be extended for a further 2 years to allow rearing, screening, and shipment of promising natural enemies of hydrilla to the United States.

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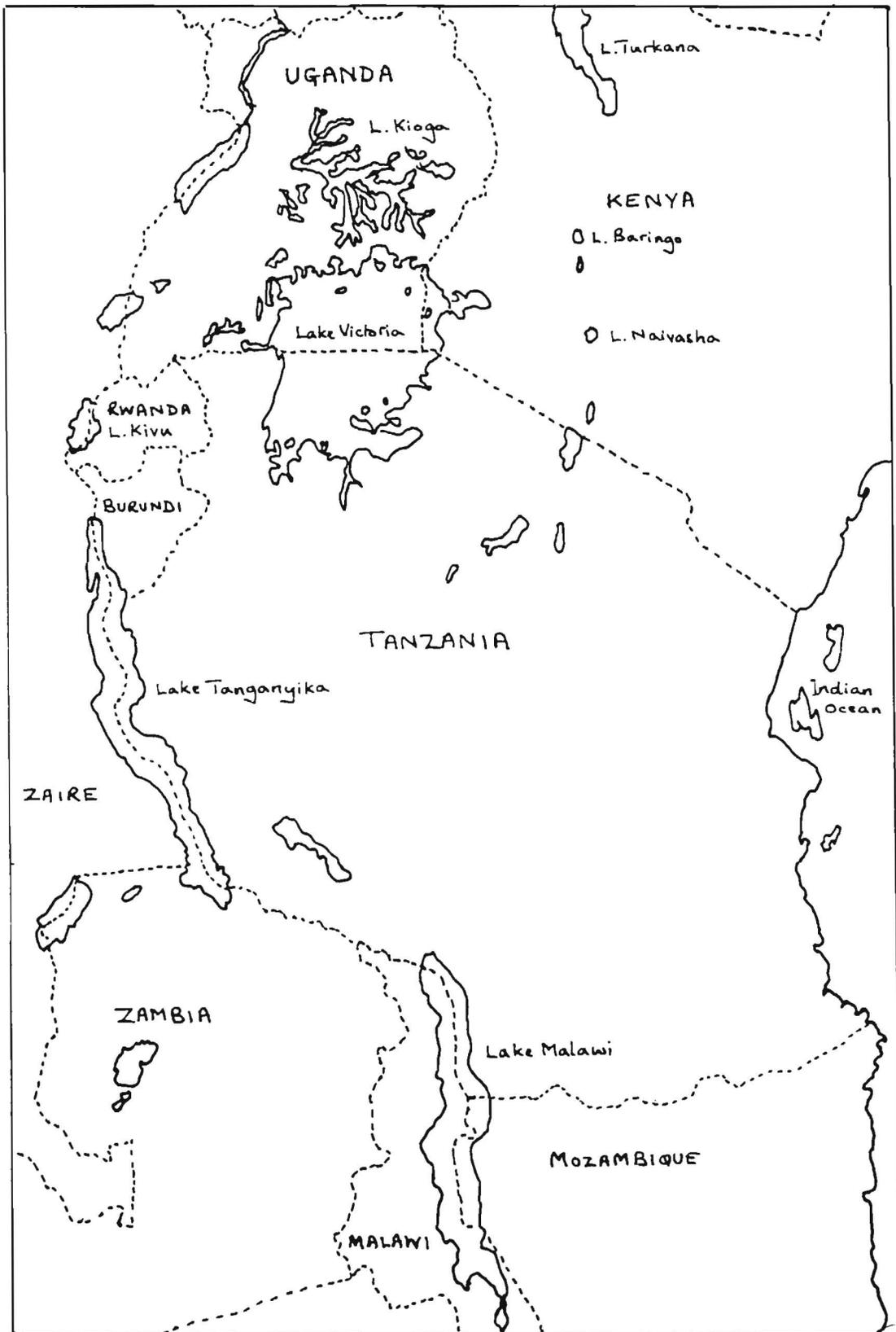


Figure 1. Outline map of East Africa showing the countries visited during hydrilla surveys for this project

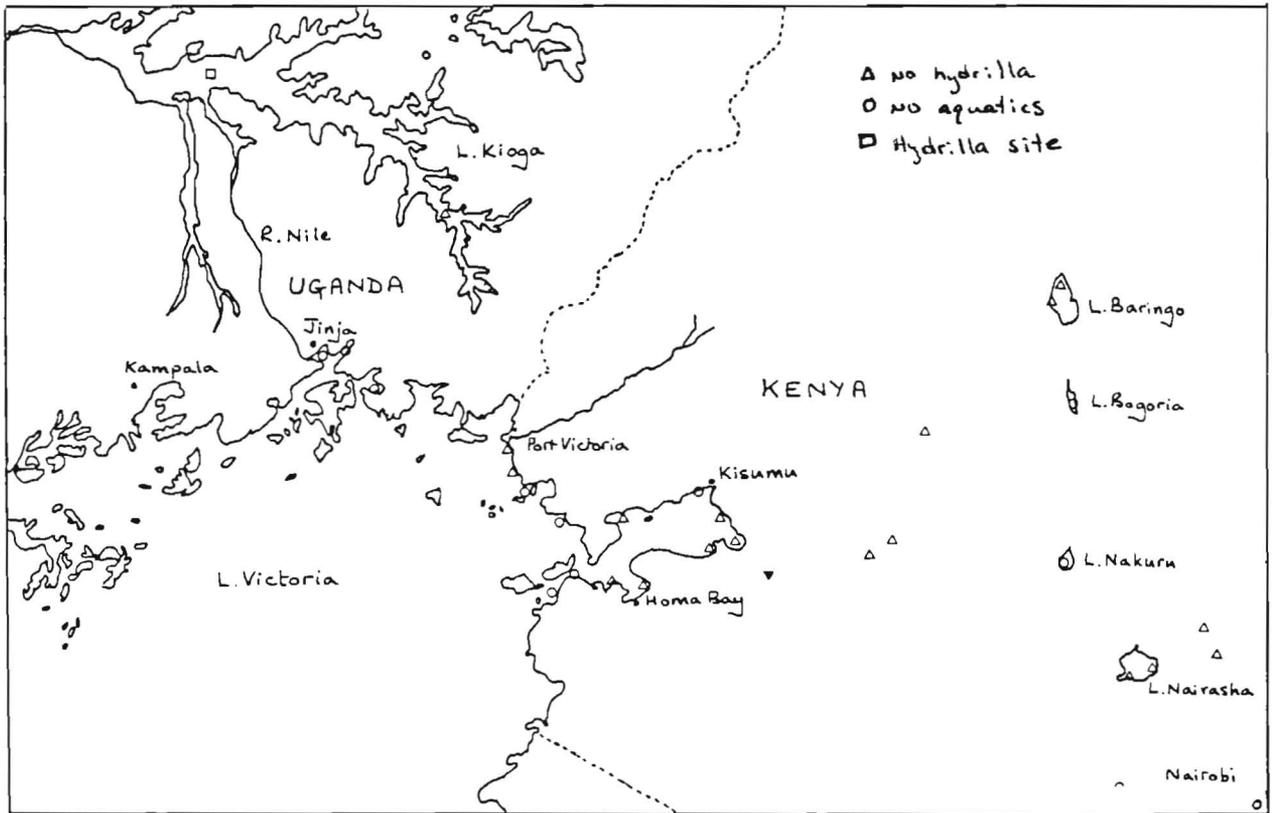


Figure 2. Map of Western Kenya and Eastern Uganda showing the main sites surveyed and the presence or absence of hydrilla and other submerged aquatics

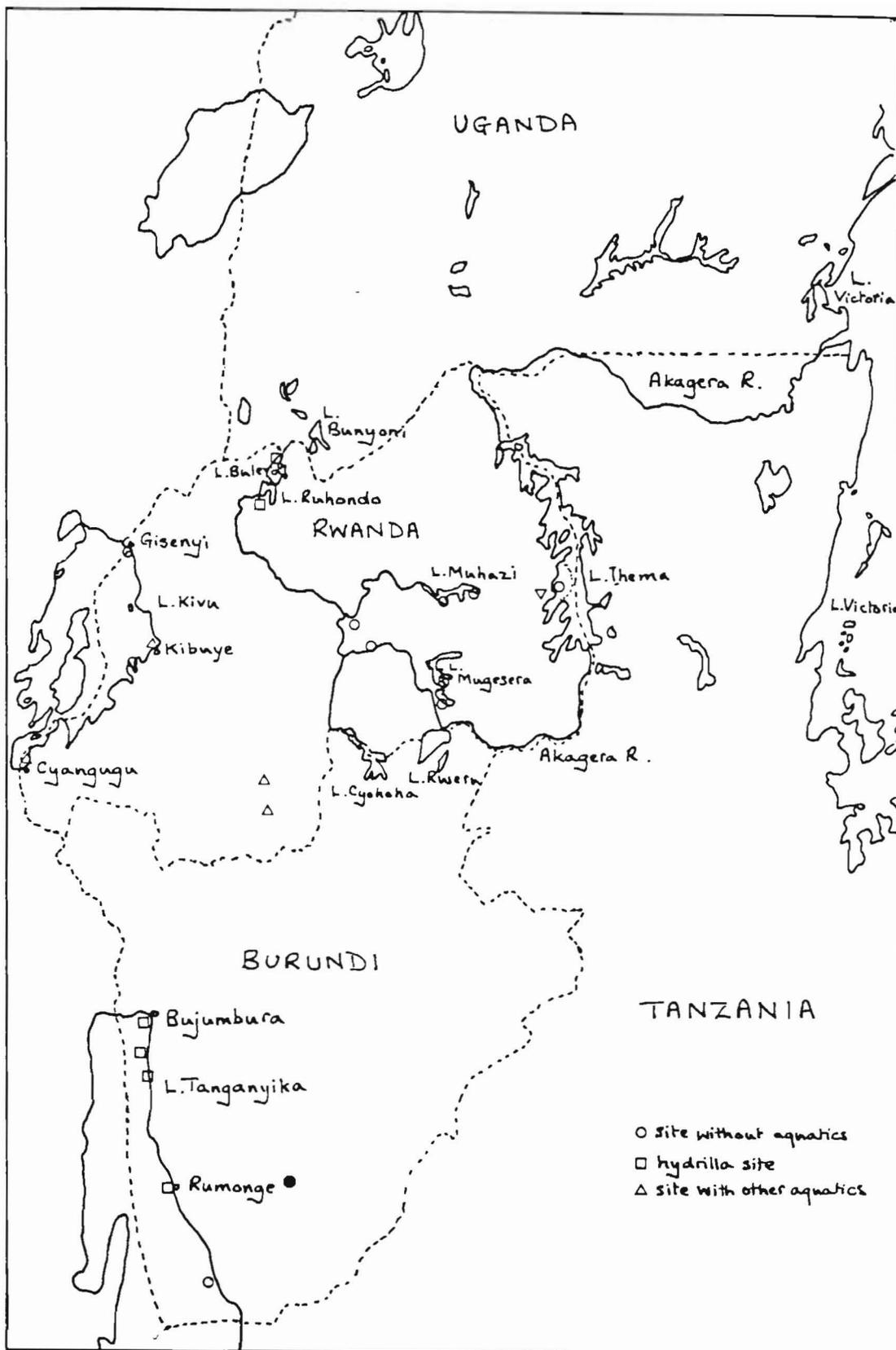


Figure 3. Map summarizing the results of searches for hydrilla and other aquatics in Rwanda and Burundi

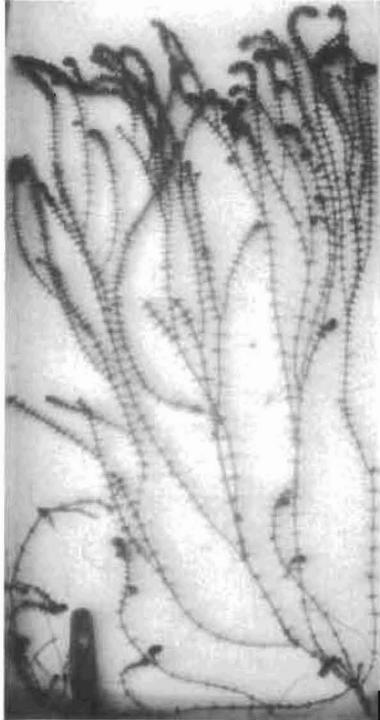


Figure 4. Well-developed hydrilla plant from Lake Kioga, Uganda (penknife, serving as scale, is 9 cm long)

Figure 5. Close-up of hydrilla from Lake Kioga showing stout stems and short, pointed leaves

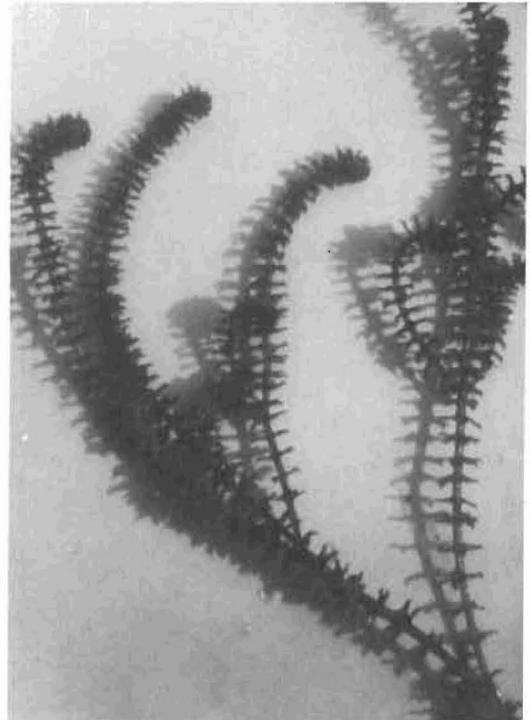




Figure 6. Lake Bulera in northern Rwanda, where hydrilla was found growing along much of the shore

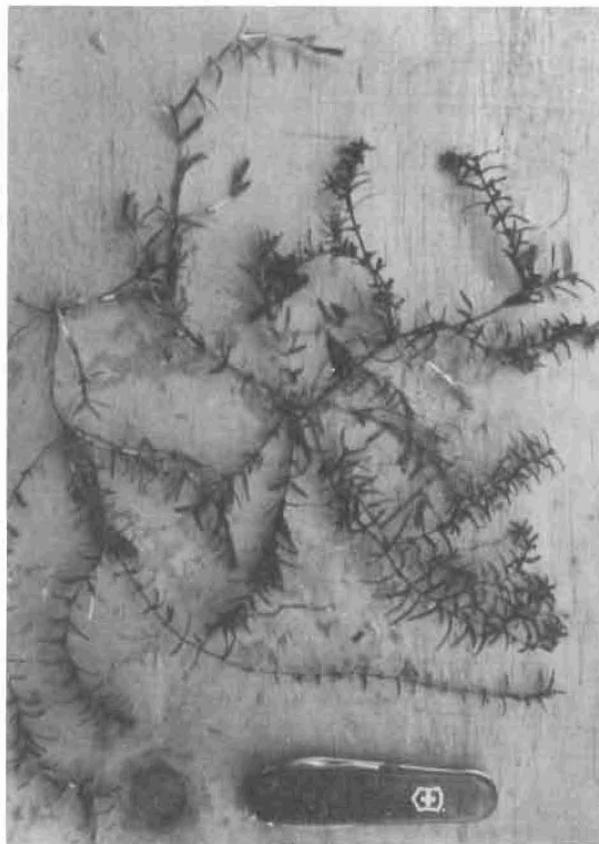


Figure 7. Hydrilla plant from the Lake Bulera population. The longest stem close to the penknife shows the leaf damage due to fish grazing typical of this site



Figure 8. Pools formed along the course of the Mukungwa River below the Remera Dam which closes the exit from Lake Ruhondo, northern Rwanda. Hydrilla was found here forming dense mats with other aquatics in very shallow water



Figure 9. Part of a hydrilla plant from a deeper pool on the Mukungwa River



Figure 10. Part of the eastern shore of Lake Tanganyika in Burundi, 25 km south of Bujumbura. Hydrilla was found growing along the beach in the center of the picture

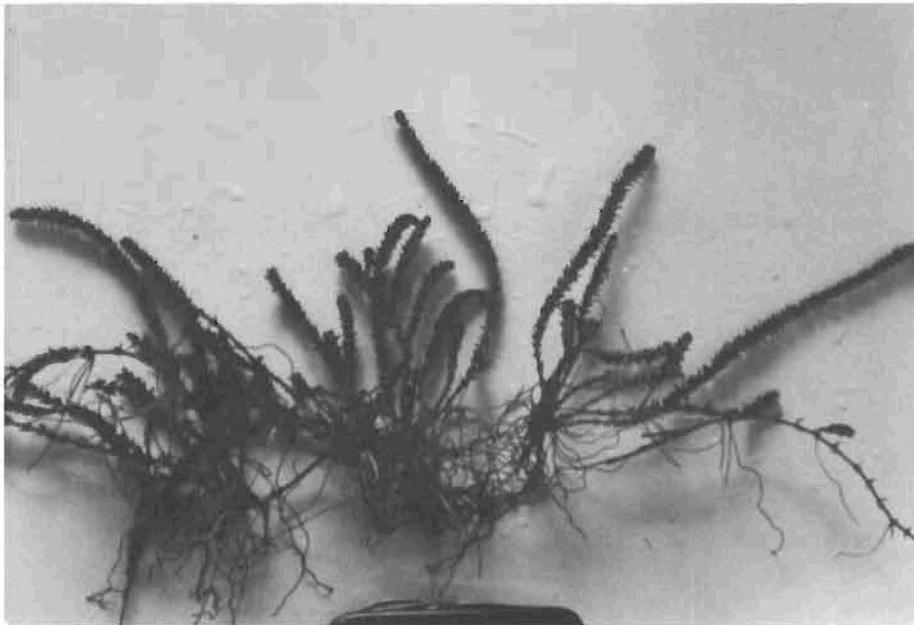


Figure 11. Hydrilla plants from the Lake Tanganyika site. The short, little branched stems form a dense mat on the hydrosol

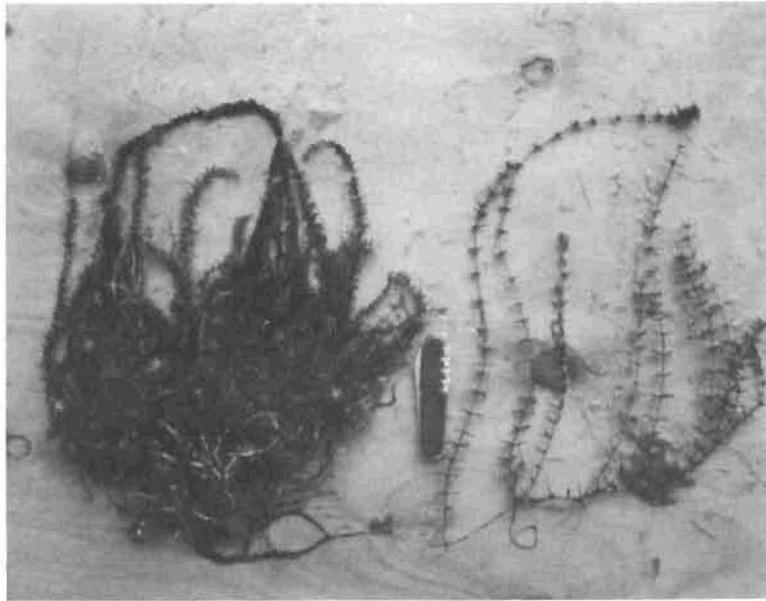


Figure 12. Hydrilla plants from two sites in northern Rwanda showing contrasting growth forms in genetically similar populations. The plant on the left was found in a shallow pool in the Mukungwa River (below Lake Ruhondo); that on the right in Lake Bulera

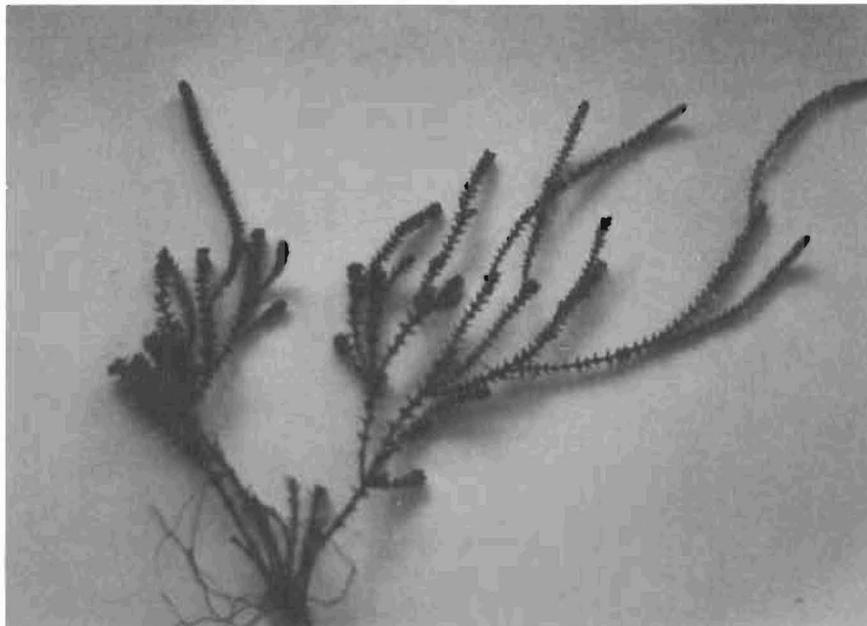


Figure 13. Hydrilla plant from Lake Tanganyika showing the characteristic growth form induced by chironomid damage. Upward growth of lateral branches is repeatedly checked by destruction of the apical meristem; a new root is usually formed just below the aborted tip

APPENDIX A: SUMMARY OF SITES SURVEYED

Aquatic sites covered in the East African survey for hydrilla are reviewed briefly herein by country. Some major aquatic habitats where hydrilla was not found are included to give background information in case return visits are considered as part of future work. Dates of main survey visits are given, together with brief notes on the habitat, aquatic flora, and associated fauna. A more complete account of surveys of some of these sites is given in the project interim report for 1981-1982 (Markham 1982) and in two trip reports (Markham 1983a and b).*

Kenya

Lake Naivasha - no hydrilla

Freshwater lake of eastern Rift Valley; 12-16 km diameter; altitude 1,880 m.

Visited: July, August, September 1981; April 1982.

Lake mainly clear, but seasonally turbid due to phytoplankton. Main lake with few aquatics: occasional outbreaks of *Salvinia molesta*, limited stands of *Najas pectinata* and *Potamogeton* spp., especially on eastern and southern shores; *Utricularia inflexa* in lagoons of swamps on western shore. Small lake at south end of Naivasha more eutrophic, carpeted with *Najas*, accompanied by *Potamogeton schweinfurthii* and *P. pectinatus*.

Lake Baringo - no hydrilla

Freshwater lake of eastern Rift valley; 22 by 12 km; altitude 1,000 m.

Visited: September 1981, February 1982.

Lake permanently turbid with suspended sediment due to excessive erosion in region. Shelving muddy shores fringed with *Typha* contain lagoons with *Najas pectinata* and *Ceratophyllum demersum*. Sheltered shallow water at north of lake with *Aeschynomene elaphroxylon*, *Nymphaea* spp., and floating *Azolla hilotica*; supports abundant submerged aquatics, especially *Ceratophyllum*, *Najas*, and *Utricularia*.

* See References at the end of the main text.

Lakes Magadi, Elmenteita,
Nakuru, Bogoria, Turkana - no hydrilla

Soda lakes of eastern Rift. First four too saline to support any submerged macrophytes. One unidentified species near Loiengelani on eastern shore of Turkana.

Lake Victoria - no hydrilla

Vast, but relatively shallow lake, between Rift Valleys; 300 by 260 km, though only northeast corner in Kenya; altitude 1,130 m.

Visited: October 1981, January, February, and April 1982.

Great variety of shores, water types, and aquatic habitats as described in Markham (1982). Lagoons in reed and papyrus swamps and shallow, sheltered inlets support abundant *Nymphaea* spp., *Ludwigia*, *Hydrocotyle*, *Trapa*, *Pistia*, and *Azolla pinnata*, with submerged *Ceratophyllum* and *Najas*. More open shores, but protected from excessive wave action, support extensive beds of *Potamogeton* spp., especially *P. schweinfurthii*, and occasionally *Vallisneria spiralis*.

Pyralid larvae recovered from *Najas* and *P. schweinfurthii*; former collected at Kusa reared out and identified as *Nymphula diminutalis*.

Artificial ponds on
Kenya Coast - hydrilla site

Two small ornamental ponds found to support abundant growth of hydrilla. Probably aquarium escape but established for some time. No phytophagous insects found.

Central Highlands, artificial
ponds and small lakes - no hydrilla

Numerous reservoirs and natural pools found at altitudes of 1,500-3,000 m. Water usually clear, especially at higher altitudes, and many water bodies support abundant submerged aquatics, mainly Hydrocharitaceae. A species superficially very similar to hydrilla, *Lagarosiphon hydrilloides*, was found abundantly on the lower slopes of the Aberdares, especially around Kinangop; several samples showed some signs of leaf damage but no phytophagous insects were found.

Uganda

Lake Victoria - no hydrilla

Comments as before; Uganda includes entire northern lakeshore but only

the area around Jinja was searched.

Visited: March 1983 and March 1984.

Water generally very clear, with great variety of shorelines from exposed sandy and rocky shores to extensive swamps. Area remarkable for the total absence of submerged macrophytes; *Pistia* and *Trapa* were the only truly aquatic plants encountered in several days of boat searches.

Lake Kioga - hydrilla site

Extensive system of lakes and swamps with numerous fingerlike projections; whole system almost 200 km long but lake only 10 to 20 km wide; Victoria Nile flows in at southern shore and out at western tip; altitude 1,030 m.

Visited: March 1983 and March 1984.

Large shallow lake, fringed with papyrus and reed swamps. Swamps contain numerous channels and where there is sufficient water flow these support abundant *Ceratophyllum*, *Utricularia*, and emergents such as *Ludwigia* and *Hydrocotyle* but no hydrilla. In the main lake submerged aquatics mainly found in shallow (1 to 2 m of water alongside the inflow of the Nile; hydrosol muddy and water clearer than elsewhere in the lake. Weed beds marked at surface by floating leaves of *Potamogeton schweinfurthii* and *Nymphaea* sp.; dominant submerged macrophyte is *Lagarosiphon* sp. but *Hydrilla*, *Najas*, *Ceratophyllum*, and *Vallisneria* all formed large clumps in mosaic pattern.

Gastropods were abundant macroinvertebrates but insects in general rather few. Pyralid larvae were found on *Potamogeton*, *Ceratophyllum*, *Najas*, and, in one instance, on *Lagarosiphon*, but not on hydrilla. Hydrilla showed some signs of fish grazing and occasional insect damage to apical buds, but no causative agent could be identified.

Rwanda

Lake Kivu - no hydrilla

Freshwater (but high pH) lake of western Rift Valley; 90 by 40 km; altitude 1,460 m; eastern shore Rwanda, western shore Zaire.

Visited: February 1983 (Kibuye) and June 1983 (Gisenyi and Cyangugu).

Lake very clear and deep, shores mainly rocky and shelving rapidly into deep water. Shallow, sandy shoreline at Gisenyi seemingly totally devoid of aquatic macrophytes. Elsewhere, and especially around Cyangugu, sheltered

inlets often have a muddy shoreline capable of supporting submerged vegetation. Single stand of small *Potamogeton* sp. near Kibuye heavily grazed by cichlid fish. Unidentified plant, abundant near Cyangugu, had robust stems bearing blunt spines and seemed undamaged either by fish or invertebrates.

Lakes Muhazi, Kilimbi,
and Rumira - no hydrilla

Freshwater lakes of Akagera system, central Rwanda; altitude ca. 1,400 m.

Visited: June 1983 and August 1984.

These lakes are typical of the numerous headwater lakes in this area which are fed by seasonal runoff from the dry surrounding hills and empty into the Akagera system. The surrounding topography is gentle and the lakes shallow. Most are fringed by papyrus swamps which help to keep the water relatively clear and probably low in nutrients. Most have high populations of depauperate *Tilapia* and, possibly as a result, are seemingly devoid of submerged vegetation. *Pistia* was present on some lakes.

Lake Ihema - no hydrilla

Freshwater lake of Akagera system, eastern Rwanda; 20 by 6 km; altitude ca. 1,300 m.

Visited: February and June 1983.

Part of an extensive system of lakes and swamps through which the Akagera River flows along the eastern frontier of Rwanda (with Tanzania). These habitats are described in more detail in Markham (1983a). The Akagera itself, here as elsewhere, is deep, fast flowing, and heavily loaded with sediment and quite unsuitable for submerged vegetation. Lake Ihema itself is turbid, mainly due to phytoplankton rather than sediment and is fringed with extensive papyrus swamps. Along the edges of these swamps there were abundant emergents such as *Hydrocotyle* and *Ludwigia* but the only submerged macrophyte found was an *Utricularia*. This lake supports a productive *Tilapia* fishery and these fish would probably be sufficient to suppress aquatic vegetation.

Lakes Bulera and
Ruhondo - hydrilla sites

Freshwater lakes on the northern watershed of the Akagera system; both lakes less than 10 km across and much divided; altitude ca. 1,800 m.

Visited: June 1983, January 1984, April 1985.

These lakes lie in a very mountainous, high-rainfall area, at the foot

of the Birunga Volcanoes near the Uganda/Rwanda frontier. Much of the shore of both lakes is precipitously steep, consisting of steeply shelving mud and rocks, but both are nevertheless fringed with almost continuous beds of aquatic plants. The water is very clear and, judging by the plant growth, rich in minerals. Lake Bulera, the higher of the two lakes, has a more diverse flora, dominated by two *Potamogeton* species, accompanied by *Nymphaea*, *Ceratophyllum*, *Hydrilla*, and some *Vallisneria*. The hydrilla is abundant but grows mainly in deeper water (1 to 2 m deep), below and further from the shore than the *Potamogeton*, and so is almost invisible from the surface. In Lake Ruhondo only the two *Potamogeton* species and *Ceratophyllum* were found but a more thorough search would probably reveal hydrilla. Hydrilla was found in shallow pools (25 to 150 cm deep) in the bed of the Mukungwa River below the hydroelectric dam which closes the exit from Lake Ruhondo. Here the water was clear and only slightly flowing with a hydrosol of mud and stones. Hydrilla formed dense creeping mats in the shallowest water and more luxuriant stands, mixed with *Ceratophyllum*, in deeper water where the two *Potamogeton* species and *Vallisneria* were also growing. The hydrilla in this situation grew abundantly up to the surface in some places.

Macroinvertebrates were very rare on the Bulera hydrilla and those found were mainly gastropods. In both lakes and in the Mukungwa River, pyralid larvae were quite numerous on *Potamogeton schweinfurthii* and in the river on *Ceratophyllum*. A very few pyralids were also found on the hydrilla in the river, but did not seem to be causing significant damage. From the situation it seemed possible that the pyralids had moved to hydrilla from the *Ceratophyllum* on which they were much more numerous.

Burundi

Lake Tanganyika, four hydrilla sites

Largest lake of the western Rift Valley; fresh water but high pH; 650 by 80 km (max. depth 1,470 m); altitude 770 m.

Visited: February 1983, June 1983, January 1984, August 1984, February 1985.

Bujumbura - 3 km north of the city

Single bed of aquatic plants, 5 to 15 m from sheltered shore, in shallow clear water (1 to 1.5 m deep) on hydrosol of sandy mud. Hydrilla

dominant, with small amounts of *Vallisneria* and *Potamogeton pectinatus*. At the time of the first visit (February) the plant did not reach the surface, but at the second, during the main dry season (June), it was growing more vigorously, reaching the surface and flowering over a large area.

A small number of gastropods and a variety of chironomids were collected at this site, but damage to the hydrilla was less than that encountered elsewhere in the lake.

Lagoons, 12 km south of Bujumbura

Shallow lagoons (<80 cm deep) cut off from main lake by beach, hydrosol sandy, water clear but rich in nutrients. Aquatic flora dominated by *Chara* sp., with two species of *Potamogeton* and *Najas pectinata*. Hydrilla was largely hidden within this mat of more vigorous plants. The hydrilla was of an unusual growth form with almost all stems procumbent and leaves sparse and much reduced in size.

No natural enemies were found.

Sand spit, 25 km south of Bujumbura

Hydrilla was found growing from the water's edge, out to a depth of 2 m, along the gravel and sand shore of a sand spit projecting out into the lake. Shore was north-facing and so not exposed to the main force of the waves moving up from the south, but nevertheless subject to considerable wave action. In the shallowest water hydrilla was growing in a mixed stand with *Chara* and *Vallisneria* and in deeper water among larger clumps of *Najas* and *Potamogeton*.

Plants were heavily damaged by chironomids and few stems rose more than 30 cm from the substrate, though there was a dense procumbent mat of hydrilla over much of the area. Small numbers of phytophagous chironomid larvae were recovered from apical meristems at this site. Many trichopterans were also reared from hydrilla samples collected at this site, but it seems unlikely that these are damaging. Some stems showed signs of fish grazing, but this seemed less important than insect damage in containing the plant; numerous cichlids were seen amongst the weed beds, but it was impossible to say which might be feeding directly on the plants.

Rumonge, 77 km south of Bujumbura

At Rumonge a sheltered bay with exceptionally clear water provided an excellent habitat for aquatic plants. The bottom was very gently shelving with a fine mud hydrosol scattered with stones. Clumps of *Chara*,

Vallisneria, and two species of *Potamogeton* formed a mosaic across much of the bay. Hydrilla appeared to be mainly confined to an area 50 to 150 m from the main beach, in the center of the bay, in water 2.5 m or more deep. In this area hydrilla was either strongly dominant or growing almost in a pure stand, forming a dense mat on the hydrosol. Vertical stems were up to 50 cm long but none approached the surface.

Chironomids of all kinds were very abundant at this site. Very few of the phytophagous species were found, but the severe damage exhibited by the plants showed that they must be abundant at times. Many stems showed signs of fish grazing.

Malawi

Lake Malawi, no hydrilla found

Second largest of the western Rift lakes; fresh water but with a high pH; 560 by 80 km; altitude 460 m. Geological history and general ecology very similar to Lake Tanganyika.

Salima

Various aquatic habitats were searched around Salima. The main lake had primarily sandy or rocky, gently shelving shores, with very few aquatic macrophytes; *Vallisneria* was the only common plant. Large, reed-fringed lagoons, with water over 2 m deep, seemed to have a bottom of organic debris and supported no macrophytes. Shallow (<1 m deep) sandy or muddy channels between reeds on the main lakeshore had stronger growths of *Vallisneria* and *Ceratophyllum* with floating *Salvinia hastata*, *Azolla pinnata*, and *Pistia stratiotes*.

Malembo

The locality most similar to Lake Tanganyika hydrilla sites. Moderately sheltered, gently shelving beach of sand and silt. Abundant *Vallisneria*, *Ceratophyllum*, and *Potamogeton*.

Cape Maclear

Very sheltered beach of sand, shelving to silt, with rocky headlands on each side. Small clumps of *Vallisneria* and some plants of *Ceratophyllum*. Fragments of a large *Potamogeton* on the strand line.