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EXPLORATION FOR NATURAL ENEMIES OF *HYDRILLA VERTICILLATA* IN EASTERN AFRICA

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The survey of East African water habitats described in this report was conducted in order to find natural enemies of *Hydrilla verticillata* Royle (Hydrocharitaceae).

Since 1960, when it was first recorded in the United States, hydrilla has spread through the southeastern part of the country and has the potential to occupy large portions of freshwater bodies. It not only precludes use of

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an infested waterway by man but can be ecologically disruptive.

The region of East Africa selected for the survey was chosen for a number of reasons, the most important of which was the known occurrence of hydrilla and the richness of Hydrocharitaceous genera and species in that area.

An itinerary was established that maximized the opportunities of finding hydrilla and its natural enemies by including as many kinds of habitats as feasible (rivers, streams, irrigation ditches, marshes, etc.), through the use of vegetation maps of East Africa.

The survey was conducted during the period September-December 1976 and consisted of two phases: (a) a wide survey through Tanzania and Kenya, followed by (b) an intense survey of Lake Tanganyika, including a preliminary study of hydrilla natural enemies at Kigoma. The materials used on the survey were standard entomological and botanical field equipment. A summary of the trip log, giving dates and sites surveyed, is included as Appendix B to the text.

Hydrilla was found growing in Lake Tanganyika from Kigoma, on the northeastern shore, to Kasanga, 482 km further south on the southeastern shore. All of the localities in which hydrilla was found were relatively quiet bays with very clear water. The hydrilla encountered differed vegetatively from that found in Florida in that the plants were shorter (10 to 60 cm) and had a higher number of primary stems, shorter internodes, and darker colored leaves with more serration.

The noted damage to hydrilla plants was of two types, fish and insect feedings. Fish damage, possibly caused by a chiclid, was in the form of either leaf removal along the stem or the removal of the stem tips.

The potentially most important insect found feeding on hydrilla was a Chironomid midge of the genus Polypedilum (species not yet determined). Damage caused by the larvae of this midge was primarily a loss of the apical meristems of the hydrilla shoots resulting in a pruning effect on hydrilla.

Recommendations, as outlined in Appendix C, include the following:

a. Study and evaluate the known natural enemies of hydrilla, Polypedilum sp., fish, mayfly, and caddis fly, to determine their ability to damage hydrilla.

b. Conduct additional surveys in East Africa to observe hydrilla populations not affected by the meristem borer and to find other natural enemies of hydrilla.

c. Use Burundi as a base for research and exploration because of the proximity of hydrilla and the availability of goods and services.

Appendix A lists the hydrilla herbarium records consulted in preparation for the survey. Appendix C, Logistics, is included to aid future researchers in Africa.

PREFACE

The study reported herein was performed under ARS Agreement No. 12-14-0203-7 Type III between the U. S. Army Corps of Engineers and the U. S. Department of Agriculture, Agricultural Research Service, Southern Region. Funds were provided by the Directorate of Civil Works, Office, Chief of Engineers, thru the Aquatic Plant Control Research Program (APCRP) conducted by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

The APCRP was formerly conducted by the Aquatic Plant Research Branch (APRB) of the Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL) of the WES. The APCRP was formerly under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and B. O. Benn, Chief, ESD, and under the direct supervision of Mr. J. L. Decell, Chief, APRB. Mr. Decell is now Manager of the APCRP, which is a part of the Environmental Laboratory (EL). Dr. John Harrison is Chief of EL.

Directors of the WES during the conduct of this study and publication of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

EXPLORATION FOR NATURAL ENEMIES OF *HYDRILLA VERTICILLATA* IN EASTERN AFRICA

PART I: INTRODUCTION

Background

1. Hydrilla verticillata Royle (Hydrocharitaceae) is a submerged aquatic plant native to the warmer regions of the Old World. Hydrilla is a problem primarily because of the density of its vegetation. It grows so densely that it not only precludes use of the infested waterway by man, but it is also disruptive ecologically, altering the flora and fauna.

2. Hydrilla was first recorded in the United States, growing in a Miami, Fla., canal around 1960. Hydrilla probably first entered the United States through the tropical fish industry, which imported it for use as an aquarium ornamental.

3. Since 1960, it has spread through the southeastern part of the country, has overwintered as far north as Iowa, and in 1976 was found in a Marysville, Calif., lake. Hydrilla has the potential to occupy a large percentage of the freshwater bodies of, not only Florida, but the entire United States. Outside the United States, hydrilla is recorded as a pest in India and Panama.

4. The present control is by mechanical and chemical means, which are difficult and expensive. Drawdowns are effective but of very limited practicable use. The ability of hydrilla to generate new plants from underground tubers, axillary turions, and small stem fragments contributes to its rapid invasion into new areas and to the control problem. The state of Florida alone spent $10 million in 1976 in direct control efforts. These efforts were directed against less than 10 percent of the total acreage infested with hydrilla. Considering the difficulty and expense of the present control methods, other methods need to be examined. Of these, biological control may offer the greatest potential

for providing an effective and economical solution to the hydrilla problem. It was with this aim that this survey was undertaken.

Investigations on Hydrilla Natural Enemies

5. The Commonwealth Institute of Biological Control has conducted a survey for, and then biological control studies of, the natural enemies they found attacking hydrilla in Pakistan. The natural enemies they found were insects belonging to three groups common to submerged plants, *Hydrellia* sp. (Agromyzidae), *Bagous* sp. nr. *limosus* (Curcuionidae), and *Nymphula diminualis* (Pyralidae). These species have not been properly studied for host specificity nor for field damage to demonstrate good control possibilities.

6. The University of Florida's Department of Plant Pathology is continuing its research of plant pathogens that may stress and control hydrilla.

7. The white amur (Chinese grass carp) is presently being studied by a number of organizations to determine its ability to reduce hydrilla and its compatibility and safety in aquatic systems of the United States. The white amur's use is, however, controversial. While many people strongly support the use of the white amur, many other people already feel that it is not a safe or compatible animal. This may ultimately prevent or severely limit its use as a hydrilla control agent, at least in the United States.

Classification and Distribution

8. *Hydrilla verticillata* Royle is a member of the family Hydrocharitaceae. This family, which is primarily tropical-subtropical, contains 15 genera with about 100 species of freshwater and saltwater plants. Most of these species are submergents, although there are some emergent and floating members. The Hydrocharitaceae are monocotyledons and are placed in the order Butomales by Hutchinson (1973).* The

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* Hutchinson, J. 1973. *The Families of Flowering Plants*, 3rd ed., Clarendon Press, Oxford.

Butomales by his scheme include the Alismaceae and the Butomaceae.

9. Benson (1957)* puts the Hydrocharitaceae in its own order, the Hydrocharitales, which he places between the Orchidales and the Triuridales. He considers the Hydrocharitaceae derived from the Alismatales but only distantly related to it. Davis and Heywood (1963)** follow Benson's scheme. Heywood (1978)† places the Hydrocharitales between the Alismatales and the Najadales (Potamogetonales). In this system, the families most closely related to the Hydrocharitaceae are:

Najadales

Aponogdtonaceae
Scheuchzeriaceae
Juncaginaceae
Lilaeaceae
Potamogetonaceae
Zannichelliaceae
Ruppiaceae
Zosperaceae
Posidoniaceae
Cymodoceaceae

Alismatales

Butomaceae
Limnocharitaceae
Alismataceae

10. The genus <u>Hydrilla</u> is monotypic and is generally placed in the subfamily Vallisnerieae with <u>Largosiphon</u>, <u>Vallisneria</u>, <u>Elodea</u>, and <u>Egeria</u> (Hutchinson 1973). Literature records give the natural range for hydrilla as South Africa through East Africa to southern Europe and east through Southern Asia to and including the subtropical parts of Australia. It is difficult to know whether hydrilla does indeed occupy this range because of the ease with which hydrilla is often confused with <u>Largosiphon</u>, <u>Elodea</u>, and <u>Egeria</u>. <u>Largosiphon</u> was probably recorded as <u>Hydrilla</u> in both South Africa and Madagascar. Also, many of the European records of <u>Hydrilla</u> may actually be <u>Elodea</u>. This confusion is due to the variable nature of hydrilla and the other aforementioned species. The characteristics often used to distinguish hydrilla are whorled leaves and the individual leaves having serrate margins in combination with a cabrous harsh leaf and stem texture. These characteristics can and do frequently

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* Benson, L. 1957. <u>Plant Classification,</u> D. C. Heath & Company, Boston.
** Davis, P. H., and Heywood, V. H. 1963. <u>Principles of Angiosperm Taxonomy,</u> D. Van Nostrand Company, Inc., Princeton, New Jersey.
† Heywood, V. H. 1978. <u>Flowering Plants of the World,</u> Mayflower Books, Inc., New York.

occur in other species belonging to the genera Largosiphon, Elodea, and Egeria. The only reliable characteristics exist in the flower morphology.

Selection of East Africa as Survey Area

11. East Africa was selected as a region to survey for a number of reasons. The most important reasons were the known occurrence of hydrilla, the richness of Hydrocharitaceous genera and species, and the fact that nothing was known about the natural enemies of hydrilla on that continent.

12. The following freshwater genera are recorded from East Africa: Hydrilla, Vallisneria, Oltelia, Blyxa, Largosiphon, Egeria, which are all native. This represents one of the richest assemblages of Hydrocharitaceous plants in the world. This is important because a region rich in genera and species of a particular family has probably had that family for a long time--time enough for co-evolved herbivores and diseases to develop. Both the number of generalized hydrocharitaceous feeders and of specific hydrilla feeders should be greater in such an area.

13. East Africa, because of its latitude and varying altitudes, has many ecological zones and thus rather diverse aquatic situations. In addition, East Africa has some very old lakes with very endemic floras and faunas.

PART II: MATERIALS AND METHODS

14. The materials utilized on the survey were standard entomological and botanical field equipment. Potato dextrose agar and cultural equipment were obtained for potential handling of hydrilla pathogens. Since schistosomiasis is common in the area, rubberized gear including surgical gloves were used to protect workers from the infective stages in the water. Polyvalent antivenin was carried in case of bites from the black mamba or other poisonous snakes common to the aquatic habitats surveyed. A malaria prophylactic was used, as were water purification tablets.

15. Sample sites were normally reached by Landrover, although large boats were used on Lake Tanganyika. Upon arrival, the shore of a body of water would be walked, the drift line inspected, and the shallows examined. Where appropriate, wading and searching in the water was done. Often, when on larger bodies of water, boats would be used to explore the area. These boats were usually dugout canoes rented from local fisherman. Various grapnels and hooks were employed in addition to hand pulling to secure plants.

16. The sites were usually characterized by type, size, bottom, and vegetation. When hydrilla plants were found, they were carefully bagged underwater, then brought to shore for examination for natural enemies and damage. The plants to be examined were normally floated in water-filled white enamel pans. The floating facilitated examination by spreading the leaves. Often a teaspoon of sugar would be added to the water to make the animals associated with hydrilla more active and thus more visible. Individual plant parts were dissected and examined using a binocular dissecting microscope.

17. To rear immature insects and to conduct simple damage tests, potential natural enemies were placed in waxed, pint-sized paper containers and gallon jars containing hydrilla stems and/or plants. A large wooden box with a mosquito net emergence trap was used in a mass-rearing attempt.

18. The hydrilla plants were measured, the leaf numbers per whorl

counted, and the number of whorls per unit of stem counted. In an attempt to identify the fish responsible for fish-damaged hydrilla at Kigoma, fish inhabiting the hydrilla beds were observed, captured, and examined. Observations were made from an anchored rubber raft and by snorkeling. Fish were captured with hand fishnets (similar to butterfly nets) and a two-man straight seine net. The examinations were for morphological evidence of herbivority (teeth type, peritoneum color, intestine length) and for actual evidence of hydrilla feeding (stomach contents).

19. Damage estimates were principally qualitative. Quantitative estimates were made by counting normal and damaged stems per plant for 10 plants per estimate. The total number of damaged stems would be figured as a percentage of all stems of the total plants per estimate.

PART III: AREA SURVEY

Itinerary

20. The itinerary followed was designed to maximize the opportunities of finding hydrilla and its natural enemies. The few records of *Hydrilla verticillata* in East Africa were from lakes. However, Den Hartog (1957)* in his "Hydrocharitaceae," recorded hydrilla from "ditches, pools, lakes, marshes, wet rice fields, slow streams, and even in tidal waters." This, plus the fact that hydrilla in Florida occurs in diverse habitats, made it necessary to examine as many kinds of habitats as feasible.

21. Vegetation maps of East Africa were examined, and, using them and the preceding habitat information, a route was planned. This route with its time framework resulted in a survey through most of the vegetation zones of East Africa and allowed time to sample bodies of water within each zone. The emphasis of the survey was on the major lakes of the region, with particular attention given to known hydrilla localities taken from herbaria collection records (Appendix A).

22. The survey consisted of two phases. The first was a driving survey through Tanzania and Kenya. The second phase was an intense survey of Lake Tanganyika, where hydrilla plants were located. Another portion of the second phase was a preliminary study of the hydrilla natural enemies at Kigoma on Lake Tanganyika. In addition, Mr. Robert Lazor, who accompanied the author on a portion of the driving survey in Tanzania, examined some lakes in the Tananarive area of Madagascar.

23. The starting point on the driving survey in Tanzania was the coast at Dar es Salaam. The routes taken by both parts of the driving survey can be seen on the area map (Figure 1), which is a very generalized geographical sketch of the survey. From there the party drove to the highlands of Kilimanjaro Province, then across the Serengeti Plains

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* Den Hartog, C. 1957. "Hydrocharitaceae," *Flora Malesiana*, C. G. C. J. van Sbeenis, ed., Vol 5, No. 1, pp 381-413.

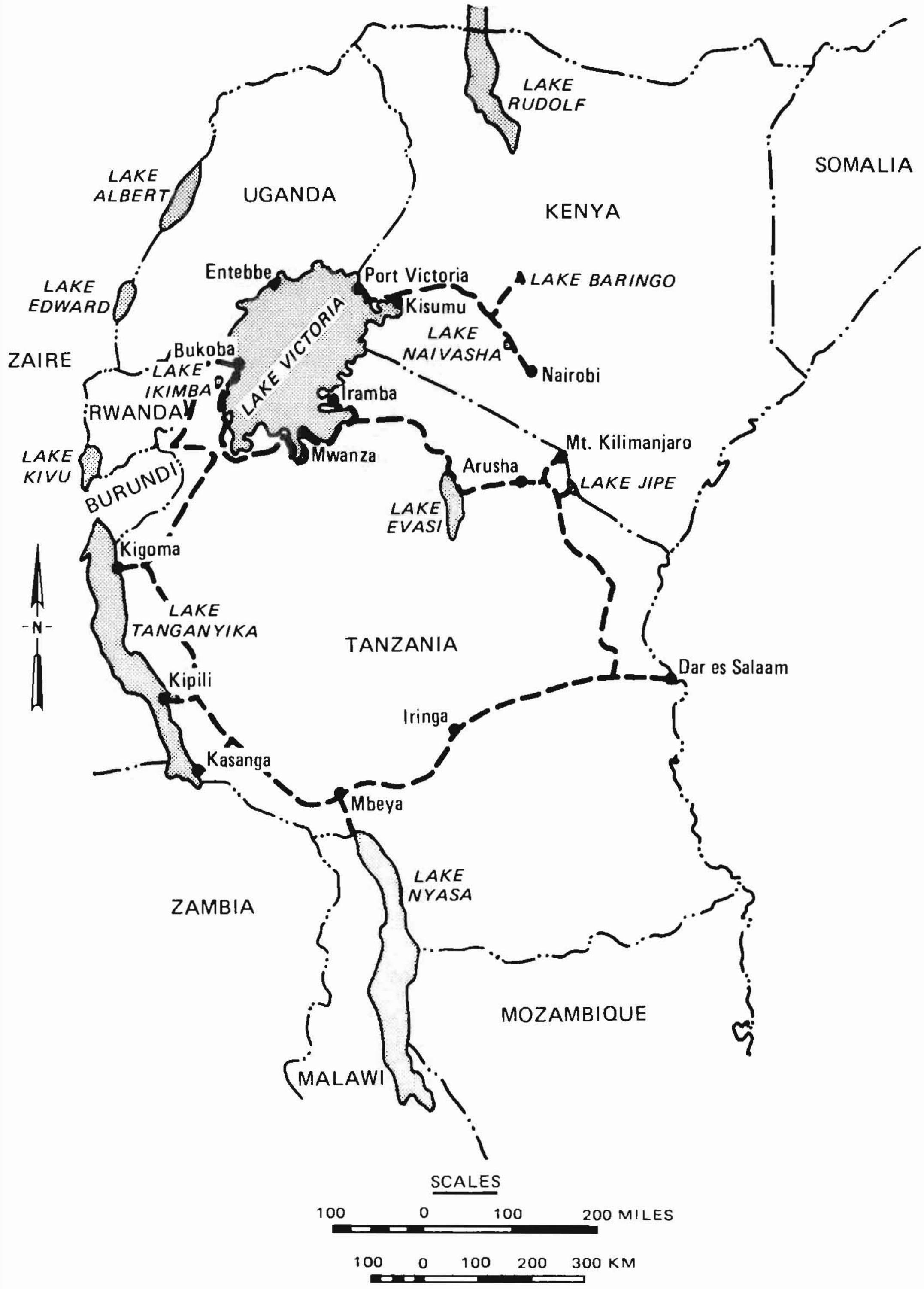


Figure 1. Generalized area map of East Africa showing the survey route

to the southeastern shore of Lake Victoria. The survey followed the lakeshore to Bukoba, just below the Uganda border, and then south to the northeastern shore of Lake Tanganyika at Kigoma. The trek then followed the shore south to Kasanga, and then continued to the northern end of Lake Malawi (Lake Nyasa). The circle was completed by driving back to Dar es Salaam.

24. The Kenyan driving survey began in Nairobi and went to Port Victoria (Nyanza Province) at Lake Victoria, then to Lake Baringo followed by Lake Naivasha before returning to Nairobi.

Habitats Examined

25. The types of habitats surveyed were (a) rivers, (b) streams, (c) irrigation ditches, (d) seasonal ponds, (e) water holes, (f) marshes, (g) man-made lakes, (h) natural freshwater lakes (small to medium size), (i) soda lakes, and (j) large natural lakes such as Lake Victoria, Lake Tanganyika, and Lake Malawi (Lake Nyasa).

Rivers

26. Short descriptions of the various conditions and characteristics encountered at each of the individual rivers included in the survey are shown in Table 1.

Streams

27. Most of the streams in the area of Kenya surveyed, and most of the ones in Tanzania, are seasonal and were dry at the time surveyed. The streams, detailed in Table 2, are primarily from the western part of Tanzania.

Irrigation ditches

28. Irrigation is not common in the region surveyed, and thus very few irrigation ditches were encountered and surveyed. The findings of those that were surveyed are shown in Table 3.

Seasonal ponds

29. Most of the survey was conducted in the dry season, so few seasonal ponds had water. Those that were encountered were in areas that receive higher rainfall and/or in which the rainy season had

already begun. Table 4 contains the information gathered.

Water holes

30. These depressions have more or less permanent water which is used by man, his domestic animals, and in wilder areas by big game. They are often sewerlike and support few vascular plants because of disturbance and turbidity. Some examples of encountered water holes are shown in Table 5.

Marshes

31. The marshes described in Table 6 are those occurring in low-lying areas and at the confluence of rivers. The lake marshes are covered in the sections on lakes. Few seasonal marshes or floodplain-type marshes were encountered due to it being the dry season when the survey was conducted.

Man-made lakes

32. The information gathered on the man-made lakes of the area that were surveyed is presented in Table 7.

Small natural freshwater lakes

33. Small- to medium-sized natural freshwater lakes surveyed are presented in Table 8. Larger natural lakes are covered individually in paragraphs 34-38.

Soda lakes

34. The soda lakes of East Africa are too saline to support macrophytes. There is usually a large bare zone at the shore which is the seasonal, water-fluctuation zone. The lakes also are devoid of any plants except a few halophytes. Lake Manyara and the seasonal lake of the Ngorongoro Crater, both in Tanzania, and Lake Nakura in Kenya were visited. No aquatics or evidence of any were found.

Large natural lakes

35. Lake Victoria. Lake Victoria is one of the largest lakes in the world. It is not part of the East African rift system and is relatively shallow considering its vast size. Much of the lake is eutrophic. There are many kinds of habitats, with vascular plants being more abundant in the quieter bays and backwaters.

36. Lake Victoria was one of the areas given special attention

during the survey. Hydrilla verticillata had previously been collected from a number of localities on the Uganda side of the lake and from Port Victoria, Kenya, and Mbarika, Tanzania. The political situation in Uganda prevented surveying that portion of the lake, so all of the areas surveyed were in Kenya and Tanzania, with special attention given to the known localities of hydrilla infestation. In spite of the effort, hydrilla was not found in Lake Victoria.

37. Table 9 lists the localities visited, arranged geographically from Port Victoria, Kenya, to Bukoba, Tanzania. Figure 2 is a generalized area map of the Lake Victoria sites surveyed.

38. Lake Tanganyika. Lake Tanganyika is a large (long and narrow) lake of the western rift system. It is very deep and its shoreline is more regular than that of Lake Victoria. The coastline is generally rocky, although sand beaches occupy some shoreline, principally that of bays. There are relatively few backwater situations; the ones that were encountered were behind barrier-type beaches and in the Malagarasi River delta. The water usually is crystal clear with a photozone of 12 m or more. The amount of wave action is surprisingly large for a lake. Waves of 0.6 to 0.9 m are common with waves oftentimes much larger. Large portions of the Tanzanian shore are essentially closed to boat traffic during much of the year because of the difficulty of landing. The wave action of the open shore restricts vascular plants to the quieter bays and backwaters. There are only three roads to the Tanzanian lakeshore and no roads along the shore. For this reason, most of the survey of the lake was conducted by larger boats, principally a Food and Agriculture Organization of the United Nations (FAO) fisheries research vessel from Kigoma. The habitat of localities containing hydrilla is described in this report's section "Occurrence of Hydrilla." Table 10 contains descriptions of a few of the other places surveyed on the lake.

39. Lake Malawi (Lake Nyasa). Lake Malawi is another large lake of the western rift system. It lies south of Lake Tanganyika and has only the northeastern and a portion of its eastern shores in Tanzania. Malawi and Mozambique are the other countries on its shoreline. It is

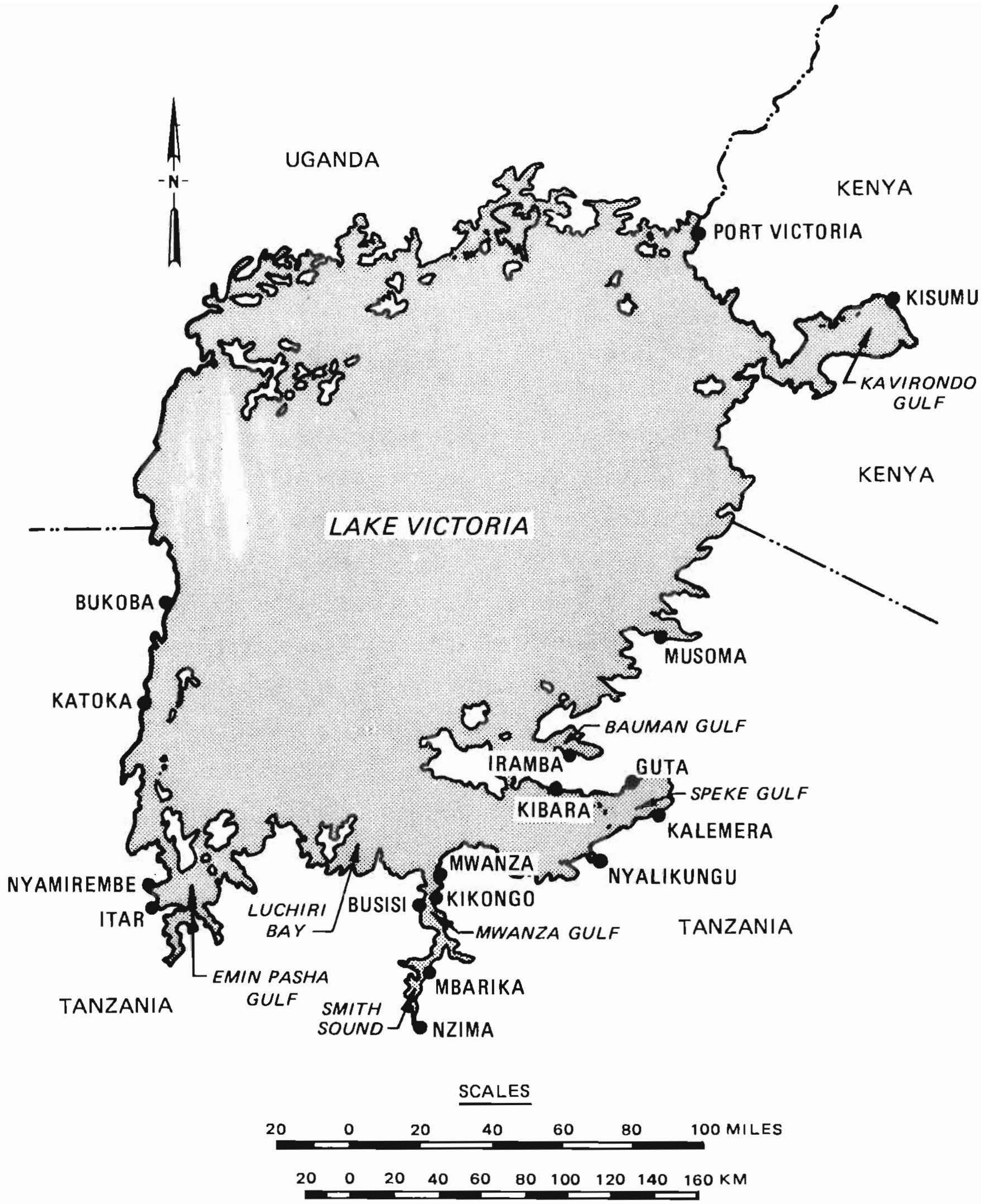


Figure 2. Generalized area map of Lake Victoria showing the sites surveyed

very similar to Lake Tanganyika. This area was very difficult in which to work because of the political-military situation. After many problems, permission was received to survey one small area called Matema. While the survey was unsuccessful in trying to enter Port Itungi, a backwater swamp belonging to the lake was observed not far from the Port. The information gathered is included as Table 11.

PART IV: FINDINGS

Occurrence of Hydrilla

40. Hydrilla was found growing in Lake Tanganyika from Kigoma on the northeastern shore to Kasanga 483 km south on the southeastern shore (see Figure 3). All of the localities in which hydrilla were found were relatively quiet bays with very clear water.

41. At Kigoma it was growing within a metre of the shore and probably out to beyond 50 m from shore. The water depth ranged from about 0.5 m to about 10 m. The bottom was a mixture of sand, mud, and many small rocks. Most of the hydrilla plants were growing between the rocks, in an area where the shore changed from a sandy beach to rocks. The associated plants were two species of *Potamogeton*, *Vallisneria* sp., and *Najas* sp. The zonation of hydrilla and other plants for the Kigoma, Kipili, and Kasanga sites is seen in Figure 4.

42. At Ujiji fragments of hydrilla were found in the drift line on the sandy beach and floating in shallow water. No population of hydrilla was located in the area. No other plants were found growing in the water except for a *Potamogeton* species.

43. Kasoge, which is about 129 km south of Kigoma (20 hr by boat), is a broad open bay with long sandy beaches interrupted by rocky outcrops. The bottom is mixed sand and rock. Fragments of hydrilla were located in the drift line, but no population was located.

44. Kipili, which is about 322 km south of Kigoma, is a very sheltered bay with a narrow mouth connecting it with the rest of the lake. The water is exceptionally calm and clear. The shore is a mixture of small rocks and soil with some sand. The bottom was mud-sand with scattered rocks. Hydrilla was growing abundantly in the shallow water near the shore. The associated plants were the same species seen at Kigoma with the addition of a *Myriophyllum* sp.

45. Kasanga, which is about 483 km south of Kigoma, is another relatively quiet bay. It is less sheltered than Kipili and broader than Kigoma. Most of the shore is sand beach with the northern and southern

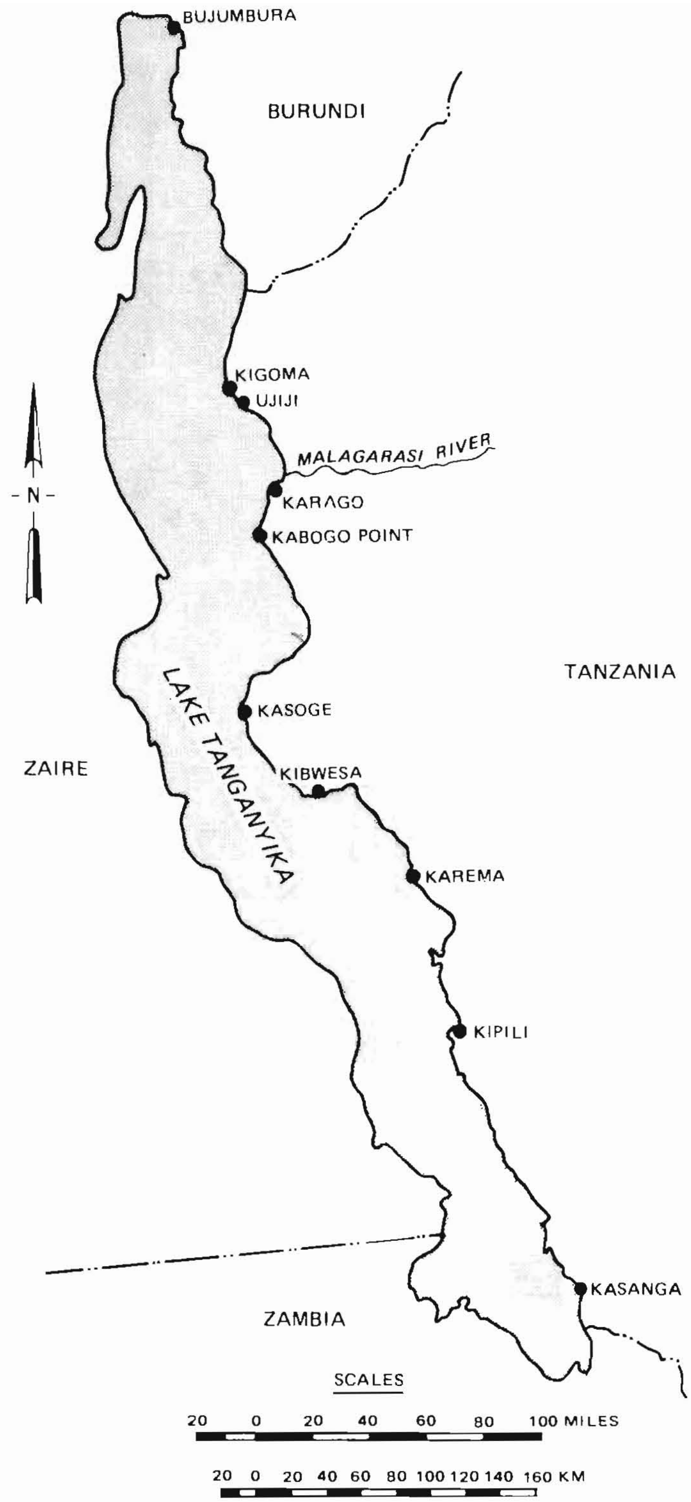


Figure 3. Generalized map of Lake Tanganyika showing the sites surveyed and the hydrilla localities

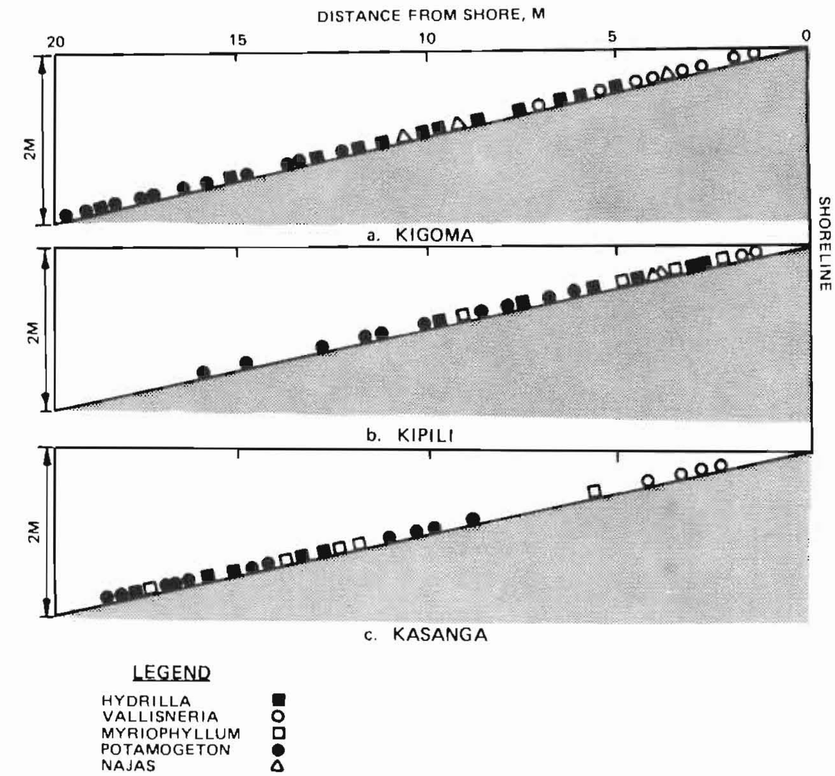


Figure 4. Zonation of hydrilla and associated submerged plants at three locations on Lake Tanganyika

ends being rocky. The bottom was sand at the beach and mud near the rocky shore. Hydrilla plants were growing in the area where the sand and mud bottoms met and in the mud, where it was more abundant. The associated plants were Vallisneria sp., Najas sp., Myriophyllum sp., and Potamogeton sp.

Plant Form

46. The Hydrilla verticillata encountered in Africa differs vegetatively from the H. verticillata seen in Florida. The most striking difference is that of plant size, principally height. At all the locations, except Kipili, the plants were very short, ranging from 10 to 60 cm. At Kipili the plants were up to 1 m, but even this is very small when compared to the Florida hydrilla. There were also many primary (originating at the ground) stems per plant. The total number of stems was also high

for such small plants, as 10 typical plants from Kigoma had an average of 15.5 stems per plant. The stem number ranged from 7 to 27 per plant for that group.

47. The internodes were generally very short, being usually less than 1 cm and often less than 0.5 cm. The number of leaves per whorl ranged from 3 to 10 and averaged about 5 or 6. The leaves themselves were medium to dark green in color (darker than Florida hydrilla). The leaf shape was ovate-acuminate, and the leaves showed less serration than is seen in Florida leaves. The length-width ratio of the leaves was 2:1 to 3:1. Their average length was 4 or 5 mm. Turions were present in some plants, but tubers were not encountered. Tubers were present on Ugandan hydrilla herbarium specimens (Appendix A) of this same form.

48. The plants at Kasanga were different from the plants seen at other localities and approached the appearance of Florida hydrilla in some respects. They were taller, had longer internodes, and were larger and had longer leaves.

49. The differences observed in the hydrilla form of the Africa plants are probably environmentally induced. Some of the physical factors inducing this form might be a pH of 8.0, wave action, and the amount of light reaching the plants. The biotic factors that appear to be quite significant will be discussed under the "Damage and Natural Enemies" section of this report.

50. Flowering was observed only in the plants of Kasanga, which was the only place that hydrilla reached the water surface. The flowers that were seen were female. Male flowers are very small and free floating and, therefore, difficult to detect. They can also be detected by the flower spathes in the leaf axils, but these were not seen. Only a few plants were seen in flower, so it was difficult to determine whether the plants were the monoecious or dioecious form (both occur in _H. verticillata_).

Damage and Natural Enemies

51. The damage to hydrilla plants was of two types: fish and

insect feeding. Two types of fish feeding were seen. One type of feeding was the removal of the leaves along the whole stem or a portion of it (Figure 5). Usually the ragged leaf bases would remain along the damaged stem. The other kind of fish damage was the removal of the stem tips (Figure 6). These kinds of damage could be together or separate.

Fish

52. Only one species of fish was observed feeding on hydrilla plants. This was a small (7 to 10 cm) species, which was probably a chiclid. It was silver-grey with vertical black bars. Attempts to catch this fish were unsuccessful. From the brief observations of this species, it is not known whether the fish was actually grazing on hydrilla or eating invertebrates off the leaves. Four other fish species often seen around the hydrilla beds were captured, examined, and dissected for evidence of hydrilla feeding and herbivority. All four species were carnivorous. They had silver peritoneums, holding teeth, and short straight digestive tracts containing invertebrates, mainly nematodes and damselfly naiads. Therefore, the fish species responsible for the described damage to the hydrilla was either not encountered or was perhaps the black and silver chiclid, or both. The fish damage was seen at all three primary localities (Kigoma, Kipili, and Kansanga). The attempts to determine the species of fish responsible for the damage were made at Kigoma.

Insects

53. The most important insect found on hydrilla was a Chironomid midge belonging to the genus Polypedilum (the species has yet to be determined). The larva of this midge eat away the apical meristems of the hydrilla shoots (stems). This damage may, or may not, be obvious, depending on the plant, but the damage is usually detectable only by close examination. The more obvious damage sign is a small hole (presumably an emergence hole) that would be chewed through the bud at the tip of the stems (Figure 7). Often the bud would appear to be normal externally, but when the bud leaves enclosing the meristem were parted, the meristem would be gone. The inside of the bud would be blackened, and, in some cases, the stem would be eaten away for 2 to 4 mm with an exit hole

Figure 5. Drawing of a hydrilla plant showing fish damage (arrows)

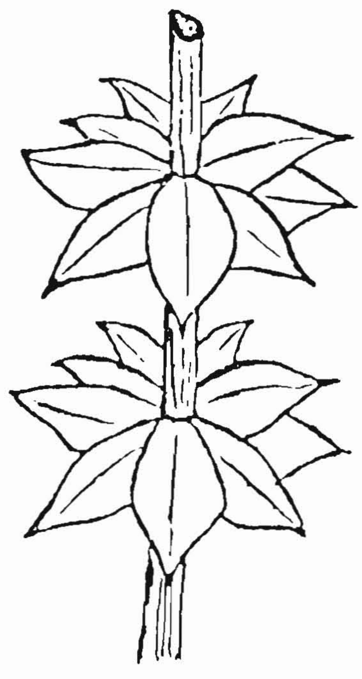
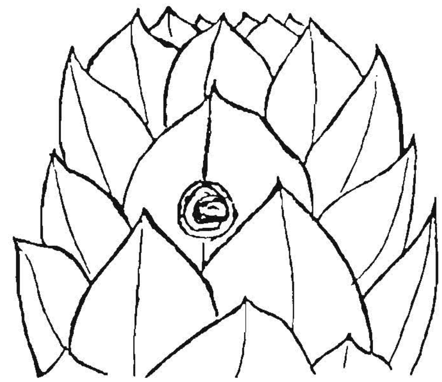


Figure 6. Fish damage where the tip of stem is removed

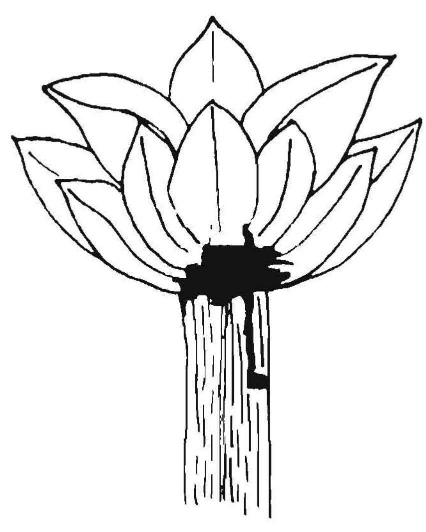
Figure 7. Apical hydrilla bud showing the exit hole in the bud



present. Figure 8 shows this damage as seen in a partially dissected apical bud. The midge apparently can bore out through the bud or stem after eating the meristem. Exiting probably can also occur by movement between the leaves. Often when the buds, which had been attacked, would be handled for examination they would fall off their stems leaving the whorl of leaves just below the bud at the stem tip (Figure 9). This apparently also occurs in nature as a part of the decay of a tip after being damaged by a midge. Many of these types of stem tips were found. The breakage or sloughing off of the damaged buds were sharp and clean. It differs from the fish-removed tip by having no stem present above the ultimate whorl of leaves. Figures 6 and 9 can be used to compare the two types of damage.

54. The midge was found inside the bud with the damage at times and in other instances outside the bud between the leaves or on the leaf

Figure 8. Drawing of a dissected hydrilla bud showing Polypedilum damage: missing meristem, blackened and chewed tissue, stem bored, and exit hole



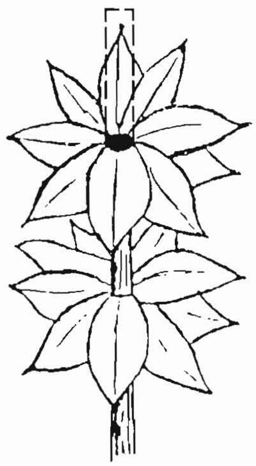


Figure 9. Appearance of a stem after the Polypedilum damaged bud has been shed (dotted lines show location of shed stem and bud)

surfaces. At the three primary localities, damaged estimates were made with 10 randomly selected plants. At Kigoma, 80 percent of the stems were damaged; at Kipili, 76 percent of the stems were damaged; and at Kasanga, 65 percent of the stems were damaged. These figures represent both fish and Polypedilum damage and may also include some breakage from waves. Quantitative separation of the respective damage types was not done. Fish might have fed on a tip, in which the meristem had been eaten away by Polypedilum sp. Breakage of the stem tips that were previously fed on by Polypedilum sp. and fish might also occur. These events obscure the initial causative factors; thus, separating the damage into types quantitatively may have led to false conclusions and impressions of the damage and the agents causing it. Polypedilum damage was very common, occurring on virtually all plants examined.

55. Most of the damage was old and usually the midge was not associated with it. To help clarify the situation, a simple feeding test was conducted. Three undamaged hydrilla stems were placed in a water-filled half-gallon jar with six Polypedilum sp. larvae. After 5 days, all three stems had had their meristems eaten away. One stem even had its apical bud leaves bored completely through (Figure 7). The control plants showed signs of decay, and one stem had a rotten meristem.

56. Attempts to rear adults were not successful. This was probably due to the lack of aeration equipment for the rearing jars and the relatively short time period in which rearings were feasible.

57. The genus Polypedilum is cosmopolitan, including species native to the United States. Some members of the genus bore into and consume plants, while other members of the genus live on the surfaces of plants and act as scavengers. The species that bore into plants have more heavily sclerotized mandibles and heads than the scavengers. Bill Beck of Florida A&M University, who identified the hydrilla midge as a species of Polypedilum, feels that the head and mandibles of this midge resemble those of the scavenger section instead of the herbivore section of the genus, as the types occur in the United States. An explanation of this apparent contradiction in the feeding and morphology of Polypedilum sp. may lie in the nature of hydrilla morphology. Hydrilla is probably like the related Elodea canadensis in that the leaves are only two cells thick and have relatively little cuticle. In addition, hydrilla apical meristems are small and soft, the ensheathing bud leaves are thin, and the upper stem is tender. To feed on these structures perhaps it is unnecessary for Polypedilum sp. to have the normal adaptations seen in other boring species in the genus. The scavengerlike morphology of Polypedilum sp. would appear to be entirely adequate for dealing with hydrilla.

58. Another natural enemy that was encountered was the mayfly, Povilla adusta Navas (Polymitarcyidae). Three mayfly nymphs were removed from the inside of hydrilla stems from Kipili. These nymphs were well inside of the lower stems and had bored into 2 to 4 cm of stem tissue. All three died before rearing attempts were possible. This plant-boring behavior is unusual for mayflies.

59. A few pupal cases of a stonefly (probably Hydroptila) were found on the leaves of hydrilla at Kigoma and were reared to adults, emerging on 17 November. Some Hydroptiids feed on vascular plants; this one was probably a filter feeder.

60. Many other insects were present on hydrilla plants, none of which, however, were herbivorous. Damselfly and dragonfly nymphs were the most common.

Others

61. Nematodes were very abundant on the surfaces of the hydrilla

plants and in the hydrosoil around the roots, but no damage was associated with them. Representatives of three to four species were tested for hydrilla feeding in jars (as with Polypedilum sp.). No damage was detected after 5 days.

62. Two species of snails were common on hydrilla stems. These were also tested with undamaged hydrilla stems. After 10 days the stems remained free of damage.

63. No obvious signs of plant disease were ever seen on hydrilla plants.

PART V: DISCUSSION AND CONCLUSIONS

64. The number of herbivorous insects found on submerged plants is generally much lower than the number found on emergent, floating, and terrestrial plants. The vast majority of herbivorous insects lack gills or other specialized respiratory mechanisms required for an aquatic existence. There are, however, a few specialized groups (belonging to families whose members are usually terrestrial herbivores) that are adapted to aquatic life. These are the insects that normally are the hervibores of submerged plants (Bagonini of the Curculionidae, Nymphulini of the Pyralidae, and Hydrellia of the Agromyzidae). Members of these groups were found attacking H. verticillata in Pakistan and were expected in Africa. To the contrary, no members of these groups were found. There is one thing which most members of these groups share; that is, the need for the adults to contact the host plant at the water surface for egg laying. Hydrilla rarely reached the water surface where the author observed it; thus, this surface guild was prevented in those areas from using hydrilla as a host. The reason that plants are short is probably due to the removal of their apical meristems by Polypedilum sp. and the whole buds by fish. If hydrilla populations could be located where these natural enemies were not present, or were present in low numbers, then the hydrilla will probably reach the water surface and have members of the surface guild on it. Some members of the surface guild could prove to be effective natural enemies and potential biological control agents.

65. The fact that hydrilla does not constitute a problem in Lake Tanganyika is significant. The principal reason that hydrilla is not a problem is that it is literally prevented from growing into one. The damage to a large percentage of the apical meristems has a pruning effect on the plants and keeps them small. Kasanga, the only location where any hydrilla stems were seen to reach the water surface and flower, had the lowest percentage of damaged stems (65 percent compared to 74 percent at Kipili, and 80 percent at Kigoma).

66. As stated before, the natural enemies of hydrilla,

Polypedilum sp. and the fish, are probably responsible for the stem damage and thus the natural control of hydrilla. *Polypedilum* sp., in particular, shows promise because the stunting it causes to the hydrilla plants would be a desirable kind of control for Florida hydrilla. Changing Florida hydrilla from large dominant plants into small plants would eliminate the problem aspect of hydrilla, while keeping those habitats closed to other problematic plants.

67. This survey was the base-level work. Some recommendations for future research and field surveys in this area of Africa are included as Appendix B. Future surveys of the area may find the advice on logistics and conditions gained from the author's experience and presented in Appendix C helpful. More research is necessary to understand this system and to properly evaluate the natural enemies before their possible use as biological control agents will be feasible.

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Table 1

Conditions and Characteristics of Rivers Sampled in Survey

River	Location	Physical Description	Types of Water Plants Encountered
Wami	Dar es Salaam-Arusha Highway crossing; Coastal Province, Tanzania	Brown turbid waters; 50 m wide	*Cyperus papyrus*, *Pistia stratiotes*
Ruva	Karfu, Kilimanjaro Province, Tanzania	Photozone down to 1 m; 10 m wide	*Cyperus papyrus*, *Pistia stratiotes*, *Ceratophyllum*, *Hydrocotyle*, *Salvinia*
Mbalageti	Nyalikungu, Mwanza Province, Tanzania	Very muddy waters	*Typha*
Name unknown	Between Nyalikungu and Nyanguge, east of Mwanza, Mwanza Province; Tanzania	Muddy water	*Pistia stratiotes*, *Nymphaea* sp., *Certatophyllum* sp.
Name unknown	Between Sima and Ibondo, Mwanza Province, Tanzania	Clear water, 10 m wide, 2 m deep	*Nymphaea* spp., *Sagittaria* sp., *Utricularia* sp., *Najas* sp., *Marsilea* sp., *Commelina* sp.
Kongwa	Nyamazugu, near Luchiri Bay, Lake Victoria, Mwanza Province, Tanzania	Medium-clear water, 10 m wide	*Nymphaea* sp., *Ceratophyllum* sp., *Utricularia* sp.
Name unknown	Between Ibwera and Kanazi, south of Bukoba, West Lake Province, Tanzania	Shallow and clear water, very slow current, mud-sand bottom, 10 m wide	*Cyperus papyrus*, *Mimosa* sp., *Nymphaea* sp., *Ottelia* sp., *Potamogeton* 2 spp., *Utricularia* 2 spp., *Chara* sp., *Ludwigia* sp.,

(Continued)

Table 1 (Concluded)

River	Location	Physical Description	Types of Water Plants Encountered
Name unknown (Continued)			*Commelina* sp., *Polygonum* 2 spp., floating grass, and unknown submergent
Name unknown	Between Kyaka and Katoma, West Lake Province, Tanzania	Very muddy, rapid current, 20 m wide	*Azolla* sp.
Kagora	Kyaka, West Lake Province, Tanzania	Fast and muddy, 50 m wide, military prevented close examination	*Cyperus papyrus*, *Pistia stratiotes*
Malagarasi	Between Kazibuzi and Nyaka Kangaga, Kigoma Province, Tanzania	Muddy water, swift current, steep banks, 80 m wide	No other aquatics other than usual grasses and sedges
Malagarasi	Uvinza, Kigoma Province, Tanzania	Photozone 1 m, clearer than at previous site	*Vallisneria* sp., *Polygonium* sp.
Makere	Makere, Kigoma Province, Tanzania	Eutrophic, steeply banked, 10 m wide	No aquatics other than usual sedges and grasses
Name unknown	59.5 km north of Mpanda, Mpanda Province, Tanzania	Shallow and rocky, photozone less than 0.5 m, 8 m wide	No aquatics
Saisi (?)	Between Laela and Ndalambo, Mbeya Province, Tanzania	Brown turbid water, photozone less than 0.5 m	Unknown submergent plant

Table 2

Conditions and Characteristics of Streams

Sampled in Survey

Location	Physical Description	Types of Water Plants Encountered
Mountain streams on eastern slope of Mt. Kilimanjaro, Tanzania, up to 2134 m elevation	Stream currents very swift	No vascular plants, probably due to swift water
Small stream 5 km west of Busisi, Mwanza Province, Tanzania	Dry except for pools	*Utricularia* sp.
Small stream several kilometres southwest of Bugonya, Mwanza Province, Tanzania	Reduced to pools	Sedges
Stream 2 km west of Geita, Mwanza Province, Tanzania		*Nymphaea* sp. in quiet areas, *Commelina* sp. at shore
Stream 5 km north of Nyamirembe, West Lake Province, Tanzania		*Commelina* sp.
Stream just south of Muleba, West Lake Province, Tanzania		*Nymphaea* sp., *Polygonum* sp., and *Cyperus papyrus*
Stream just north of Katoke, West Lake Province, Tanzania	3 m wide	*Potamogeton* sp., *Polygonum* spp., *Nymphaea* sp.
Stream 3 km west of Kyaka, West Lake Province, Tanzania	With pools	*Cyperus papyrus*, *Nymphaea* sp., *Polygonum* sp., *Utricularia* sp., *Ceratophyllum* sp.
Small stream in wet forest between Lukokorome and Kasherazi, West Lake Province, Tanzania		Zingberaceous plant, *Polygonum* sp.
Stream between Nyaka Kangaga and Malagarasi River, Kigoma Province, Tanzania	Has pools	*Commelina* sp., *Potamogeton* sp., unknown Hydrocharitaceous plant

Table 3

Conditions and Characteristics of Irrigation Ditches Sampled in Survey

Location	Physical Description	Types of Water Plants Encountered
Busisi, Lake Victoria, Mwanza Province, Tanzania	Channels lead from adjacent papyrus marsh through cassava patches	*Nymphaea* sp.
Rulenge Valley, Rulenge, West Lake Province, Tanzania	Large-scale irrigation system in valley, *Potamogeton* thick enough to be a problem	*Ottelia* sp., *Ludwigia* sp., *Potamogeton* sp., *Bootia* sp. (?), *Cyperus papyrus*, *Chara* sp.
Family farms between Kangaga and Makere, Kigoma Province, Tanzania	Stream went through channels and pools into vegetable gardens	*Nymphaea* sp., sedges

Table 4

Conditions and Characteristics of Seasonal Ponds Sampled in Survey

Location	Physical Description	Types of Water Plants Encountered
University of Tanzania, Dar es Salaam, Tanzania	Small pool, 5 m in diameter on undeveloped part of campus	*Nymphaea* sp., *Esquisitum* sp., *Largosiphon crispa*, *Utricularia* sp., *Echidorus* sp.
Roadside ponds between Makere and Mulenbera, Kigoma Province, Tanzania	1-2 m deep, 20 m in diameter, very clear water	*Nymphaea* sp., *Utricularia* sp., *Najas* sp., *Brasenia schreberi*, *Sparganium* sp., others unknown
Pond between Kalemera and Nyahanga, Musoma Province, Tanzania	Small and shallow	*Nymphaea* sp.

Table 5

Conditions and Characteristics of Water Holes Sampled in Survey

Location	Types of Water Plants Encountered
Water holes at Ngorongoro Crater, Arusha Province, Tanzania	*Typha* sp., *Hydrocotyle* sp. at edge of large pool
Water holes at Serengeti Natural Park, Seronera, Musoma Province, Tanzania	No aquatic vegetation
Water hole west of Bunda, Musoma Province, Tanzania	No aquatic vegetation
Water holes 1 km north of Mwanangwa, Mwanza Province, Tanzania	*Marsalea* sp., *Nymphaea* sp.

Table 6

Conditions and Characteristics of Marshes Sampled in Survey

Location	Types of Water Plants Encountered
Marsh at junction of Duma Mara and Simyu Rivers at Nyalikungu, Musoma Province, Tanzania	*Pistia stratiotes*, *Cyperus papyrus*, *Ceratophyllum* sp., *Azolla* sp., *Spirodela* sp.
Marsh 11 km south of Bukoba, West Lake Province, Tanzania	*Cyperus papyrus*, *Nymphaea* sp.
Marsh between Katoma and Kyaka, West Lake Province, Tanzania	*Cyperus papyrus*, *Zingiberaceous* plant, *Impatiens* sp., *Nymphaea* sp., *Melastromaceous* plant
Marsh at northside of Subawanga at Kasanga turnoff, Mbeya Province, Tanzania	*Cyperus papyrus*, *Hydrocotyle* sp., *Potamogeton* sp.

Table 7

Conditions and Characteristics of Man-Made Lakes Sampled in Survey

Location	Physical Description	Types of Water Plants Encountered
Lake Kalimawe, Kilimanjaro Province, Tanzania	Dammed in 1959, quite eutrophic, photozone near zero	*Nymphaea* sp., *Ipomea* sp., *Mimosa* sp. (?), *Ludwigia* sp.
Lake Myumba ya Munga, Kilimanjaro Province, Tanzania	Dammed in 1973, large fluctuation zone, gravel bottom, turbid water	*Typha* sp.
Small lake at Sengerema, Mwanza Province, Tanzania	Eutrophic photozone about 0.5 m	*Ceratophyllum* sp., large infestation of *Trapa* sp., probably *natans*
Small lake between Tanduma and Mbeya, Mbeya Province, Tanzania	Looks recently dammed, photozone less than 0.5 m	*Photamogeton* sp., *Polygonum* sp.

Table 8

Conditions and Characteristics of Small Natural Freshwater Lakes Sampled in Survey

Location	Physical Description	Types of Water Plants Encountered
Lake Jipe, Kilimanjaro Province, Tanzania-Kenya border	Brown water, large swamp at lakeshore due to *Typha*	*Typha* sp., *Caladium* sp., *Lemna* sp., *Spirodela* sp., *Najas* sp.
Lake at Nyamirembe, West Lake Province, Tanzania	Cut off from Lake Victoria by sandbar, shallow, eutrophic, sand bottom	*Typha* sp., *Cyperus* sp.
Lake Ikimba between Katoro and Ibwera, West Lake Province, Tanzania	Photozone 1 m plus	*Cyperus papyrus*, *Utricularia* sp., *Nymphaea* sp., *Ceratophyllum* sp.
Lake Ikimba between Ibwera and Rubare, West Lake Province, Tanzania	*Papyrus* swamp	*Cyperus papyrus*, *Azolla* sp., *Ricciocarpus* sp., *Polygonum* sp.
Lake Baringo, Baringo Province, Kenya	Silted and mud brown from erosion	*Typha* sp.
Lake Naivasha, Nakuru Province, Kenya	Photozone 1.5 m, mud bottom	*Cyperus papyrus*, *Typha* sp.
Small lake 6.4 km west of Gieta, Mwanza Province, Tanzania	Clear and deep, 0.8 km by 0.2 km, mud bottom	*Nymphaea* sp., *Najas* sp., *Ceratophyllum* sp., *Mimosa* sp., *Commelina* sp.

Table 9

Conditions and Characteristics of Sites Sampled on Lake Victoria

Location	Physical Description	Types of Water Plants Encountered
Small bay at Port Victoria, Kenya	Sand and rock shore, bottom sand with scattered rocks, photozone 1 m	*Cyperus papyrus*, *Typha* sp. (dominant), no plants on shoreline, no other plants observed
Sites 1 and 2, 3 km south of Kismu, Nyakach Bay, Kenya	Rocky shore, coarse mud and rock bottom, shallow water, photozone 1.5 m+, floating grass	*Typha* sp., *Cyperus papyrus* (at shore), *Pistia* (in sloughs and on shore drift line, no submergents), *Ipomea* sp. (Site 2 only)
Iramba, Baumann Gulf, Musoma Province, Tanzania	Mud bottom, turbid water, small photozone	Shore lined with papyrus and floating grass, papyrus islands, no submergents or floating plants
Speke Gulf, Mwanza Province, Tanzania	Areas surveyed had sandy beaches	Pistia on shore drift lines, canelike grass on beaches
Mwanza, Mwanza Province, Tanzania	Large boulders and sandy areas on shore, sand-mud bottom, murky water, much wave action	Few plants, no submergents
Kikongo, Mwanza Gulf, Mwanza Province, Tanzania	Similar to Mwanza site (above)	*Cyperus papyrus* and floating grass
Mbarika, Smith Sound (southern continuation of Mwanza Gulf)	Sound narrower than gulf, papyrus islands created shallow channel along shore with almost no wave action, mud bottom, clear water 2 m deep. Open-water side--murky water, moderate wave action	Channel side-- *Utricularia* spp., *Potamogeton* sp., *Ricciocarpus* sp., *Spirodela* sp., *Pistia stratiotes*, *Trapa* sp. (dominant plant), *Nymphaea* sp., *Cyperus papyrus* and

(Continued)

(Sheet 1 of 3)

Table 9 (Continued)

Location	Physical Description	Types of Water Plants Encountered
Mbarika, Smith Sound (Continued)		floating grass were larger plants. Open-water side--no plants found, even though extensively explored because it was a recorded hydrilla locality.
Nzimu, Smith Sound, Mwanza Province, Tanzania	Area similar to channel area of Mbarika (above), water 3 m deep, more photozone depth	*Utricularia* spp., Papyrus emergents, *Trapa* sp., *Potamogeton* sp. in deeper areas
Busisi, Mwanza Gulf, Mwanza Province, Tanzania	Smaller papyrus-formed backwater similar to Mbarika site, clear water, mud bottom	*Pistia stratiotes*, *Nymphaea* sp., *Utricularia* sp., *Ludwigia* sp., and *Cyperus papyrus*
Ferry crossing, west side of Mwanza Gulf across from Mwanza, Tanzania	Moderate wave action, clear water, 2 m photozone, mud-sand bottom between rocks	No aquatic plants except patches of papyrus and grasses
Luchiri Bay near Nyamazugu, Mwanza Province, Tanzania	Shore was sandy beaches and small papyrus patches, sandy bottom, murky water	Only aquatic was *Cyperus papyrus*, none on drift line at shore
Buzirayombo, West Lake Province, Tanzania Bay on southern end of Emin Pasha Gulf	Mud bottom, murky water	Papyrus along shore, no other plants
Itar, Emin Pasha Gulf, West Lake Province, Tanzania	Very shallow and clear water, mud-sand bottom	Shore patches of papyrus and canelike grass, no floating or submergent plants except *Pistia stratiotes* in drift line at shore
Nyamirebe, Emin Pasha Gulf, West Lake Province, Tanzania	Similar to Itar, but more papyrus	No submergents or floating plants

(Continued)

Table 9 (Concluded)

Location	Physical Description	Types of Water Plants Encountered
Katoka area, West Lake Province, Tanzania	15.2- to 30.4-m cliffs form shore, much wave action	No aquatic plants
Bukoba, West Lake Province, Tanzania	Cliffs and sandy beaches line bay, small backwaters behind beach contained only aquatic plants, backwaters shallow and pondlike with clear water, mud bottoms	*Polygonum* sp., *Commelina* sp., *Azolla* sp., *Nymphaea* sp., *Potamogeton* sp., and *Utricularia* sp.

Table 10

Conditions and Characteristics of Sites

Sampled on Lake Tanganyika

Location	Physical Description	Types of Water Plants Encountered
Site 1,* papyrus swamp just west of Usali	Papyrus floating at the shore, water clarity less than 0.3 m on lakeside of papyrus, water clearer on shore side	*Utricularia* sp., *Azolla* sp., *Ceratophyllum* sp., *Potamogeton* sp., *Pistia* sp., *Ipomea* sp., and *Ludwigia* sp.
Site 2,* sandy barrier beach with lagoon behind it, between beach and shore	Water quality poor on beach side, lagoon water clearer, mud bottom	*Vallisneria* sp. only plant on beach side; lagoon had *Typha* sp., *Ceratophyllum* sp., *Potamogeton* sp., *Trapa* sp., and floating grass
Site 3,* rocky shore near southern end of bay	Water clarity poor, mud-rock bottom	No plants or fragments except patches of floating grasses near shore
Ujiji, just south of Kigoma, Tanzania	Marsh lagoon behind barrier beach, shallow water, clear mud bottom	Completely choked with *Ceratophyllum* sp., *Typha* sp. also very abundant
Kabogo Point area, 80.4 km south of Kigoma, Tanzania	Sandy beach between rocky shores, very rough water	No plants present even in drift line at shore
Karembe, about 112.6 km south of Kigoma, Tanzania	Broad and open bay, sandy beaches, rocky points, mud bottom, murky water, much wave action	No plants on north or south ends of bay

(Continued)

* Malagarasi River delta (three sites) 64.3 km south of Kigoma, Tanzania. River empties into large bay. Submerged plants were present only in backwaters as the bay water was murky due to the silt carried by the river.

Table 10 (Concluded)

Location	Physical Description	Types of Water Plants Encountered
Kibwesa, about 225 km south of Kigoma, Tanzania	Broad and open bay, sandy beaches with rocky points, mud bottom, much wave action	No plants on north or south ends of bay
Karema, about 257 km south of Kigoma, Tanzania	Sand and rock beaches, mud flats in bay, water murky and rough	No plants

Table 11

Conditions and Characteristics of Sites Sampled on Lake Malawi (Lake Nyasa)

Location	Physical Description	Types of Water Plants Encountered
Port Itungi, Rungwe Province, Tanzania, swamp area west of port	Water very shallow and clear, mud bottom	Sedges and grass dominant emergent vegetation; others were *Salvinia* sp., *Ottelia* sp., *Ceratophyllum* sp., *Nymphaea* sp.
Matema, Rungwe Province, Tanzania, northeast corner of the lake	Sand-pebble beach, crystal clear water, very deep at shore, large waves	No plants except a few fragments of *Vallisneria* in drift line on shore

APPENDIX A: HYDRILLA HERBARIA RECORDS

1. In preparation for the survey, a list of *Hydrilla verticillata* localities was prepared from herbaria information. This information was obtained by visits to herbaria, or by correspondence with them. The following was obtained:

- *a*. U.S.N.M., Washington, D. C. One sheet from Madagascar - not hydrilla but *Largosiphon* sp.
- *b*. Missouri Botanical Garden. No African hydrilla.
- *c*. University of California, Jepseon Herbarium. No African hydrilla.
- *d*. California Academy of Sciences Herbarium. No African hydrilla.
- *e*. National Museum of France (Paris). No African hydrilla.
- *f*. University of Rome; Italy. No African hydrilla.
- *g*. University of Palermo; Sicily. No African hydrilla.
- *h*. National Museum of Kenya. Many specimens of *H. verticillata*, all from Uganda.
- *i*. University of Tanzania, Dar es Salaam. Many records, primarily from Uganda, but a few specimens from Lake Tanganyika.
- *j*. Royal Botanical Gardens, Kew, Richmond, Surrey, England. Many records, again primarily from Uganda. Table A1 was assembled from their material.
- *k*. For additional African localities, the author suggests contacting Prof. C. D. K. Cook, Botanic Garden, University of Zurich, 40 Pelikanstrasse, 8001 Zurich, Switzerland.

Table A1

Hydrilla Herbaria Information Obtained from Royal Botanical Gardens

Locality	Dates Collected	Habitat	Flowering Period	Variation of Plant Form	Insect Damage
Ivory Coast: Abidjan Botanic Garden	11 Mar 1974		Flowering male	Whorls of leaves, long internodes, spreading fronds	No
Congo: Kivu Province			No	Small leaves, compact fronds	No
Uganda: Makerere Univ. Hill, Kampala	1 May 1969	Cultivated in pond in Botany Garden but originally from Lake Bunyoni, Kigezi Gnd Ref No. RJ-24-57	Flowering male	Whorls of leaves, long internodes, spreading fronds	No
Uganda: Lake Bunyoni, Kigezi	31 Dec 1933	Water 0.9 m deep	No	Whorls of leaves, long internodes, spreading fronds	No
Uganda: Lake Entebbe	March 1929		No	Small leaves, long internodes, spreading fronds	No
Uganda: Busoga Butembe Bunya 16 km east of Jinja. Also on margin of Lake Victoria	3 Oct 1952	Small pools, stagnant, shallow 0.3 to 1.2 m full sun, submerged	No	Small leaves, long internodes, spreading fronds	No
Uganda: Kigezi Lake Bunyoni	4 Jun 1952	In *Nymphaea* zone	No	Large leaved form	No
Uganda: Lake Nutanda, Mushungero, Kigezi	22 Aug 1938	Shallow, sheltered water	No	Medium compact plant	No
Uganda: Nyahasura	6 Jan 1936	Side of ditch cut through swamps	No	Spreading fronds, long internodes	No
Uganda	Nov 1862	--	No	Small leaved, very long internodes	No
Uganda: Atura Lango	12 May 1941	River Nile	No	Small leaved, spreading fronds	No
Uganda: Entebbe Lake Victoria	Nov 1930	Just below surface of water	No	Small leaves, compact fronds	No
Uganda: Jinja District, Bugaia Island, Lake Victoria, Nyanza	7 Apr 1955	3 m water, off sandy beach	No	Small leaves, long fronds	No
Uganda: Lake Bunyoni, near Kifuka resthouse 1°17'S, 29°55'E	22 Apr 1970	Submerged in 1-m deep water at lake edge	No	Medium leaves, spreading fronds and large leaved form	No
Uganda: Bugungo Ferry opposite Jinja	July 1953	In channel, submerged between reeds and jetty	No	Small leaves, compact fronds	No
Kenya: Port Victoria, Lukala	12 Mar 1950	In 0.45 m of water submerged	No	Medium leaves, compact fronds	No
Kenya: Victoria, Nyanza	1928	--	No	Medium leaves, compact fronds	No

(Continued)

Table A1 (Concluded)

Locality	Dates Collected	Habitat	Flowering Period	Variation of Plant Form	Insect Damage
Tanzania: Mbarika, Mwanza, Lake Pisv.	15 Aug 1953	Growing at lake edge	No	Small leaves, compact fronds	No
Tanzania: Capriporrt Mwanza, Lake Pisv.	10 Oct 1953	Subaquatic plant, floats about 7.62 cm below surface	No	Small leaves, compact fronds	No
Zambia: Abercorn District Lufubu River, Iyendwe Valley	9 Jul 1959	On edge of Lake Tanganyika	No	Small leaves, compact fronds	No
Cambia: Abercorn District	20 Oct 1947	In sandy mud in 1.2 m water near lakeshore	Flowering female	Small leaves, compact fronds	No
Botswana: Northern District, Edge of Thamalakane River Maun	June 1955	Edge of river	Flowering male	Medium leaves, spreading fronds	No
Botswana: Ngamiland, Matsibe River, near Tsetse Camp, Okavanga	16 Mar 1961	In pool in dry river bed	No	Medium leaves, spreading fronds	No

APPENDIX B: RECOMMENDATIONS

1. For this recommendation appendix, an outline form was used for ease of reference for specific items.

I. Research on known natural enemies

   A. *Polypedilum* sp.

      1. Rear adults
      2. Obtain species name
      3. Literature work
      4. Determine life cycle and general biology
      5. Determine capability to damage hydrilla in the laboratory
      6. Host-specificity testing

   B. Mayfly, *Povilla adusta*

      1. Literature work
      2. Field and lab studies if deemed desirable

   C. Caddis fly, *Hydroptia* sp.

      1. Literature work
      2. Field and lab work to determine feeding habits and see if this species involved in meristem damage

   D. Fish

      1. Identify species causing damage to hydrilla
      2. Literature work
      3. Determine ability to damage hydrilla in lab aquaria
      4. Fieldwork if deemed desirable

II. Additional surveying in East Africa

   A. More exploration

      1. Find hydrilla populations without meristem borer damage
      2. Discover other natural enemies

   B. Places to survey

      1. Burundi shore of Lake Tanganyika
      2. Lake Kivu, Rwanda
      3. Lake Edward, access from Zaire
      4. Lake Albert, access from Zaire
      5. Lake Malawi, approach and survey from Malawi

6. Lakes of northeastern Zambia

7. Uganda, if political situation improves, highly desirable because of the many hydrilla records

III. Burundi as a base for research and exploration

A. Advantages - Hydrilla

1. Hydrilla along lakeshore in Burundi

2. Burundi only 64 km north of Kigoma, should be same complex of natural enemies

B. Advantages - Environment in Burundi as opposed to Tanzania

1. Better availability of goods and services

2. Direct air link with Europe (Bujumbura to Paris)

3. Level of personal safety higher

4. Living standards more suitable

5. Future survey areas more accessible

6. U. S. Government presence stronger

C. Disadvantages

1. French speaking

2. History of tribal conflicts

APPENDIX C: LOGISTICS

1. This section is included for the purpose of preparing and aiding future workers in the area. It is drawn mainly from the author's experience in Tanzania, but may apply to other countries in the area (with the exception of Kenya). It is particularly applicable to anyone making a similar survey.

- a. Obtain government permission to work in the country prior to arrival. This may be a long process. Entering as, and functioning as, a tourist will greatly limit the areas in which you will be allowed to visit. Some official connections (U. S. Government, Food and Agriculture Organization of United Nations (FAO), etc.) will aid the process.
- b. Be as informed about the country as possible. Restricted areas, use of cameras, and dress codes are examples of things that you should know about.
- c. Purchase and ship well before departure virtually all of the equipment that you will need. The simplest items (vials) may be difficult or impossible to purchase in some countries.
- d. Air freight is usually more reliable than postal service. Only two of five boxes the author mailed to Tanzania ever arrived. Anticipate problems with Customs--import permission and fees, export permission and fees (even on items you imported), and red tape causing many delays.
- e. Currency may cause problems. The money of some countries is not accepted in other nations, not even at a fraction of official exchange rates.
- f. Recognize the unfortunate fact that being an American may be a disadvantage in some areas. You may even be suspected of being a CIA (Central Intelligence Agency) agent. Try to behave in a manner which will not make you more suspect.
- g. When first arriving in the country, expect that preparation for the field will take awhile. Red tape, etc., will cause delays, so do not expect to go immediately into the field.
- h. Establish a periodic contact system with the embassy, etc., before departing for the bush.
- i. Obtain the most reliable vehicle possible and carry some spare parts. Use a vehicle common to the area. The vehicle should be 4-wheel drive (absolutely necessary in many areas) and should have a hard top. Canvas-topped or open vehicles need constant protection to prevent theft of their contents.

j. Before departing for the bush (this may mean beyond the country's capital), buy large amounts of food. Such staples as flour, rice, and sugar may be difficult or impossible to obtain in the bush.

k. Try to be as self-sufficient as possible while on driving surveys. Lodging and restaurants may be rare, unsuitable, or nonexistent in many areas. Camping may provide a good solution. However, that is not without problems. It may be difficult to find a camp spot which is away from people. If you are near people, you may have to deal with the local political officials, as well as all of the villagers, who may come in large numbers to your camp and who do not know when to go home. Animal danger while camping is usually not a problem. Food stuffs and dirty pots will attract hyenas, which may steal those things. For hyena reasons and others, it is wiser not to sleep in the open when in high animal areas. Tents, even screened ones, may provide sufficient protection.

l. Check on the friendliness of local people. Most people of the areas are friendly, but exceptions do occur. The Masai of Ngorgoro Crater take sport in terrorizing tourists and park employees. They are most troublesome near camp areas. The park service provides armed guards in those areas.

m. Health precautions are necessary. Water purification tablets and a malaria prophylaxis are important. In schistosomiasis areas (most of the region), avoid water contact except with rubberized gear. Polyvalent antivenin is a wise addition to a well-stocked first-aid kit. This kit should contain more than would be necessary in the United States, since medical service is virtually absent from bush areas. Mosquito netting is very useful.

n. "White Fathers" (Catholic missionaries) often are hospitable priests. These people are excellent sources of local information. Many offer lodging in remote areas.

o. Be well informed as to the limitations and services of local transportation (air and boat). Printed schedules are usually out-of-date. Flights are often booked well in advance, yet frequently cancel. Many cities (including Kigoma) have dirt runways and are closed to air service during the rainy season. Attempt to know something about the safety of local carriers. Safety standards as we know them are nonexistent, or are not adhered to. Many forms of transportation, such as passenger boats on Lake Tanganyika, are notoriously dangerous.

p. On surveys, especially in remote areas, it is wiser for the researcher not to work alone.

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Exploration for natural enemies of Hydrilla verticillata in eastern Africa / by Robert W. Pemberton, U. S. Department of Agriculture, Agricultural Research Service, Southern Region, Gainesville, Fla. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
30, [22] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; A-80-1)
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