Hydrilla in Lake Izabal, Guatemala

Current Status and Future Prospects

A Final Report to USAID
Guatemala City
Guatemala

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List of Institutions Cited in this Report That are Involved in Resource Management In the Lake Izabal/Rio Dulce Area.

CONAP = Consejo Nacional de Areas Protegidas

AMSURLI = Autoridad Para el Manejo Sustentable de la Cuenca del Lago de Izabal y Rio Dulce

MARN = Ministerio del Ambiente y los Recursos Naturales

MAGA = Ministerio de Agricultura, Ganaderia y Alimentacion

USAID = United States Agency for International Development

USEPA = United States Environmental Protection Agency

USAC = Universidad de San Carlos de Guatemala

UVG = Universidad del Valle de Guatemala

UF = University of Florida, Gainesville, FL

Travel Itinerary
William T. Haller
USAID Consultation
University of Florida

Friday, Sep 6: pm Meet with Ministry of Agriculture, Scientific Commission, University, CONAP and other government officials and stakeholders.

Saturday, Sep 7: am Helicopter tour of Lake Izabal with Roberto Dorion, Alejandro Arrivillaga, Gilbert Daniels and Jorge Bosch. Flew perimeter of lake, boat tour on southern area near Los Limones.
pm Boat tour of upper Rio Dulce, eastern end of Lake Izabal. Sampling hydrilla, talking with stakeholders and Scientific Commission. Meet at CONAP with scientists and stakeholders.

Sunday Sep 8: Tour Golfete with Roberto Dorion, Luis Ferrate, Alejando Arrivillaga and Margaret Dix, members of the Scientific Commission. Find hydrilla in central and western Golfete and Potamogeton nodosus (?) in lower Rio Dulce/eastern Golfete.

Monday Sep 9: am Fly along the northern shore of Lake Izabal and delta of the Polochic River with Gilbert Daniels and Roberto Dorion, up the Polochic Valley to Guatemala City.
pm Meet with USAID

Tuesday Sep 10 am Prepare oral report
pm Meet with Ministry of Agriculture, USAID and Vice-President. Seminar at San Carlos University Museum.
Wednesday Sep 11 am Meet with local stakeholders and Scientific Committee members.
pm Return to Florida

Distribution and Ecology of Hydrilla

Hydrilla (*Hydrilla verticillata* (L.F.) Royle) has been described as the perfect aquatic weed. Introduced into North America via the aquarium trade from southeast Asia in the late 1950's, it was cultured and sold as an ornamental plant and spread rapidly in natural waterways of the southern United States in the 1960's and 1970's. Despite cessation of its commercial sale by the U.S. government, it continues to invade natural waters in the west, central and eastern USA. Current estimates for control efforts in the USA indicate mechanical, biological and herbicidal control efforts of $30 million/year, half of this sum spent in the state of Florida where hydrilla is a particularly serious problem in numerous mesotrophic, shallow lakes typical of that state (Langeland, 1996).

In Central America, hydrilla was found in Lake Gatun in Panama in approximately 1960 (Hearne and Pasco 1972), and became a problem in northern Mexico in agricultural canals and the Rio Grande in the 1980's. Hydrilla has also been reported in Venezuela and Colombia in northern South America.

Hydrilla is also widespread in Asia (India, China, Thailand, among others), and in Australia and New Zealand. Though not found in South Africa or Mozambique (C.D.K. Cook, Zurich, personal communication), herbarium specimens in the East African Herbarium (Nairobi, Kenya) indicate a long presence in East Africa, and apparently hydrilla has been in Lake Victoria for many years,possibly being native to central and east Africa. Hydrilla is not problematic in Africa probably due to herbivory by the large diversity of herbivorous fishes native to Africa

(Fred Bugenyia, NARO, Uganda, personal communication).

The native home of hydrilla is not known with certainty. Cook has reported that he believes hydrilla is native to the Indian subcontinent, which is particularly rich in hydrocharitaceae species, but is not strongly opposed to the theory that hydrilla may be native to east Africa. Hydrilla was also been reported in Europe early in the 1900's, most recently in Poland and Lithuania, but only isolated and small populations currently exist. Though classified as a single taxonomic species worldwide, recent enzymatic and DNA analyses suggests the existence of several "types" of hydrilla including monoecious and dieocious plants (Madeira et al. 1997). In summary, hydrilla is quite diverse and produces excessive growth causing problems in the western hemisphere, Asia and Australia, but is not a problem in Europe and Africa.

Hydrilla possesses some unique characteristics which are particularly suited to rapid growth in turbid, low carbon dioxide waters. Light being the most limiting factor prohibiting submersed plant growth, hydrilla can photosynthesize at light levels only 10-20% of levels required by other native submersed plants in North America. It has been shown to "store" carbon dioxide in air spaces and as organic acids derived from dark respiration for photosynthetic use the following day. In dense vegetated conditions where pH is high (> 9.0), it switches carboxylating enzymes to glean any remaining carbon dioxide from the water. Thus hydrilla can "outcompete" and dominate native submersed vegetation and can grow in deeper waters than native species. The depth at which hydrilla grows is directly a function of water clarity, and has been found growing in water 2428 feet deep with Secchi depths of 12-15 feet.

Hydrilla grows 2-4" per day under ideal conditions and produces numerous lateral shoots as it nears the water surface. Despite this rapid elongation and apparent rapid growth, hydrilla only produces a standing crop of less than a ton/acre of dry weight, being 92-96% water depending upon how long and thoroughly it is drained/dried for fresh weight/dry weight determinations. The excessive shoot production in the top 2 feet of the water column (70% of total biomass in top 2 feet) produces a dense canopy limiting light penetration to slower and lower growing submersed native species. This excessive surface growth, occurring in the littoral or shallow areas of waterways (0-10 ft + deep) is the area of heaviest recreational and fisheries use. Canals, reservoirs, rivers and lakes with shallow waters are particularly suited to excessive hydrilla growth. Some lakes in Florida, such as Lake Istokpoga (30,000 acres, average depth 7 feet) can be as much as 90% or greater covered by dense hydrilla growth.

Hydrilla greatly slows water flow in flood and irrigation canals, impedes recreational boating, commercial fishing, navigation in rivers and lakes, and can shut down hydropower and water cooled electric generating facilities. Dense hydrilla growth changes phytoplankton -zooplankton relationships which can

result in oxygen depletion and fish mortality. This submersed plant, when growing to the water surface, impedes wave action, provides additional habitat for snails and mosquitos, and serves as a temporary substrate for growth of other aquatic plants such as *Lemna, Eichhornia* and various grasses.

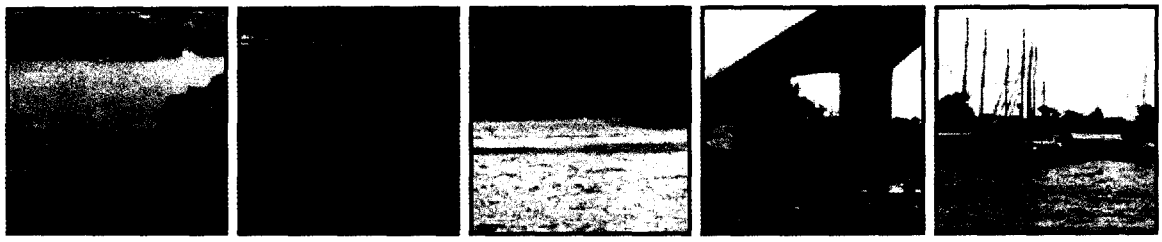
Hydrilla does not usually produce seeds, but spreads and grows from vegetative fragments and also produces specialized axillary and subterranean turions, often referred to as turions and tubers, respectively. These specialized vegetative buds make eradication very difficult, if not impossible, once hydrilla has been discovered in a large system.

Hydrilla in Guatemala

Herbaria records in Guatemala might show the earliest collections of hydrilla in Guatemala, but this is largely academic. Dr. Margaret Dix, University del Valle indicated that she had collected hydrilla outside the Polochic watershed in Guatemala in approximately 1990. Identification of hydrilla from Egeria and other species of the hydrocharitaceae is difficult, but I would expect that of the similar appearing hydrocharitaceae, only Egeria and hydrilla are present in Guatemala at this time. Of these, Egeria should not become a serious problem because it prefers somewhat cooler water temperatures than most hydrilla "types." Fishermen noted that hydrilla was first observed in Lake Izabal in approximately 2000. This date is approximately correct based on current characteristics of the distribution of hydrilla in Lake Izabal. Hydrilla is now occurring in many locations with some areas of growth approaching 400 to 500 acres in size. Other areas of less than 1 acre suggest hydrilla is in an early colonization mode. Likely, hydrilla was present in the watershed, in a pond or isolated area, in 1998 when floodwater from Hurricane Mitch moved it into the lake.

In Florida, as well as in Panama, the "type" of hydrilla is the dioecious female plant which only produces female flowers twice a year near the fall and spring equinoxes. Hydrilla in Lake Izabal was flowering during early September 2002 and no rhizomes suggestive of tuber production were located. Consequently I believe the hydrilla in Lake Izabal is the same type as that in Florida, Texas, Mexico and Panama. This could be confirmed by planting hydrilla in shallow pans in October to determine if tuber production proceeds during October through April, indicative of diecious female plants in the southern USA where hydrilla produces tubers during short day conditions (< 12-13 hours of daylength).

Hydrilla in Lake Izabal



Recent surveys conducted by Alejando Arrivillaga for the Scientific Commission and CONAP show over 2,000 ha (5,000 acres) currently growing in the 170,000 acre lake (Table 1). The lake is sustained by several rivers, primarily the Polochic entering Lake Izabal from the west. The lake outlet to the east is a heavily populated area, the Rio Dulce, which after approximately three to four miles widens into the Golfete. The Golfete is a large (15,000 Añ), shallow, and tidally influenced area which contains a manatee preserve and is largely surrounded by public lands. Further east, the Golfete narrows once again and passes through the "Gorges" area for approximately four to six miles emptying into the Gulf of Honduras at the City of Livingston. My visit coincided with the end of the wet season so water flows in the Rio Dulce were high with whirlpools and strong currents very noticeable wherever the river was narrow. For further hydrologic information please see Brinson and Nordlie 1975. During, and for a period after, the wet season the system from the shallow Golfete through the Upper

Table 1 Areas of Lake Izabal, upper and lower Rio Dulce and the Golfete as provided by Alejandro Arivillaga working for CONAP and the Scientific Commission.

Area	Km^2	Hectares	Acres
Lake Izabal	717	71,700	177,000
Upper Rio Dulce	8.1	810	2,000
Golfete	60	6,000	14,800
Lower Rio Dulce	5.6	560	1,380

Rio Dulce is essentially fresh water, with salinities sufficiently low for hydrilla growth. Additional data are needed on the salinity levels in the Golfete during the dry season (Nov-May). Hydrilla was present to the water surface in the upper Rio Dulce and western Golfete during September 2002, near the end of the wet season. It is possible that salinity will control this growth during the dry season, but it appears hydrilla will become a problem in the Golfete for two to three

months at the end of the wet season and persist until killed by saltwater intrusion in the dry season.

The water depth of the Golfete appears to be suitable for hydrilla growth, the limiting factor in this area will be the effects of salinity as hydrilla cannot tolerate extended periods in excess of 6 parts per thousand or 20% the salt concentration of seawater (Haller, Sutton and Barlow 1974). In my opinion, the Rio Dulce east of the Golfete is too deep and too saline for hydrilla to cause problems, though it may grow on and up creek deltas of inflowing fresh water in the lower Rio Dulce and interfere with local boat traffic. Research on the salinity during the wet and dry season and water depths of the Rio Dulce and Golfete will permit more accurate prediction of the future extent of hydrilla growth downstream of the Central Golfete.

Extent of Problem

At the current level of infestation, primarily in beds in Lake Izabal, hydrilla is causing relatively minor problems to fishing and transportation. Hydrilla is currently growing to water depths of 15 feet (ñ). If hydrilla continues to expand to cover the 15-18 foot contour of the lake bed, it is estimated that hydrilla will cover 10-15% of the lake surface (20,000 to 30,000 acres of the 170,000 acre lake). While this level of infestation appears small, it will cause access and navigation problems from villages and create problems for fishermen.

The major concern I have is if hydrilla were to establish in the upper Rio Dulce, near the river bridge, where marinas, transportation, and tourism will be severely impacted. Many people in this area rely on river transport for commerce, and tourism and recreation is a significant industry. Though water flow in this area is high during the wet season, flows are negligible during the dry season which will permit hydrilla to become established in these shallow waters. In fact, hydrilla beds were noted in the upper Rio Dulce and western Golfete during my visit. The Golfete provides access to the transportation and commerce center of the upper Rio Dulce and is likely to be severely impacted as well. It is these areas, the western Golfete and the upper Rio Dulce where I fear hydrilla will cause severe economic hardship. Hydrilla tolerates flowing water fairly well and water depths in a large portion of these areas are less than 15 feet. Extensive growth of hydrilla here will impact commerce, tourism and possibly even public health through mosquito production, but very little research is reported on the latter subject.

Hydrilla is currently too widespread to be eradicated from this system and Guatemala needs to be prepared for expansion of hydrilla into areas which would be economically impacted. While we can hope hydrilla does not spread further, historically it has. Continued expansion is likely.

Immediate Research and Monitoring Needs

The Scientific Committee and concerned Guatemalan officials and agencies have already initiated critically needed research, monitoring, and an evaluation of management options.

The following information is critically needed for decision-makers to be able to accurately predict the ultimate impact/expansion of hydrilla.

1. **Vegetation surveys** should be conducted at the end of the dry season and again at the end of the wet season for the next two to three years. A list of submersed aquatic species and the extent of hydrilla infestation will determine impacts on biodiversity and enable prediction of future hydrilla expansion.

2. **Development of a new bathymetric map**to accurately determine areas subject to hydrilla growth in the entire lake/river system based on water depths. The depth data we are currently using for the lake was developed by Brooks in 1969 and cited by Binson and Nordlie in 1974. While visiting the lake, I was informed that no areas of the lake are 50 ft deep due to extensive erosion as a result of hurricane Mitch in 1998. Based upon the old depth contours, we estimate hydrilla can grow in 10% to 15% of the lake, but we will be more confident in this prediction when it can be based on new bathymetric maps. Additional depth mapping should also be conducted on at least the Golfete and upper Rio Dulce.

3. **Fisheries surveys** should also be undertaken to determine the native and endemic species present and their approximate populations in the lake, Rio Dulce and Golfete. From what I could ascertain, over 100 species of fish inhabit the lake including Tilapia nilotica and Tilapia mossambica, omnivorous species, and several large predatory fish (snook). Documentation of the current fish population, and impacts of hydrilla on fish populations, will affect how we approach some possible long term weed management options (see later section on long term control). In addition, Cichlids are a very important food source and commercial fish to local inhabitants and need to be monitored, protected, and increased if these are found to be feeding on hydrilla.

4. **Salinity monitoring** in the Golfete will help determine the potential of hydrilla infestation in this area. It appears hydrilla will establish during the wet season at least in the western portion of the Golfete as it was found growing there in September 2002. Will salinity levels in the dry season control this hydrilla? If so, then we may concentrate control efforts to navigation channels in the western Golfete at the end of the wet season and

also concentrate management efforts in the upper Rio Dulce.

5. **Insect surveys** in and around hydrilla beds may be especially important to long term control efforts. Two reasons for insect surveys are noted:

a. There are two insects that feed on hydrilla and offer potential for possible reduction of hydrilla biomass. Paraponyx species are present in Panama and apparently were accidentally introduced into the USA (Buckingham and Bennett 1996). This species devastates hydrilla that we grow in experimental tanks, away from fish predation. We have to stock predators (small bluegill - Lepomis macrochirus) when we set up experiments to prevent Paraponyx from destroying our plants. Hydrellia pakistanae, the other insect which feeds on hydrilla, was discovered in Pakistan, studied, and released in Florida in the 1980's (Buckingham, Okrah and Thomas 1989). While this insect is not effective in the US, predation by fish may be the reason for the lack of high insect numbers. Are there aggressive insectivorous fish in Lake Izabal (see 2 above)? Are Paraponyx and Hydrellia already present in Guatemala? If so, this long term option may not be of consequence.

b. Insect surveys should also consider potential impacts of hydrilla on public health. The upper Rio Dulce is a center for commerce, tourism and is heavily populated. Both Denque and Malaria are present in this area and mosquito production in hydrilla has never been determined. If hydrilla were to become established in the Rio Dulce and found to increase production of vectors of these diseases, then it becomes imperative to undertake hydrilla management programs.

The reader of this report can now better appreciate the inter-relationships among these immediate needs and note the inter-relationships with long and short-term management options outlined in later sections. A thorough knowledge of the current biology of Lake Izabal is extremely desirable in developing long term, environmentally compatible management plans.

6. **Herbicide acute toxicity studies** on selected fishes of Lake Izabal. One of the short-term options outlined in later sections is the use of aquatic herbicides in high priority areas. The aquatic herbicides available for hydrilla control have been registered by the USEPA and have been used in the US and other countries for many years. Acute and chronic toxicity studies have been conducted on many aquatic species for aquatic registration, but it is unlikely that any data exists on the toxicity of these herbicides to cichlids. While I have no reason to believe there are any problems or acute toxicity concerns to cichlids, it is better to be certain as these data are easily and quickly collected. We have Tilapia aurea in Florida and have never noted any toxicity problems when treating hydrilla with these aquatic herbicides in Florida lakes inhabited by *Tilapia.*

7. **Baseline limnological studies** have been conducted at various times since the 1970's, but time and funds need to be committed for regular monitoring of the lake and its important components. Many in Guatemala consider Lake Izabal and the Rio Dulce the "Jewel of Guatemala." It is certainly one of the most beautiful and diverse areas that I have ever visited. Numerous individuals expressed concern for the future of the lake, citing agriculture, fisheries, sewage effluents, erosion, and population as concerns and threats to the ecological integrity of the area. Similarly, these have also affected aquatic ecosystems throughout the world. If tourism and commerce are expected to develop further in the Izabal/Rio Dulce area, an organized long term water quality monitoring program should accompany and compliment items 1 and 3 noted above. This discussion is not intended to simply consider only Lake Izabal or the Rio Dulce, research of the entire watershed is needed to determine practices and management options that will protect these waters.

SHORT TERM MANAGEMENT OPTIONS

While the current hydrilla infestation is causing problems in Lake Izabal, it has not invaded what I consider high priority economic sites. It is critical to be prepared for this event. This system is very large and dynamic in which it is impossible to predict with certainty the ultimate infestation. Short term options for weed management need to be considered and implemented where possible, as soon as possible. Thus, if hydrilla continues to expand, management options will be in place for rapid implemention.

1. **Mechanical harvesting provides immediate resolution of hydrilla problems for 3-5 months.**
The United States has decades of experience in mechanical harvesting of submersed aquatic weeds. Equipment used has varied from steel I-beams towed behind powerful boats to dredging and harvesting with 90 foot long harvesters. Typical equipment costs $100,000 to $300,000 and can harvest from four to twelve acres per day, depending upon disposal of the cut hydrilla. Utilization of hydrilla for animal feed, fertilizer, mulch, or for paper production have all been evaluated and are considered economically not feasible due to the high water content of hydrilla. Hydrilla often weighs 24,000 lbs/acre wet, but only 1,500 lbs/acre dry. Although no economically viable use for harvested vegetation has been developed in the US, this should not stop attempts to utilize the vegetation in Lake Izabal. Uses must be economially sustainable, and to date the uses have not been feasible for long term utilization, particularly in the humid tropics where vegetable matter is abundant.

There are almost as many mechanical harvesters as there are mechanical engineers. I recommend that Guatemalan officials visit locations in Florida and

other areas where harvesting is currently underway.

Advantages and disadvantages of mechanical harvesting systems are as follows:

Advantages:
- immediate clearance of hydrilla problem area
- used near potable water intakes
- used in flowing water sites where herbicides will not work

Disadvantages:
- often need additional equipment, conveyer, trucks, cranes
- operating costs vary with equipment
- high initial capital outlay
- non-selective, controls all native plants where used
- by-catch fish, amphibians, reptiles - the faster the machine, the more by-catch (Haller, Shireman and DuRant 1980)
- difficult to use in marinas, boat storage areas, anchorage sites
- limited by water depth depending upon size of machine
- fragments early infestations, spreading the problem
- must be big if used on Lake Izabal
- wind and waves reduce efficiency
- can cut 80-90" deep, hydrilla grows at least 1"/day, requires re-cutting
- see Haller 1998, and McGehee 1979

Despite the high cost and other disadvantages, mechanical harvesting is used in Florida, possibly on 3% to 6% of hydrilla areas controlled. In northern states, such as Wisconsin, Eurasian watermilfoil can be harvested once or twice a growing season (June-September) and this provides weed control for the high use summer months. Mechanical harvesting is not used more in Florida for hydrilla control, because in contrast to Eurasian watermilfoil, hydrilla grows throughout the year. This longer growing season for hydrilla requires that harvesting operations be conducted four to six times/year for effective control.

The key to successful harvesting is to have simple equipment, few moving parts, and it will have to be large to navigate the flows of the Rio Dulce during the wet season and of sufficient size to be safe and effective in the waves and winds of the lake.

Caution: It is easy to spend thousands of dollars on mechanical equipment. I have seen essentially new equipment in several countries stored unused due to poor design, lack of parts, or lack of operating funds.

To prevent this, should Guatemala lease equipment from the suppliers? build equipment locally? These and other options need to be considered.

2. **Application of USEPA registered aquatic herbicides.**
The proper use of aquatic herbicides provide three to twenty-four months of weed control that is usually more cost effective than mechanical removal. The difference in longevity of control depends upon the herbicide selected and hydrilla stage of growth at the time of application. The herbicides most widely used in the United States and registered there for aquatic use are the contact herbicides copper, diquat and endothall, and the systemic herbicide fluridone (Table 2). It is impossible in this report to provide detailed information on the specific use sites and application techniques. However, a generalized summary is provided. Herbicide labels are important sources of information and can be found on a manufacturers' website or at www.greenbook.net.

The contact herbicides are rapidly absorbed by hydrilla, as compared to the systemic herbicide fluridone which requires long exposure for hydrilla control. Despite this long contact time for fluridone, it is widely used in the US because it often provides one to two years of hydrilla control. Unfortunately, there are few places infested with hydrilla in Lake Izabal where fluridone will be effective due to high water exchange. If hydrilla moves into protected bays on the Lake and Rio Dulce, fluridone could possibly be effective applied during the dry season with split applications. The residues of the contact herbicides in water are also short relative to fluridone (hours, days compared to weeks). It is difficult to make generalizations on all four of these herbicides because they are very dissimilar. Consequently a few lines are devoted to each below:

Table 2. HERBICIDES REGISTERED FOR USE FOR HYDRILLA CONTROL IN THE USA

Herbicide (type)	Copper sulfate and chelated copper complex (contact)	Diquat (contact)	Endothall (contact)	Fluridone (systemic)
Activity on Plants	cell wall mem-brane enzymes	(oxidase) electron trans.	respiratory inh. cell membrane	carotenoid/photo inhibition
Hydrilla Exposure Time	2-4 hours	6-18 hours	10-36 hours	50-80 days
Typical Rate	1.0 mg/l	0.37 mg/l	3.0 mg/l	8-25 ug/l
Maxium Label Rate	1.0 mg/l	0.37 mg/l	5.0 mg/l	150 ug/l
Acute Toxity Values	470 mg/kg (rat) 44 mg/l (bluegill) 0.135 mg/l (trout) 17 mg/l (shrimp)	230 mg/kg (rat) 67 mg/l (bluegill) 67 mg/l (carp) 21 ppm (trout)	240 mg/l (bluegill)	> 10,000 mg/kg (ra 14,000 ug/l (bluegil
Water Half-life in	hours to few days	hours to few days	1-8 days	20-40 days

Closed Ponds				
Degradation by	chelation adsorption precipitation	photolysis adsorption microbes	microbial	photolysis microbial
Probable Use Sites in Lake Izabal	approved for potable water; potable water intakes; rapid flow area	most any location; can be combined with .2 ppm copper for better control	granular in deep water (bottom 6' at 3 mg/l); liquid in shallower water	only closed bays, coves with minima water flow; sugges use of SRP pendin further study; ver effective where it can be used

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Copper has been used for many decades for algae and weed control, and is a required micronutrient formulated into animal feed and vitamin supplements. It is approved in drinking water at 1 mg/l which is the maximum application rate allowed for aquatic weed control. Consequently, copper can be used adjacent to potable water intakes. It is also rapidly taken up by hydrilla and can thus be used where water is moving at a reasonable rate. Copper toxicity and chemical precipitation is greatly affected by water hardness. Hydrilla can recover quite rapidly from copper treatments (eight to twelve weeks). Copper is an element and does not biodegrade. It ultimately recycles in the ecosystem as it is required for plant and animal growth. Some copper becomes biologically inactive in the sediments.

Diquat was first registered as a herbicide in the mid-1950's and has been widely used for water hyacinth (*Eichhornia*), water lettuce (*Pistia*) and submersed weed control in the US (hydrilla, *Egeria* and *Potamogeton*). Formulated as a liquid, it is inactivated by colloids in very turbid water where it is adsorbed very strongly to clay and organic particles in the water column. It is then transported to the sediment where microbes ultimately break it down. The half-life of diquat in water is short but when bound to colloidial materials can be much longer. Hydrilla control with diquat is enhanced by the addition of 0.1 to 0.2 mg/l of copper. Hydrilla control with diquat can persist for three to nine months depending on water depth, flow, etc.

Endothall has two salts that are registered for aquatic use in the US, but I suggest we consider using only the potassium salt in Guatemala at this time. The other sale, the amine salt, is much more fish toxic and has to be applied by well trained applicators. The potassium salt of endothall is sold in granular or liquid form. When hydrilla is growing in deep water (> 12 to15 ft), the granules are applied at a rate of 3 mg/l calculated on the bottom 6 feet of water. The granules sink down to the hydrilla and provide control for three to nine months.

Fluridone was discovered in 1974 and fully labeled by the USEPA for aquatic use in 1986. Its use is very different from the previously mentioned herbicides because the application rates are much lower (ppb rather than ppm) and the time required for hydrilla to have received a lethal dose of the herbicide is much longer (weeks). Two formulations of fluridone, liquid (AS) and slow release pellets (SRP), are available in commerce. The slow release pellets, containing 5% fluridone by weight, are federally (USEPA) registered for use in quiescent and slow flowing rivers. There are not many locations in this system where fluridone will be effective. Hydrilla currently is growing, where rapid water exchange precludes extensive use of fluridone. However, fluridone is a very effective herbicide where it can be used correctly. It is most effective in ponds and lakes with little or no water exchange, but we have been able to split treatments and control hydrilla where limited water exchange occurs.

In general, the advantages and disadvantages of herbicide use would include:

Advantages:
- usually less expensive than harvesting
- can treat more acres/day, i.e. 15 to 20 acres per boat/day
- can apply around and near obstacles, marinas, boats, stumps, rocks
- weed control usually longer than cutting alone
- some selectivity, i.e. control hydrilla not *Chara, Vallisneria*, etc. (depends on herbicide)

Disadvantages:
- specialized training required
- expensive, $100 to 600/A
- innate fear of synthetic chemicals by the public
- limited by water flow
- set-back limits for drinking and irrigation for some products
- not enough selectivity, *Najas*, some *Potamogetons* are affected by all these herbicides

Due to the high cost of herbicides and mechanical harvesting, I would anticipate that only a small portion of the hydrilla in Lake Izabal will be controlled annually. Currently, there is no reason to control more than a few acres of the 5,000 acres of hydrilla in the lake, and this will be to provide navigation channels and access to populated areas. If hydrilla infests the area, high priority treatment areas will be in the upper Rio Dulce and Golfete. If hydrilla grows to the 15 foot contour of Lake Izabal, this will constitute approximately 15% of the lake, or 25,000 acres of the 170,000 acre lake. Navigation channels will have to be cut in the lake to provide access, but the major economic problem will be in the 5,000 to 10,000 A of the upper Rio Dulce and Golfete. In this latter location I would anticipate much more effort to be expended. It might be expected that total acres managed will be in the range of at least 2,000 to 3000 acres/year, to maintain

navigation and commercial activities, if hydrilla continues to expand its range in this system.

The most current data I have available on Florida hydrilla control is the 1988-90 time period when the state annually controlled an average of 12,800 acres of hydrilla per year. The cost of herbicide control averaged $470 per acre and mechanical control $550 per acre, but this includes labor and equipment costs. The average annual use of endothall was 89,000 pounds per year, 18,000 pounds per year of diquat (most on water lettuce?), and 11,000 pounds per year of fluridone (Nelson and Galloway 1991). Endothall and fluridone are used almost exclusively for hydrilla control in Florida. Consequently, large scale hydrilla management is not uncommon. Though not nearly as extensive, the states of North Carolina, South Carolina, Louisiana, and California also manage large areas of hydrilla.

Funding for aquatic weed control in the United States varies from state to state. The federal government provides 100% funding for aquatic plant management in large navigable river and reservoir systems, such as the Tennessee River, Mississippi River, St. Johns River (Florida), etc. Smaller rivers and lakes are the responsibility of individual states. As hydrilla expanded in Florida, in 1969 the state government dedicated 1% of the gasoline tax for hydrilla control. Some states add fees to fishing licenses, boats or boat trailers to provide funds for weed control.

The Lakes Izabal and Rio Dulce are so large and economically important to Guatemala that aquatic weed management funding and coordination would likely be the responsibility of a government agency.

It is suggested that the Guatemalan Ministry of Agriculture (MAGA) proceed by asking manufacturers for data and reviewing these herbicides for registration for aquatic use in Guatemala. Herbicide training and application is discussed in a later section.

The problem is that hydrilla, whether controlled annually with mechanical means or herbicides, continues to reappear and even infest new locations. Due to the high cost of short term hydrilla control, Guatemala must consider long term solutions.

LONG TERM MANAGEMENT OPTIONS

If hydrilla continues to expand its range and if funding for 2,000 acres of hydrilla control (~ $800,000 ñ) were available, only a small portion of the total hydrilla area would be managed, leaving many people, (fishermen?) feeling that not enough is being done. Large floating mats of hydrilla will break loose and

flow downstream during the wet season hindering boat traffic and snagging in marinas, and on boat anchorages. Despite the fact that a weed management program would be in place, hydrilla would not be fully controlled, and problems will still occur. Consequently, long term solutions have to be considered, and some of these may require harder decisions than the short term management options discussed above.

1. **Consideration of introduction or augmentation of Cichlid species**
Apparently the Lake Izabal system is rich in native cichlid species, and *Tilapia niloticus* and *Tilapia mossambicus* introduced into Central America many years ago are a significant part of the Fishery. Apparently the herbivorous *Tilapia zillii* are not present in the Polochic watershed, and though they have been introduced into many countries, none have been reported in Central America. (Note: The scientific names of some Tilapia have been changed to *Sarotherodon*.) *Tillapia zillii* are used for submersed aquatic weed control in heated effluents in power plants in the U.S. (Crutchfield et al. 1992).

The food habits of the common African tilapias are indicated in Table 3, along with records of introduction into Central America as of 1982. The major Sarotherodon species typically feed upon algae and organic detritus, and *T. zillii* and *rendalli* are considered more herbivorous.

Submersed aquatic plants are rarely a problem in the tropical regions of South America, Africa and Asia. This may be partially due to water quality, usually turbid water, and the presence of floating aquatic plants. I believe this is also due to feeding by herbivorous fishes in the cichlid and cyprinid families, which are common in tropical countries.

Table 3. Food habits and introductions into Central America as of 1982 of African tilapia and *Sarotherodon* species (Pullin and Lowe-McConnell 1982)

Species	Central America	Lake Izabal	what they eat
S. niloticus	Mexico	yes	algae, detritus
S. mossambicus	Nicaragua Mexico El Salvador	yes	algae, detritus
T. zillii	None reported in 1982; however, introduced into US	no	aquatic plants
T. rendalli	Mexico	no?	aquatic plants

* *T. rendalli* was introduced into Brazil, particularly hydroreservoirs

in San Paulo State with reports of overpopulation and destruction of vegetation. Similar reports from Colombia. However, in June 2002 I visited three reservoirs in San Paulo State (Brazil) and all were having problems with *Egeria.*

Submersed vegetation has never been reported as wide spread in Lake Izabal. Submersed plants have obviously never covered significant areas of this lake, despite some 10% of the lake being 4.6 m deep, or less (Brinson and Nordlie 1974). Is it possible that native or introduced herbivorous fishes have maintained submersed aquatic vegetation as a small component of the ecosystem? Is it also possible that Hurricane Mitch (1998) created so much erosion or other environmental disturbance that a year class or two of fish failed to recruit into the fishery in 1999 and 2000 (?). Has over fishing reduced populations of herbivorous species so that now hydrilla is able to expand? Likewise, if these herbivorous fishes re-populate, will hydrilla gradually decrease?

The fisheries survey listed above as an immediate and critical need will begin to answer some of these questions.

If *Tilapia zillii* is present in the Polochic watershed, it will not be difficult to raise significant numbers of these fish in cage culture for release into the lake augmenting existing populations. This will both increase herbivory on hydrilla, as well as provide additional fish for food and commerce.

Apparently *Tilapia rendalli* is an aggressive species and a voracious vegetation feeder. Both Brazil and Colombia expressed some reservations about introductions of this species and their current status in these countries is unknown.

If the fisheries surveys show that *zillii* or even other native herbivorous species (Caracidae) are present in low numbers, augmentation of these species should be economically very desirable.

Another family of herbivorous fish that need to be considered for reducing the density and coverage of hydrilla is the Characidae or silver dollar fish, which has some family members native to Guatemala. This family's center of origin is considered to be South America and various genera now occur from Northern Mexico to 14ø S in Chile. This family has some 800+ species (Berra 1981).

Yeo (1967) reported that two species of Caracidae family, *Metynnis roosevelti* and *Mylossoma argenteum*, grazed rapidly and readily on several species of submersed aquatic weeds. According to F. Chapman, University of Florida, Fisheries Department, these silver dollar fish cannot be placed into aquaria where aquatic plants are desired due to their eating habits. If these fish are already

present in Lake Izabal, they should be currently exerting an influence on hydrilla. If these species are not present, then they should be considered for possible stocking. The silver dollar fish are sold commercially throughout Central and South America and they attain an edible commercial size which may be acceptable to fishermen and consumers.

It is my opinion that we should try to utilize herbivorous fish species that are already naturalized in the Polochic watershed, or at least those species with close relatives in the watershed. Though difficult to predict, fisheries biologists should be able to determine with reasonable certainty the environmental risks of new fish introductions.

While visiting several beds of hydrilla in Lake Izabal and Golfete I noticed few if any young plants. Ordinarily when hydrilla is expanding you find the plants to the water surface and on the edges of the surfaced plants, plants 1-2 feet below the surface, further out 2-3 ft below the surface, etc. All the beds I noted were either surface matted or close to the surface. This was readily observed on the inside portions of the hydrilla beds where no hydrilla occurs in two to four feet of water. As you leave shore, you see bare bottom then suddenly a surface mat of hydrilla. Is it possible, as Yeo reported, that herbivorous fish in Lake Izabal readily eat the new growth first, least preferring mature plants?

Unfortunately, a list of fish species in Guatemala (HTTP://fishbase.org) indicates that neither *Tilapia zillii, rendalli,* the silver dollar characids mentioned are currently present in Guatemala.

If there are no herbivorous species in the watershed, then major and difficult decisions on non-native introductions will have to be evaluated.

2. **Introduction of the grass carp**
The grass carp (*Ctenopharyngodon idella*) is a strictly herbivorous fish of the Cyprinid family which is native to the Amur River between China and Russia. Since the 1960's it has been extensively studied and introduced into North America. It is tolerant of cold water conditions which has essentially prohibited the use of Tilapia in temperate regions of the world.

The sterile grass carp is made so by heat or pressure shock to fertilized eggs under controlled conditions, resulting in triploidy or sterility. These fish readily consume hydrilla, eating about their body weight of hydrilla per day at least until attaining a weight of 10-15 kg. Though they prefer hydrilla, they will consume most any submersed aquatic plant and are thus essentially non-selective.

This fish, stocked in large reservoirs in Texas and South Carolina (100,000 acres), has totally removed hydrilla and most other submersed plants. The fish **cannot** be stocked in numbers which provide "partial" control of hydrilla. As the

fish feed, they open holes in the hydrilla beds actually increasing the production of hydrilla by allowing room for hydrilla growth near the water surface. Alternatively, when stocked in sufficient numbers to overcome predation, the grass carp at 15 to 20 fish per acre of hydrilla will completely control hydrilla. Thus, if we have 10,000 acres of hydrilla in Lake Izabal, a population of 200,000 grass carp surviving and staying in the lake should totally remove over 99% of the hydrilla from the system.

In the US, 0.5 kg grass carp cost about $4/fish, so environmental impact aside, the capital outlay for grass carp will be in excess of $500,000. The grass carp live for 15 to 20 years and attain sizes of 20 to 30 kg in Florida. Currently, most states in the US do not stock grass carp into large, open ecosystems such as Lake Izabal. The reasons for this are:

a. Opposition by fishermen and many biologists against removal of large areas of submersed vegetation and destruction of native submersed plants.
b. Grass carp predation by fish, birds, reptiles and mammals in large systems is unpredictable, usually leading to gross overstocking.
c. Escape or movement of the fish through dams, locks and estuaries. Some grass carp would no doubt leave Lake Izabal and wander into the Gulf of Honduras and into other rivers and streams along the coast in the wet season, potentially migrating into waters of neighboring countries.
d. Difficult or impossible to catch and remove from stocked lakes and fish flesh is not highly valued in North America.

In the unliely case that Lake Izabal, Rio Dulce, and Golfete were to become totally covered (not likely) with hydrilla, the grass carp may become more economically and environmentally acceptable due to the devastation that 80 to 90% infestation levels cause. The grass carp can also be raised in cage culture in the lake if necessary and fed with mechanically harvested hydrilla until they grow to stocking size. Unfortunately, demand is unlikely for grass carp as a food fish, otherwise they could be raised on mechanically harvested hydrilla. The artificial spawning and culture of sterile grass carp is well developed by fisheries scientists.

I believe predation and escape of grass carp from Lake Izabal will be a problem but could be overcome by mass culture and release. Predation and escape can be estimated by stocking ten to 20 5-kg grass carp implanted with radio-tags and monitoring their movement in this system, similar to studies conducted in many locations in North America (Kirk et al. 2001).

One other possible concern with the triploid grass carp is that triploidy is not always 100%. Areas where grass carp reproduce are characterized by large rivers (Polochic?) in which fertile eggs remain suspended in water currents for 20 to 30 hours during which time they hatch into larval fish. The larval grass carp then

have to enter quiet water, preferably with aquatic vegetation, to escape predation and attain optimum growth (Lake Izabal?). I am unaware of any locations outside of Asia that grass carp have been introduced and have reproduced that this fish constitutes more than a small fraction of the total fish population (< 5%). This concern will need to be considered by qualified fisheries biologists.

3. **Introduction of Hydrellia and Paraponyx insects to reduce hydrilla density.**
As indicated in the critical research needs sections, the search for insect biocontrol agents for hydrilla has been aggressively pursued for three decades by Australian and US scientists. *Paraponyx* suddenly appeared in the United States in the 1970's, apparently introduced with aquatic plants, and is also common in Panama. Nevertheless, both Paraponyx and Hydrellia pakistanae do considerable damage to hydrilla when we raise hydrilla for research purposes in Florida. Unfortunately these insects have not reduced hydrilla populations under field conditions, probably due to heavy predation by native fish.

Ideally, these insects would remove hydrilla from the top meter of the water column, reducing biomass by 50% to70%. This will probably not happen, but these insects need to be considered for possible long term hydrilla biomass reduction.

The insect survey suggested above will likely find that*Paraponyx* is already present in Lake Izabal. The *Hydrellia* fly is host specific to hydrilla and should be evaluated for potential introduction into Guatemala. Any risks associated with these two and potential other hydrilla insect biocontrols should be minimal. Steps should be taken to import and study these insects as soon as possible.

SUMMARY

The short term management options are typically used wherever hydrilla is discovered and needs immediate control. Implementation in Guatemala will give scientists and government officials time to evaluate long term management options, which in reality have greater long term environmental implications. The key element in the above, particularly the long term options, are the fisheries, vegetation, and insect surveys. These will indicate three crucial elements on which decisions will be based:

1. Is the hydrilla going to continue to spread and to what extent will it impact the upper Rio Dulce and Golfete?

2. What fish are already present in the lake and in what numbers? If a native herbivorous fish is present in low numbers, will augmentation of the populations be feasible? Is this true of*Sarotherodon, Metynnis* and

Mylossoma species?

3. It is possible that the biocontrol insects would have less fish predation in Lake Izabal and be more effective in Guatemala than they are in the US? What insects are already present on hydrilla in Lake Izabal?

This report raises numerous questions regarding fish, insects, herbicides, harvesting, utilization, hydrilla spread and growth, and salinity. I recommend that as a followup to this report, that a scientific meeting be held in Guatemala to address the many issues needing further discussion. Scientific and governmental participants can clarify and direct research and management efforts in Guatemala once these crucial elements have been considered and resolved.

SCIENTIFIC COLLABORATION

I cannot formally commit the University to provide resources and long term assistance to the scientists in Guatemala, but can introduce and discuss the benefits that such a program can achieve. The University of Florida is interested in and committed to participation in mutually beneficial cooperative programs throughout the world. Several faculty in International Programs, Entomology, Geology, Fisheries, and Weed Science have expressed their desire to assist on the hydrilla program in Guatemala. Faculty and student exchanges, training, and scientific collaboration can be developed by appropriate administrative personnel.

I envision three immediate needs that will provide long term benefits in Guatemala.

1. A Guatemalan fisheries student(s) should pursue a graduate degree at the UF and learn fish culture/aquaculture techniques and conduct spawning studies of Tilapia and grass carp. Students might also participate in the surveys of fish in the Polochic watershed. Certainly some of these studies can be conducted by students at Guatemalan universities, but experience with sterile grass carp production can most effectively be learned at UF. See HTTP://cals.uf.edu and HTTP://fishweb.ifas.ufl.edu. Drs. Chapman and Watson, Fisheries Dept.

2. A Guatemalan Entomology student(s) should pursue graduate level research at the UF to learn aquatic insect identification, participate in insect surveys in Lake Izabal, and learn how to identify and culture Hydrellia and other potential biocontrol insects not currently present in Guatemala. See HTTP://ifas.ufl.edu, Dr. Jim Cuda, biocontrol of invasive plants.

3. A Guatemalan student(s) should attend UF in Agronomy- Weed Science

to learn and conduct research on safe and proper application of aquatic herbicides so this person can assist/train applicators in Guatemala. This student will become knowledgeable about mechanical and chemical means of hydrilla control and be taught limnology, taxonomy, plant physiology and terrestrial weed science. Knowledge in this subject area will assist Guatemala in developing and implementing other invasive plant research and control efforts. See HTTP://agronomy.ifas.ufl.edu. Drs. Haller, Langeland, Fox and Stocker.

I recognize and appreciate the excellent scientific and teaching faculty and facilities in Guatemalan universities. In my opinion, it would be expedient to work on the above projects at the University of Florida where *Hydrellia,* grass carp, and herbicide experience currently exists. Student training and research will effectively be undertaken at Guatemalan universities and institutes to address the many questions posed in this report. If it is determined that university faculty and government scientist training is preferred, then arrangements for visiting scientific exchanges (Florida and Guatemala) can be developed.

Also, there needs to be more scientific discussions, 4 days were not sufficient to cover these complex issues in detail.

APPRECIATION

It is impossible to thank all the individuals and agencies that provided assistance during my visit to Guatemala. It was a well organized and mutually educational experience. I look forward to returning soon.

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