Vogtia malloi, A NEWLY INTRODUCED PYRALID (LEPIDOPTERA) FOR THE CONTROL OF ALLIGATORWEED IN THE UNITED STATES

By

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By

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Vogtia malloi pastrana was introduced into the United States in the spring of 1971 as a biological control agent of alligatorweed, *Alternanthera philoxeroides* (mart.) Griseb. *Vogtia* populations were established and survived the winter as far north as Columbia, S. C., and as far south as Fort Lauderdale, Florida.

Vogtia populations dispersed randomly from release sites, and at one location in 1971 reduced the number of aerial stems/ft.^{2} from 52.5 to 4.0 in four generations.

Studies reported herein include: a canonical analysis which describes the insect-host plant relationship between

two insects and alligatorweed, the relationship between nutrient levels and alligatorweed growth, and a comparison of alligatorweed growing in lakes and in streams; a multivariate regression analysis which measures the significance of each of 12 measured variables in influencing the growth and spread of alligatorweed. Also included are measurements of alligatorweed productivity in greenhouse studies and in field plot studies during the spring and summer growth periods.

INTRODUCTION

Alligatorweed, Alternanthera philoxeroides (Mart.) Griseb., a vascular aquatic plant in the family Amaranthaceae, was probably introduced into the United States in the 1890's (Weldon 1960). In recent years alligatorweed has become one of the most troublesome weeds in fresh water ecosystems in the southeast, and by 1970 more than 66,000 acres were infested (Gangstad and Guscio 1970).

Alligatorweed may occur as a terrestrial plant in lowlands, as a semi-aquatic plant along streams or lake shores, or as an emersed aquatic plant. Floating mats which may extend 50 feet or more out over the surface of the water are formed of interwoven stems rooted near the shore. The stems are marked by nodes at intervals of about 2-6 in. each of which is capable of producing a new plant.

Most aquatic plants cannot compete with alligatorweed where it has been introduced and are quickly crowded out (Weldon 1960).

Alligatorweed is not as susceptible to herbicides as some of the other aquatic plants, requiring application at higher rates and shorter intervals.

The lack of a suitable chemical control and the alien status of alligatorweed led to consideration of biological control as a possible solution. In 1959 the U. S. Army

Corps of Engineers provided funds to the Agricultural Research Service, USDA, to explore the possibilities of importing natural enemies of alligatorweed capable of suppressing its growth and spread (Vogt 1960, Zeiger 1967, Maddox et al. 1971). As a result of these studies, three insects have been introduced into the southeastern region of the United States. A Chrysomelid beetle, *Agasicles hygrophila* Selman and Vogt, introduced in 1964 has been very effective in controlling alligatorweed in certain areas (Zeiger 1967, Maddox et al. 1971). *Amynothrips andersoni* O'Neill, a thrips, was introduced in 1967, and although still present in some release areas, it has not caused significant damage to alligatorweed (Maddox et al. 1971).

The release and establishment of the third insect, *Vogtia malloi* Pastrana, the so-called alligatorweed stem borer (Lepidoptera: Pyralidae: Phycitinae), is the subject of this dissertation.

LITERATURE REVIEW

Alligatorweed

Alligatorweed, also known as "Lagunilla" in South America, was probably introduced into the United States in the ballasts of sailing ships late in the nineteenth century. It was first recorded in Florida in 1894 (Weldon 1960). Mohr (1901) discovered the plant completely filling a creek near Mobile, Alabama in September 1897. He states that the source of the introduction was from the West Indies and Brazil.

According to Weldon (1960), the species was first described in 1826 as *Bucholzia philoxeriodes* Mart. and in 1897 it acquired its present name, *Alternanthera philoxeroides* (Mart.) Griseb.

Vogt (1960) studied over 1500 herbarium specimens of *Alternanthera* and related genera including approximately 80 species of *Alternanthera*.

Penfound (1940) described the anatomy and the life history of alligatorweed along with its aquatic growth habits in Alabama while Arceneaux and Herbert (1943) reported on alligatorweed growth in the cultivated fields of Louisiana.

Weldon (1960) extensively reviewed the literature concerning past chemical and mechanical controls for alligatorweed.

Vogtia malloi

The moth Vogtia malloi (Pyralidae: Phycitinae) was named in 1961 when Jose A. Pastrana described it as a new genus and species. Vogtia may be recognized by the following characteristics: large labial palpi, three times the diameter of the eye, pointing forward with loose, thick scales and an obtuse third joint; no maxillary palpi are present; ocelli are present; the front wing has smooth scales, a slightly curved edge, and ten veins. The wingspan is 20-22 mm and the wings are straw-colored, dashed with brown scales on the edge and tip of the wing.

This insect was discovered by George Vogt in his surveys in South America for natural enemies of alligatorweed for possible introduction into the United States. Vogtia was one of the four insects considered by Vogt (1961) as a major suppressant of alligatorweed in South America. He found that Vogtia was almost coextensive with alligatorweed, both geographically and ecologically occurring as far south (La Plata, Argentia) and as far north (Georgetown, British Guiana) as his survey extended.

Vogt (1961) reared Vogtia from Alternanthera philoxeroides and from Alternanthera hassleriana, the plant he considered most closely related to alligatorweed.

Field observations in Argentina and starvation tests in the laboratory (Maddox and Hennessey 1970) indicated that *Vogtia* could not complete its life cycle on plants outside the genus *Alternanthera*. Plants were selected for feeding tests on the basis of their taxonomic relationship to or ecological association with alligatorweed, or their economic importance. In field observations (1962-1967) 51 native and introduced species of plants were examined for feeding damage by *Vogtia* and 30 plant species were examined in starvation tests for larval feeding and survival (Maddox and Hennessey 1970).

Biology

Egg---Eggs are deposited singly on the upper portion of the aerial stems of alligatorweed. The average length and width of *Vogtia* eggs was 0.69 mm and 0.37 mm respectively (Maddox 1970). When the egg was first deposited, it was opaque white; as it aged it gradually changed from white to light yellow to amber. The head capsule was visible through the chorion usually after the second day. Maddox (1970) reported the average incubation period was 3.6 days at an average of 32.9°C and 41.4 % RH.

Larva---According to Maddox (1970), head capsule measurements indicated that there were five instars. The first stage larva was approximately 2.25 mm long with a dark brown to black head capsule about 0.27 mm in diameter (Maddox 1970). In later stages the head capsule was brown to light tan, and tan wavy longitudinal lines appear on the dorsum and pleura of the thorax and abdomen. The mature fifth stage larva averaged 13.7 mm long with an average head capsule width of 1.25 mm (Maddox 1970). Larval development required 24 days at 23^{O}C and 64 % RH (Maddox 1970).

Prepupa--As with most holmetabolous insects, a relatively inactive larval period immediately preceeded pupation. The larva becomes shorter, thicker, and may appear greenish in color at the time the cocoon was constructed.

Pupa--The pupa was amber or light tan when first formed. It gradually turned a dark brown or almost black just prior to emergence. Pupal length varied from 9 to 10 mm and the width from 1.5 to 2.0 mm (Maddox 1970). The pupal period averaged 9.5 days at 23.3^{O}C and 49.7 % RH (Maddox 1970).

Adult--The adult is approximately 13-14 mm long with light tan scaled (both sexes). Variation occurs in both the size (females are usually larger) and in the definition of the color patterns of the adult moth. Females often have scales with a reddish tan hue forming indefinite patterns, and the males often have black or gray scales forming definite spots along the front margin and tip of the wings.

METHODS AND MATERIALS

Biology and Behavior of *Vogtia malloi*

Fecundity and Fertility

In laboratory studies newly emerged adults were confined in pint and gallon ice cream cartons covered with a fine mesh net. One female and two males were placed in each container and fed a 1:10 honey-water solution. There were 10 replications using the pint containers and 25 replications with the gallon containers. Eggs were deposited on the net covers which were changed daily and the eggs counted. The temperature and RH were maintained at 27°C and 72 %.

To determine hatchability, as an indicator of fertility, 447 eggs collected from the moths in the gallon containers and 1079 eggs collected from the pint containers were held at 31°C and 60 % RH for 6 days. After 6 days the unhatched eggs were removed and counted.

Oviposition

To duplicate natural conditions in the placement of *Vogtia* eggs for field releases it was necessary to determine the ovipositional preference of the female moth.

One male and two female adults were confined in a 15 X 15 X 18 in. screen cage which contained a bouquet of 10 to 15 alligatorweed stems in water.

Egg and Larval Mortality

Studies were conducted at Lake Lawn, Orlando, Fla. to determine the percentage of (1) the eggs oviposited that hatch and (2) the larvae that survive and successfully enter the stems of alligatorweed. One hundred *Vogtia* eggs were placed singly with a camel's hair brush in the axils of therminal leaves at the rate of 1 egg per stem, along about 30 linear feet of a continuous mat of alligatorweed. These stems were then marked with red flagging tape for later recovery. Five days later, the number of surviving first instar larvae was determined by locating the marked stems and recording the number of plants injured within a radius of about 10 in. around each flagged stem.

In a separate study at Lake Alice *Vogtia* eggs in groups of 50 or more attached to strips of cloth were pinned to stems of alligatorweed to detect and collect egg parasites. The eggs were left in the field for two days, after which they were collected and held in the laboratory for emergency of moth larvae on parasites.

Larvae, prepuase, and pupae collected from the Lake Alice samples were removed to the laboratory where they were observed for parasitism. In this study, approximately 250 larvae and 45 pupae or prepupae were collected.

Greenhouse Colony

Permission to release *V. malloi* in the United States was obtained in 1970. Pupae or eggs were collected from the Buenos Aires area of Argentina, an area with climatic conditions similar to the gulf coast states, and shipped to the USDA quarantine facility in Albany, California. One generation of *Vogtia* were reared at the Albany laboratory to exclude parasites and diseases. Eggs collected from that laboratory were shipped to the USDA laboratory in Gainesville, Florida where a greenhouse colony was established on alligatorweed growing in water tables to obtain sufficient numbers for field release.

Vogtia was first released in Florida in the spring of 1971 and later in the year in Georgia, North Carolina, and South Carolina.

In 1972 specimens were collected 450 km south of Buenos Aires, the latitudinal equivalent of Richmond, Virginia, to broaden the genetic base of populations already established and perhaps obtain a more winter-hardy strain.

Specimens from the southern area of Argentina were released at Fort Jackson (May 10, 1972), Twin Lakes (July 12, 1972), and Garden's Corner, S.C. (May 20, 1972). *Vogtia* from this colony were also released in Tennessee Valley Authority projects and in North Carolina by individuals employed in these areas.

Field Releases

1971

During the summer of 1971, Vogtia were released at the following locations (Fig. 2): Lake Lawn, Orlando, Fla.; Lake Alice, Gainesville, Fla.; USDA Plant Introduction Station, Savannah, Ga.; Black Lake, Melrose, Fla.; Fort Pierce, Fla.; Ashapoo River at Hwy. 17, S.C.; Savannah River, near Savannah, Ga.; unnamed ditch, Gainesville, Fla.; Santee Reservoir, near Lone Star, S.C., and Greenfield Lake, Wilmington, N.C. Populations at the Ashapoo River, the Savannah River, and the unnamed ditch sites were destroyed by flooding, and the Fort Pierce site was destroyed by dredging.

Lake Alice, Fla.-- At Lake Alice, on the University of Florida campus, conditions were similar to those found at Lake Lawne, i.e. high nutrient levels and a luxuriant growth of alligatorweed. The Vogtia releases were made in a small stream, about 20 ft. wide flowing into Lake Alice from a sewage treatment plant. At the time Vogtia were released, alligatorweed extended out 5-10 ft. from the banks on either side of the stream for a linear distance of about 100 ft. A similar area, about 150 ft. upstream from the release area, was designated as a control area. No Vogtia were released there and there was no attempt to prevent the spread of Vogtia to this area.

On May 18, 1971 small strips of cloth (ca. 2 $in.^2$), on which Vogtia eggs had been deposited (a total of 64), were

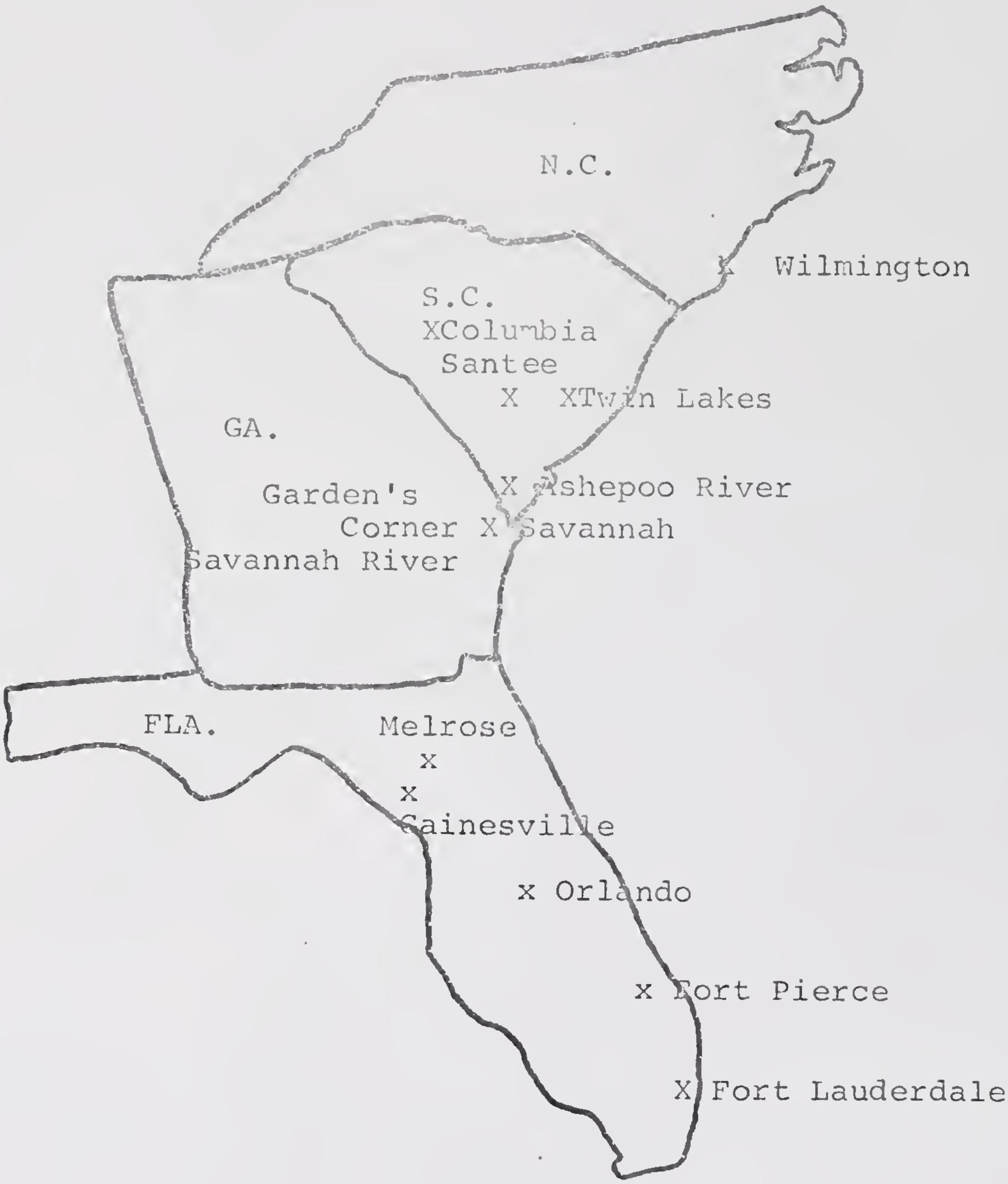

Fig. 2. <u>Vogtia</u> Release sites, 1971 and 1972

taped to apical tips of alligatorweed. A second release on June 6 consisted of 81 eggs or newly hatched larvae (ca. 10 of the eggs had hatched). In this release the strips of cloth were pinned to the aerial stems in a yd^2 area near the shore. Additional releases of 200 eggs on July 20 and 580 eggs on July 26 were made as in the second release. These releases were made a few yards upstream from the first two.

The Vogtia population was sampled during the larval period of each of the 4 generations which occured at this site following the original release (sample dates: July 5, August 28, September 29, and October 26). A sample consisted of a 1-$ft.^2$ area of alligatorweed, from which aerial stems were removed and counted. Samples taken on July 5 were evenly spaced along arcs 1 yd. and 4 yds. out from the point of release. Seven samples were taken along the 1 yd. arc and 5 were taken along the 4 yd. arc. Subsequent samples were taken by randomly throwing a $ft.^2$ wooden frame on the mat of alligatorweed at 15 ft. intervals along either side of the stream.

On January 27 after the first frost the Vogtia population was checked to determine mortality due to cold and again on May 2 to determine winter survival. These samples were taken by randomly selecting injured stems.

Lake Lawne, Fla.-- Lake Lawne is a 33 acre lake located in Orlando, Florida. Sewage effluent from the surrounding community drains into the lake creating severe nutrient pollution which contributes to the luxuriant growth of alligatorweed extending out 50-60 ft. from the shore in some areas at the time of the releases.

On April 5 and May 20, 1971, 232 and 150 eggs respectively, were placed on alligatorweed in the northwest corner of the lake. Small strips of cloth, each with 10-15 Vogtia eggs attached, were taped to aerial stems. Five days later the eggs and stems were inspected. On June 23, a 2 x 4 ft. section of alligatorweed mat was removed from the lake and replaced by a Vogtia-infested mat of the same size from the greenhouse colony. The infested mat and the surrounding alligatorweed were inspected weekly to determine the number of Vogtia larvae persent. Releases of adult Vogtia were made in the same general area on July 23, August 13, August 18, and August 26 of 10, 7, 40 and 21 moths, respectively.

The Vogtia population was monitored periodically by counting the number of injured plants in the release area.

Black Lake, Melrose, Fla.-- Alligatorweed growth on this 20-25 acre lake was much less vigorous than at other sites when Vogtia were released. The stems were smaller and more fibrous and the alligatorweed supported several (Sacciolepis striata (L.) was the dominant species) species of grass and weeds. The lake was encircled by alligatorweed mats 5-20 ft. wide. On August 20, 1971, 19 adults were released in a 3-ft.^{2} screen cage placed on the alligatorweed mat. Seven days later after the moths had completed oviposition the cage was removed. No further releases were made at this site. Counts of larvae or wilted tops were made November 15, 1971 and January 28, February 11, and April 17, 1972 from randomly selected sites.

Savannah, Ga.-- The only release at the USDA plant Introduction Station consisted of *Vogtia* eggs placed in 3 screened plots (5 X 6 ft.) containing terrestrially-rooted alligatorweed by Mr. Willey Durden on April 14, 1971 (Willey Durden, personal communication).

Greenfield Lake, Wilmington, N.C.-- *Vogtia* eggs and larvae were placed in a small stream 20-30 ft. wide flowing into the northern end of the lake. The stream was completely covered by a solid mat of alligatorweed for several hundred feet. On August 2, 1971, a 4-$ft.^2$ section of mat was removed and replaced by a *Vogtia*-infested mat of the same size from the greenhouse colony. The mat was wrapped in 6 mil polyethylene and a small amount of water added for transporting.

Santee Reservoir, S.C.-- *Vogtia* were released on the south side of the reservoir, near the town of Lone Star. Alligatorweed at the release site appeared as rooted plants in shallow water. The stems were small and fibrous, a condition often observed in rooted alligatorweed. On August 3, 1971, a 2-$ft.^2$ section of *Vogtia*-infested mat from the greenhouse colony was placed in the stand of alligatorweed after a section was removed.

Field Releases

1972

Releases were made in 1972 at the following locations: Fort Jackson (Upper Legion Lake, Columbia, S.C.), Twin Lakes, S.C., Peeples' Pond (Garden's Corner, S.C.), and a roadside ditch (Fort Lauderdale, Fla.) (Fig. 2).

Fort Jackson, S.C.-- Upper Legion Lake is a small man-made lake (10-15 acres) ringed with alligatorweed extending out 5-20 ft. from the shore. On May 10, 72 larvae were released on the east side of the lake, by placing them individually, with a camel's hair brush in the terminal leaves of alligatorweed stems.

During the summer, 1972, the Vogtia release site was subjected to malathion fog, used in mosquito abatement, and to Diquat at 2 lbs./acre sprayed in alternating strips. The Vogtia population was sampled September 11 and November 15, 1972 and June 16, 1973.

Twin Lakes, S.C.-- Twin Lakes consists of two ponds, about 5 acres each, connected by an old riverbed and located near Summerville, S.C. Alligatorweed normally covers all but a small area in the center of both ponds.

On July 12, 100 adults were released in the northermost pond where alligatorweed was 16 to 18 in. tall in relatively dense stands. The Vogtia population was sampled on September 12 and November 15, 1972.

Garden's Corner, S.C.-- Peeples Pond is approximately 10 acres in size and ringed with alligatorweed extending

20 - 30 ft. out from the shore. On May 20, 150 *Vogtia* eggs were placed on the aerial stems of alligatorweed and 25 adults were released.

Both *Agasicles* and *Vogtia* populations were sampled on July 13, and September 11, 1972 and June 16, 1973.

Fort Lauderdale, Fla.-- On April 19, 85 first instar larvae collected in the wilted tops of alligatorweed at the Melrose, Fla. (Black Lake) site were released in the road-side ditch (20 to 30 ft. wide) alongside the Sunshine State Parkway 1/2 mile north of exit 16. Three months later, July 18, 125 adults from the greenhouse colong were released in the same general area. Alligatorweed grew luxuriantly along the ditch for approximately 0.5 mile on either side of the release site.

The *Vogtia* population was sampled July 18 and September 20, 1972 and April 26, 1973.

RESULTS AND DISCUSSION

Biology and Behavior of *Vogtia malloi*

Fecundity and Fertility

According to Maddox and Hennessey (1970), the female moth lays an average of 267 eggs with 6, 34, 18, 15, 12, 6, 5, and 4% of the total laid from the first through the eighth day, respectively.

In laboratory studies 25 female moths held in gallon containers laid only 132 eggs (average). The adults used in the test were taken from a crowded greenhouse colony and may reflect a reducted activity due to crowding. This study confirmed Maddox's findings that the greatest percentage (69) of the eggs were laid on the second day following emergency (Fig. 1). Although some eggs were laid on the first day, most were apparently infertile and did not hatch.

Only 84.3% of the eggs collected from moths in gallon containers hatched. Of 1079 eggs from moths in pint containers, the percentage was only 49.7%, presumably from a lack of mating in the small containers.

A mated female, held for observation in a pint container, laid 47 eggs in one period which began at 11:00 PM. The average time interval between eggs was 17.3 seconds.

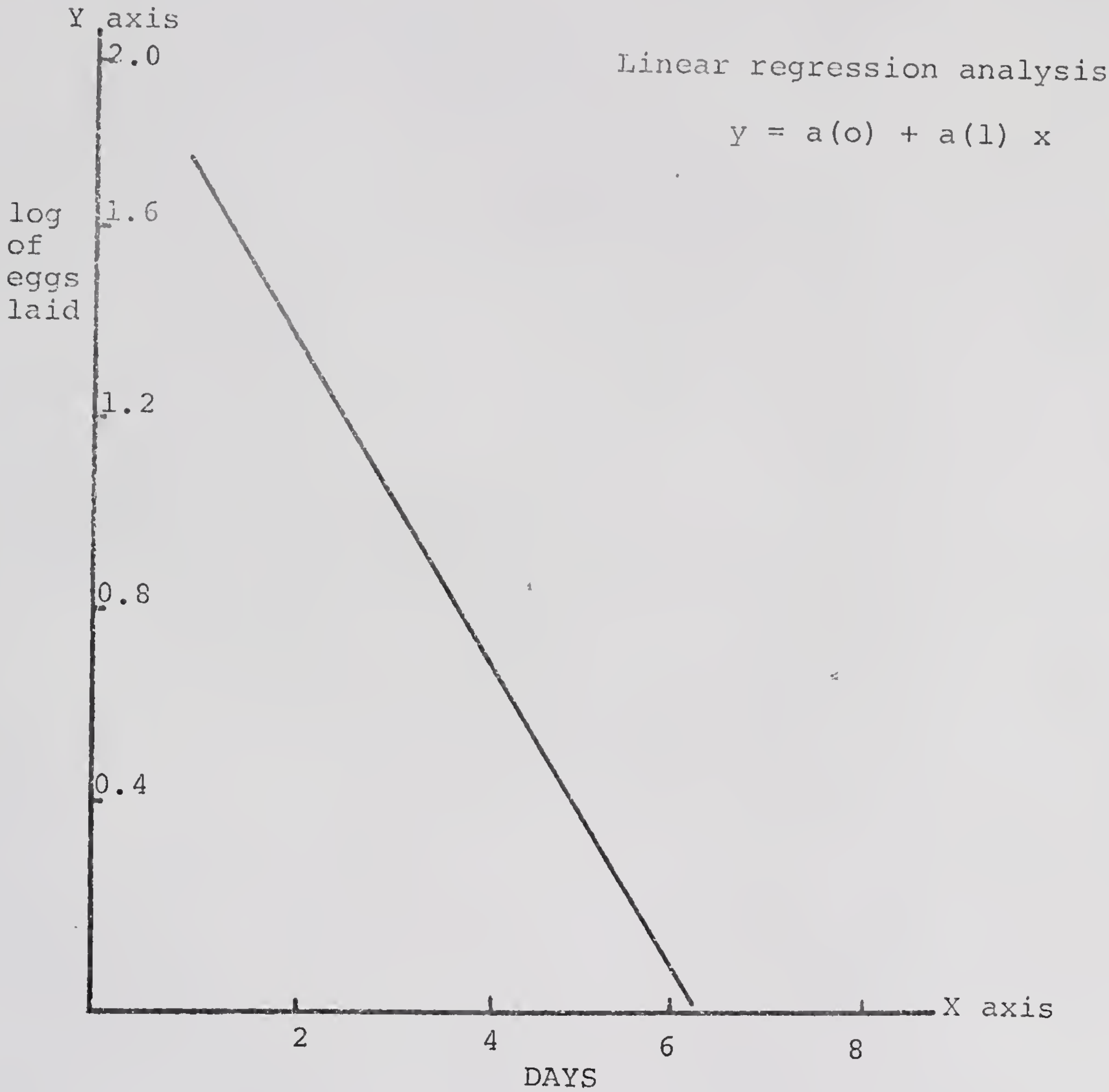

Fig. 1. Log number of *Vogtia* eggs laid plotted against time.

This moth was very active during oviposition, flitting around the container and stopping only long enough to deposit an egg.

Oviposition

Most of the eggs (60.6%) were deposited on the underside of the terminal leaves, with progressively fewer eggs being placed on leaves of the lower nodes (Table 1). These data confirmed Maddox's earlier report that eggs are deposited on the underside of a leaf in the first through fourth pairs of apical leaves on the host plant.

Table 1. Egg placement by *V. malloi* female moths caged over alligatorweed.

	Margin	Midrib	Axil	Total	% Total
Terminal leaves	17	19	24	63	60.6
Below 1st node	3	8	8	19	18.3
Below 2nd node	4	4	7	15	14.4
Below 3rd node	2	1	4	7	6.7
	26	32	43	104	

Egg and Larval Mortality

The expected egg viability as indicated by laboratory studies was 85%. The number of damaged stems recorded indicated that 41% of the eggs produced larvae which caused visible injury to the alligatorweed stems, leaving 44% of the *Vogtia* eggs or larvae lost to predation or other environmental factors.

Several specimens of the egg parasite Trichogramma perkinsi Girault (identified by L. R. Ertle USDA) were collected from the Vogtia eggs attached to alligatorweed for 2 days.

Six internal parasites belonging to 2 species of ichneumonids were reared from the Vogtia larvae and pupae collected from Lake Alice: 4 were Gambrus bituminosus (Cushman) and the other 2 were G. ultimus (Cresson) (determi-ed by R. W. Carlson USNM). Both species have been collected from a number of Lepidoptera in the United States (Muesebeck et al. 1951).

Behavior

Upon hatching, the first stage larva enters and girdles the alligatorweed stem, usually at the second internode. Later in the season, the aerial stems may become tough and fibrous, and the young larvae may descend on a silk strand to the axillary shoots growing farther down the stem which are still tender (Brown and Spencer 1973).

Within a few hours, the girdled top is wilted, and within a few days it usually breaks off at the node just below the girdle and falls onto the supporting mat of alligatorweed with the young larva still inside. The larva soon leaves the dead top and bores into another stem, or the same stem at a lower level, and the process is repeated.

As the larva matures the process of girdling and feed-ing on the interior of the hollow stems above the girdle may be repeated many times (as many as 9 stems were reported destroyed by a single larva, Maddox 1970). The mature larva is known as a roving stem borer because of its characteristic feeding habit. The larger the larva, the farther down the stem it girdles, and frequently mature larvae are found feeding below the water line, protected from drowning by the air-filled cavity of the hollow stems.

When the *Vogtia* larva bores into a stem it quickly seals the entry hole with silk strands to make it waterproof. The exit holes however are never sealed leaving the plant open to attack by other organisms.

Just prior to pupation the mature larva enters an internode and seals off both ends at the nodes. A small "window" is chewed in the stem wall, leaving only a thin layer of the outer epidermis intact. The larva spins a cocoon and orients itself so that the head region is adjacent to the window, through which the adult will eventually emerge.

Field Releases

1971

Lake Alice, Fla.-- Larval counts taken at Lake Alice (July 5) along arcs 1 yd. and 4 yds. from the release area were not significantly different, and no directional movement was indicated; the mean number of larvae/ft.^{2} along these arcs were 5.4 and 5.2, respectively. The standard deviation of insect counts in the 12 samples was 2.84. The population, within this limited area was distributed with $\overline{X} = 5.3$, $S^2 = 8.06$, $S^2/\overline{X} = 1.52$, and $K = 10.19$. Adult dispersal appeared to be random. Counts from later samples indicated that the population expended at a nearly uniform rate in all possible directions with each new generation. Population density increased to 9.4 larvae/ft.^{2} by the second generation in the immediate release area and then began a steady decline as the attractiveness of the alligatorweed was reduced and the number of available egg deposition sites diminished (Fig. 3).

During the first two generations the area of infestation was not significantly expanded based on observations of wilted tops. The mean number of healthy aerial stems of alligatorweed/ft.^{2} was reduced from 52.5 to 36.9. An invasion of the test area by the southern beet webworm, *Herpetogramma bipunctalis* (F.), occurred during the second generation which resulted in partial defoliation of many of the aerial stems. Although webworm damage was temporary, it may have influenced the observed movement of *V. malloi*

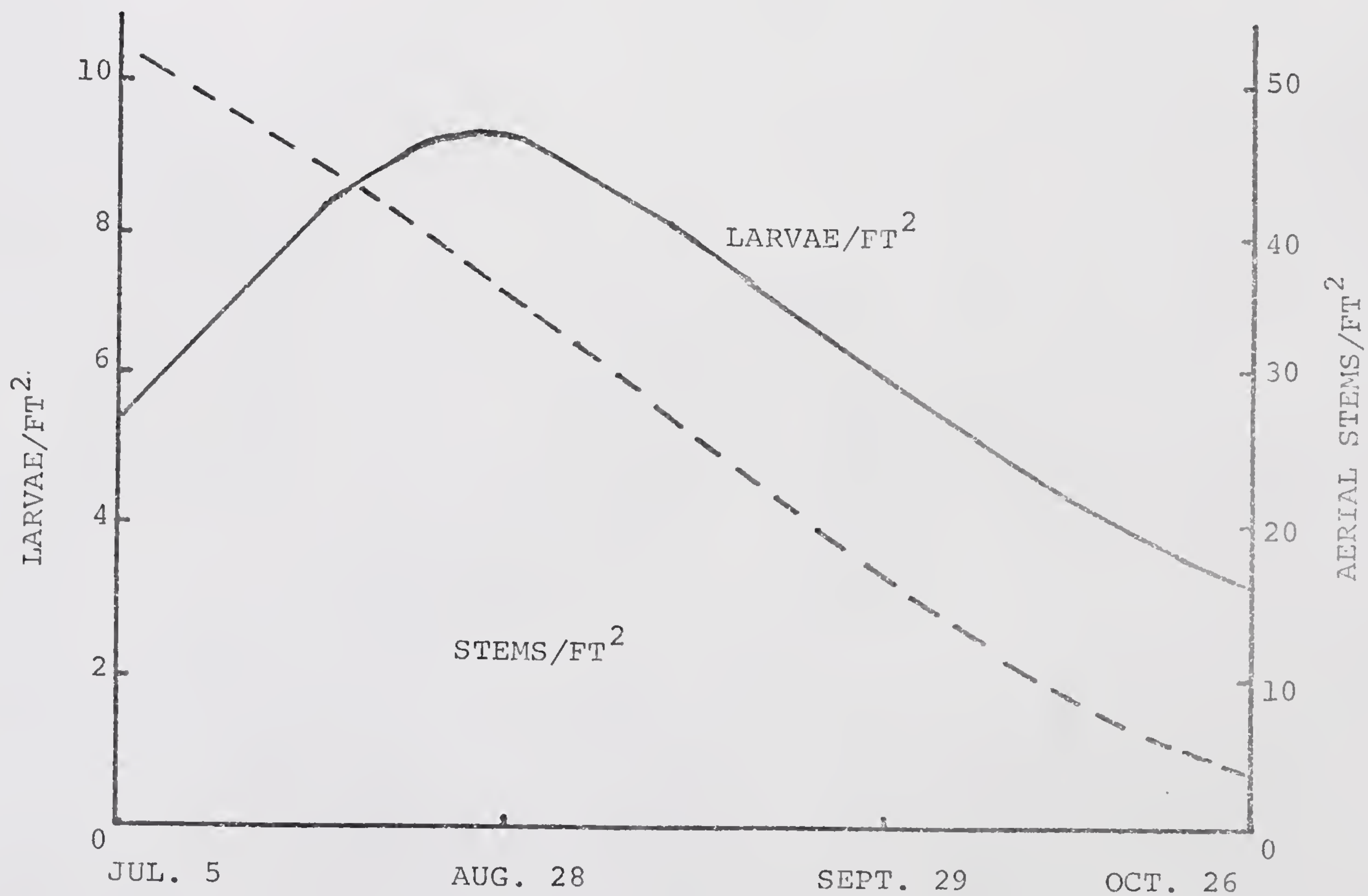

Fig. 3. _Vogtia_ population build-up and its effect on alligatorweed, Lake Alice, 1971.

adults from the release area to the nearby control area during the second generation, a distance of 150 yds.

In the third generation samples (September 29), the number of larvae.ft.^{2} had dropped to 6.3, with the number of healthy aerial stems reduced to 17.4/ft.^{2}. By the middle of the fourth generation (October 26), the mean number of larvae and aerial stems/ft.^{2} had dropped to 3.4 and 4.0, respectively. With this damage the alligatorweed mat was beginning to break up in the release area and was no longer increasing. Other semiaquatic plants began to move in over the submersed portion of the alligatorweed mat.

A one-way analysis of variance showed that the reduction in the number of aerial stems between sample dates was statistically significant (0.01 level) but there was no significant difference between insect counts for these dates, probably due to the wide variation between samples.

The January 27, 1972 data consisted of superficial observations only. The lack of alligatorweed stems due to the cold and to Vogtia and Agasicles damage made detailed samples impractical. Ten first and second instar larvae collected from wilted stems in 2 small mats of alligatorweed were not in diapause, but were actively feeding.

On April 25, 1972, the alligatorweed had attained a height of 15 in. when the Vogtia population was sampled. The mean number of larvae/ft.^{2} was 3.3 at the release site; therefore a substantial number of Vogtia survived the winter.

In 1972 the Lake Alice population duplicated the 1971 response, i.e. the Vogtia population peaked at about the same density and then began a decline (Fig. 4).

Lake Lawne, Fla.-- The first releases made in this area (April 5 and May 20, 1971) were probably unsuccessful since no damaged stems were found, a result of the newly hatched larvae becoming entangled in the tape. The second attempt to establish a Vogtia population in Lake Lawne (June 23) was likewise unsuccessful; no larvae were found after the first week. Most of the Vogtia present in the infested alligatorweed were probably drowned due to flooding of the cut stems. A few larvae were found the following week but they apparently did not survive to reproduce. On July 23, 10 adults were released at the same location from which a small larval population became established. Three additional releases were made in August to supplement the population.

The Vogtia population did not expand its numbers rapidly. The population remained at low levels (ca. 0.1 larvae/ft.^{2}) and larvae were never found more than 50 yd. from the point of release during the summer of 1971. At Lake Lawne where no frost occurred the alligatorweed remained green throughout the winter. On May 21, 1972 the population had increased to 3.7 Vogtia larvae/ft.^{2} in the release area.

Black Lake, Fla.-- Only one release of 19 adults was made at this site on August 20, 1971. On November 15

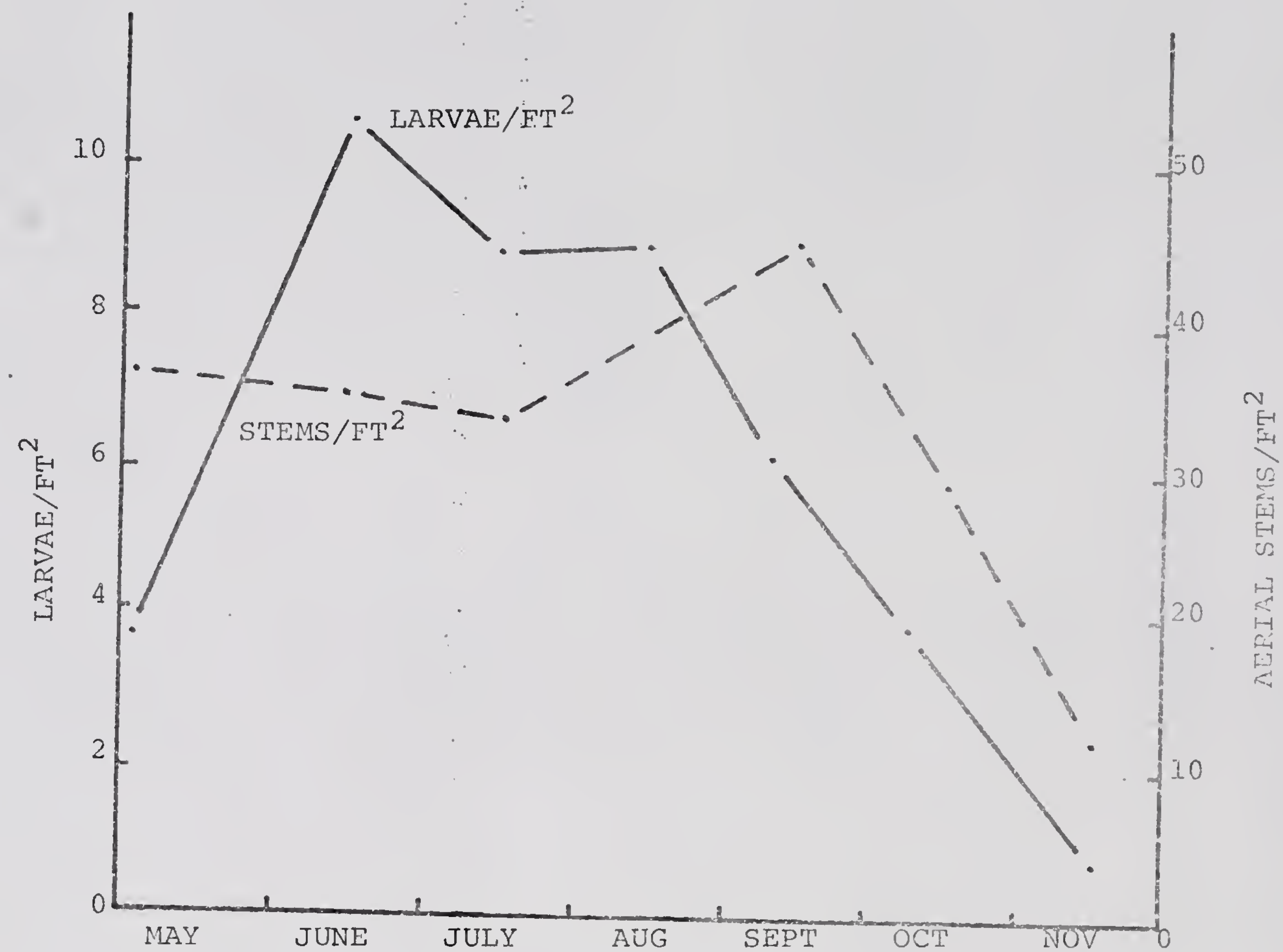

Fig. 4. Vogtia population build-up and its effect on alligatorweed, Lake Alice 1972.

numerous injured alligatorweed stems were found up to 50 ft. from the point of release and a few injured plants were found about 100 ft. away. By January 28, 1972, the Vogtia population had expanded to all areas infested by alligatorweed in the lake. Vogtia larvae were active and still feeding inside aerial stems recently killed by frost; most of these were early instars. On February 11 the larvae were found feeding below the frost-killed aerial stems on green stems that were protected from frost. By April 17, 1972, the Vogtia population had attained a density of about 4.0/ft.^{2} around the entire lake.

By the end of the summer the alligatorweed at Black Lake had been so reduced in area and density of the stems that in many areas of the lake it was no longer the dominant species. The suppression of alligatorweed at this site was probably due to a combination of factors, i.e. insect pressure, interspecific plant competition, and low nutrient levels in the water.

Savannah, Ga.-- A Vogtia population became established and survived the 1971-27 winter despite killing frosts on terrestrially-rooted alligatorweed in experimental plots. Mid-winter sampling failed to locate the overwintering insects (*Durden, personal communication). In South America, Vogtia was found during the winter in the roots of terrestrial alligatorweed (Vogt 1960).

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*Willey C. Durden

Greenfield Lake, N.C. and Santee Reservoir, S.C.--
Vogtia has not been recovered at the 2 northermost release sites. The method of release, i.e. the transfer of infested mats, was proved unsatisfactory at Lake Lawne and may be one reason for lack of establishment at these sites.

Field Releases

1972

Fort Jackson, S.C.-- By the end of 1972 only small patches of alligatorweed remained at this site because of the herbicidal treatment. The effect of removing most of the alligatorweed on the *Vogtia* population was to concentrate the insects on the remaining mats of alligatorweed. Samples taken November 15 indicated a population density of 5 larvae/ft.^{2}. Earlier samples taken September 11 showed only 1 larva/ft.^{2}.

On June 16, 1973 after a severe winter in this area, the *Vogtia* population was 0.6/ft.^{2} and the alligatorweed was killed back to the water in most mats. A few protected areas had healthy alligatorweed, and in one such area adult *Agasicles* were found which had presumably survived the winter as well.

Twin Lakes, S.C.-- The September 11 sample date showed 1.0 *Vogtia* larva/ft.^{2} with moderate defoliation by *Agasicles* (approximately 50% of the leaf area missing). By November 15 the *Vogtia* population had increased to 2.6/ft.^{2}. This area was not sampled in 1973 because of spring flooding.

Garden's Corner, S.C.-- Garden's Corner was the only site where *Agasicles* stripped all the foliage and many of the small shoots from the aerial stems of alligatorweed after a *Vogtia* population had become established. The *Vogtia* population remained low but was not elimianted. When the *Vogtia* release was made (May 20, 1972) the *Agasicles* adult population was 5 adults/$ft.^2$. By July 13 the alligatorweed was under severe stress and the *Agasicles* population was 11 adults/$ft.^2$ and the *Vogtia* population was 0.66/$ft.^2$.

Samples on June 16, 1973 indicated the *Vogtia* population density was 1.6 larvae/$ft.^2$ after a severe winter for that area.

Fort Lauderdale, Fla.-- Samples on July 18 indicated that the *Vogtia* population had attained a density of 0.43 larvae/$ft.^2$ from the first release. A population of 3.4/$ft.^2$ was recorded on September 20, 1972. In both cases the sampling was done within approximately 100 yds. of the release site. The population density declined as the distance was increased from the release area.

On April 26, 1973 just after spring growth had begun the population was 2.25/$ft.^2$. Therefore the population was probably not reduced significantly during the winter period. This was expected since frost did not occur in this area.

ALLIGATORWEED PRODUCTIVITY

Introduction

To evaluate the effects of stress caused by biological control agents to growing plants, comparisons must be made between that plant growing undisturbed, and that plant with the additional stress factors added. Environmental conditions, nutrient levels, and many other factors play a significant role in regulating a plant's growth and spread. This is especially true of plants such as alligatorweed that are adapted to a wide range of conditions. With these limitations in mind, attempts were made to determine the net rate of biomass production in alligatorweed growing under favorable greenhouse conditions, and in four lakes which had varying levels of injury from biological control agents.

Methods and Materials

Greenhouse Studies

Alligatorweed was grown in a 4 X 12 ft. X 6 in. greenhouse table divided into three 4 X 4 ft. sections. The two end sections were covered with 6 mil polyethylene and filled with tap water to a depth of 5 in. On December 13, 9.5 lbs of alligatorweed from the floating portion of a mat of weeds taken from Lake Alice, Gainesville, Fla. were placed in the water-filled sections. The middle section contained a Henry J. Green hygrothermograph, which recorded the temperature and relative humidity at the approximate water level.

Artificial lighting, about 3000 ft. candles, was supplied by 12 Sylvania 40w VHO cool white florescent bulbs and 24, 75w incandescent lamps attached to a light board and suspended 11 inches from the table top. An Intermatic model T101 timer controlled the 12 hour photoperiod.

Each plant section was initially filled with tap water to which 150g milorganite and 200g of 20-20-20 soluble plant food was added. On January 4 another 180g of the same fertilizer plus 45g of 1.82% iron supplement were added to each section.

Half of the growing mat in each section was removed on January 10, the remainder on January 16, terminating the study. To reduce experimental error, alligatorweed was taken from alternate sides of the table. The plant material was allowed to drain for 5 minutes and then weighed on a Fairbanks Morse portable platform scales.

Water samples were taken at the beginning of the experiment and on January 4. These samples were analyzed for common nutrients, i.e. nitrates, phosphates, potassium, chlorides, magnesium, manganese, iron, copper, and calcium by the Soils Laboratory, IFAS, University of Florida.

The mean daily temperature was 29°C, the mean daily RH was 50.6%, and the pH of the water was 7.5. The water temperature on the first sample date was 26°C.

Field Studies

Standing biomass samples were taken in early spring, before much growth had occurred (March 19, 20, 22, and 23), in early summer (May 2, 10, 20, and 24), and in midsummer (July 13, 18, 27, and August 1) at two lakes (Black Lake, Melrose, Fla. and Garden's Corner, S.C.) and three streams (stream flowing into Lake Alice, Gainesville, Fla., roadside ditch, at Ft. Lauderdale, Fla., and Twin Lakes, S.C.). Alligatorweed characteristically grows very rapidly in the spring and then considerably slower during the rest of the growing season. These samples represent both growth periods for alligatorweed at these sites.

A stainless steel cylinder was constructed to extract a 1.2 $ft.^2$ core sample from the floating mats of alligatorweed. One end of the cylinder was sharpened to facilitate cutting through the mass of alligatorweed, and the other end was covered with 1/4 in mesh hardware cloth. A sample was removed from the water, after cutting, by inverting the sampling device. The sample was allowed to drain for 5 minutes and then emptied into a plastic bag and weighed with a hand-held scales. The same mat of alligatorweed was used for all sample periods at each location. All samples were taken half way between the shoreline and the leading edge of the mat.

Results and Discussion

Greenhouse Studies

Although the study began December 13, the actual growth period of the alligatorweed did not begin until several days later. When the alligatorweed was transferred to the greenhouse table the aerial stems were broken and disoriented to such an extent that growth was effectively stopped until new stems were produced. Therefore the first samples at 28 days showed little change (Table 3), since the plants had been actively growing for 10 days or less. The increase in biomass during the first period was 64%. The second sample period, lasting only 6 days increased its biomass by 48%.

Nutrient levels (Table 2) were much higher than those normally found in natrual lakes or streams. In Lake Alice, for example, only phosphates were higher than in these water tables (2.98 ppm). Iron was 0.25 ppm, nitrates were 5.3 ppm, chlorides were 25.0 ppm, and the pH was 7.75 on May 2, 1972.

Table 3. Net productivity of alligatorweed in greenhouse tests

	Wet weight of samples (lbs)			
	Initial wt.	28 days	34 days	% increase
Rep. 1	9.5	14	19	200
Rep. 2	9.5	11	18	189

Table 2. Nutrient levels in water tables used for productivity studies (ppm)

Sample	No3	P	K	Cl	Mg	Mn	Fe	Cu	Ca
Rep. 1	22.0	0.25	70.9	92.0	1.43	.075	1.80	0.20	0.90
Rep. 2	22.0	0.30	70.0	92.0	1.28	.075	1.90	0.20	0.82
tap water	4.3	0.0	0.0	22.5	0.73	0.0	0.0	0.10	1.10

Field Studies

Alligatorweed productivity in the field did not approach that in the greenhouse. The Twin Lakes site had a high percent increase, but the growth period was 52 days, compared with 34 days for the greenhouse study (Table 4).

The early summer daily increment factors for the five sites were .104, -.003, .082, .035, and .028 for Twin Lakes, Fort Lauderdale, Garden's Corner, Lake Alice, and Black Lake, respectively. The daily increment factor for the greenhouse alligatorweed was .26, or 2 1/2 times the highest increment factor recorded in the field.

On a per acre basis, the Twin Lakes growth rate was equivalent of 3,775 lbs of biomass produced per acre per day. In the 52 day period an acre of alligatorweed would produce 193,300 lbs of new growth. That is approximately twice as productive as the most productive aggricultural crop, in half the time. Corn grown on muck soils produces 2-30 tons of silage in about 100 days (Cunha and Rhodes 1965).

At Garden's Corner during the summer sample period, and at Fort Lauderdale, to a lesser extent, the standing biomass was reduced. The reduction at Garden's Corner corresponded with a heavy attack of the *Agasicles* beetle, in which the aerial stems of alligatorweed were completely stripped of their foliage and small stems. The reduction at Fort Lauderdale was less dramatic and may have been due, in part, to severe interspecific plant competition.

Table 4. Field studies of alligatorweed productivity, 1972

Location	Sample period	No. days	% increase	Daily increment (Lbs.) Wt./1.2ft.^{2}	Wt./Ac/day
Twin Lakes, S. C.	Mar. 3 - May 10	52	110	.104	3775
Lake Alice, Gainesville Fla.	Mar. 23-May 2	40	42	.035	1270
	June 1-Aug. 1	61	24	.02	726
Garden's Corner, S.C.	Mar.20-May 20	61	73	.082	2976
	May 20-Jul 13	54	-24	-.052	-1887
Black Lake, Melrose, Fla	Mar 22-May 24	63	40	.028	1016
	May 31-Jul 27	57	6	.007	254
Ft. Lauder-dale, Fla.	April 20 - July 18	89	-6	-.003	-109

INTERRELATIONSHIPS BETWEEN ALLIGATORWEED
AND TWO INSECTS-- *Vogtia* and *Agasicles*

Introduction

Pioneering plants or opportunists such as alligatorweed may because of their tolerance to wide environmental conditions appear in different areas with very different growth and morphological characteristics. Alligatorweed in some areas may produce numberous, short, fibrous stems while in other areas the aerial stems may be much less dense in number and taller, thicker, and more rapidly growing. Under these conditions, it becomes increasingly difficult to evaluate the host plant-insect relationship, and almost meaningless to compare insect population data between the areas. Therefore a great number of samples (287) from all the release areas have been combined to provide an overall estimate, or comparison, of the effect of a given parameter on alligatorweed with the effect of all other parameters considered at the same time. The variables representing the two insects have been evaluated with and without the influence of the other variables being included in the model.

Two stastical methods were used to show the interactions between the *Vogtia* and *Agasicles* populations, between each of these insects and alligatorweed, and between available nutrients and alligatorweed growth.

In the canonical correlations program, 24 variables were grouped into sets. The sets were then compared and significant relationships were defined. The second program was a full multivariate regression model which explained the significance of each of the measured variables in influencing alligatorweed growtn.

In canonical correlations, a set of independent variables may be compared with a set of dependent variables to find the linear combination of variables in each set which when correlated is maximum. The resultant variable is known as a canonical variate. If some linear relationship between the sets of variables still remains unaccounted for by the first set of canonical variates, the process of finding new linear combinations that would best account for the resideual relationships between the sets can be continued. This process can go on until there are no significant linear associations left. Each canonical variate is orthogonal to (or unrelated to) other canonical variates. The chisquare test is used to evaluate variates for significance.

In canonical correlations, variables in one set may be combined to predict maximally the variations of the variables in the other set. This process was utilized to compare data from lakes and streams, and to predict the number of samples that should occur in using different sets, lakes or streams (See Morrison (1967) for detailed discussion of canonical correlations and tests of significance). All statistical methods were analyzed by computer program, BND, SPSS (Nie, 1970) on the University of Florida North East Regional Data Center's IBM 370/165.

Methods and Materials

The Vogtia and Agasicles sampling procedure was described in the section on colonization, i.e. a ft.^{2} frame was used to determine the population density, as well as to gather plant material for stem measurements. Sample sites were selected either by a random process (Lake Alice, Black Lake, and Lake Lawn) or by taking samples at preselected 15 feet intervals (Garden's Corner, Ft. Lauderdale, and Twin Lakes). Aerial stems which were selected for measurement were representative of the sample in both height and diameter. In most cases, the uniformity of the samples made multiple plant measurements unnecessary.

Measurements for each of the sample sites included the following: stem height, length of the fourth internode, diameter of the fourth internode, stem density, percent leaf area missing, Agasicles/ft.^{2}, vogtia/ft.^{2} (expressed as a total and as each of the instars as a separate variable), pH, alkalinity, iron (ppm), turbidity (jtu), chlorides (ppm), phosphates (ppm), nitrites and nitrates (ppm), hardness, water depth, and whether the sample was taken from a lake or stream. The fourth internode was chosen for plant measurements because it was the first fully developed internode.

Water samples were analyzed for nutrients in the laboratory with the use of a Hach water testing kit.

A total of 287 samples were taken from the six following release sites, three of which were lakes and three were streams. The number of samples taken from each site is shown in parenthesis: Lake Alice, Gainesville, Fla. (76); Black Lake, Melrose, Fla. (155); Lake Lawn, Orlando, Fla. (34); Peeples Pond, Garden's Corner, S.C. (2); Roadside ditch, Ft. Lauderdale, Fla. (17); and Twin Lakes, Summerville, S.C. (3), (Fig. 2).

Results and Discussion

Insect-Host Plant Relationship

In the first analysis, the set of plant characteristics was compared with the set of variables representing numbers of Agasicles and Vogtia present and a measure of Agasicles feeding damage. As a result of these correlations, 3 new canonical variates were formed (Table 5 and Table 6). Each of these new variates was significant at the .01 level of probability, indicating that 3 independent and significant linear relationships existed.

If we examine the coefficients of the individual variables (Table 7), we can explain the combinations of variables making up each of these associations. The first canonical variable represents the most important of the linear associations, and in this case there is a positive association between plant height, internode length, inter-mode diameter and the number of Agasicles and Vogtia, and a negative association between the same plant characteristics and Agasicles feeding. Therefore, both Vogtia and Agasicles tend to occur more frequently in alligatorweed with larger, taller stems. Vogtia, having a larger coefficient, probably favors these conditions more than Agasicles. The negative association between the plant characteristics and Agasicles damage was expected. The more damage done by Agasicles, the more stress is placed on the growing plants, resulting in smaller unthrifty stems.

The second canonical variate of less importance than the first, but equally as significant, consisted of a negative association between Agasicles feeding and plant height, and internode diameter. This may appear to be in contradiction of the first canonical variate; however, the canonical variates must be considered separately. Therefore, 2 relationships exist, one superior to the other. When plants are heavily attacked by Agasicles, the upper internodes may be damaged sufficiently to cause them to be dropped off resulting in a condition described by this relationship.

Table 5. Variables used in canonical correlations with mean and standard deviations.

Variable	Mean	Standard Dev.	Cases
SET I			
Plant Height	11.895	3.90	287
Internode Length	2.2250	1.321	287
Internode Diameter	.12007	.05771	287
No. Stems	51.212	21.85	287
Percent damage	15.174	26.328	287
SETII			
No. Agasicles	1.536	2.634	287
No. Vogtia	3.515	4.138	287
1st Inst. Vogtia	1.268	2.095	287
2nd Inst. Vogtia	0.651	1.219	287
3rd Inst. Vogtia	0.498	0.876	287
4th Inst. Vogtia	0.456	0.918	287
5th Inst. Vogtia	0.418	0.280	287

Table 5 continued.

Variable	Mean	Standard Dev.	Cases
Vogtia Prepupae	0.066	0.288	287
Vogtia Pupae	0.177	0.465	287

Table 6. Canonical Variates in Analysis I

Number of Canonical Variate Sets	Chi-Square	Degrees of Freedom
1	156.99149	12**
2	75.90101	6**
3	12.57912	2**

** indicates significance at .01

Table 7. Canonical Coefficients for Individual Variables, Analysis I

	Can. Var. 1	Can. Var. 2	Can. Var. 3
1 Plant Height	0.345*	-1.152	-0.469
2 Internode Length	0.487	-0.022	0.628
3 Internode Diam.	0.329	0.726	0.188
4 No. Stems	-0.027	-0.535	0.906
5 % Leaf Area Missing	-0.638	0.704	-0.554
6 No. Agasicles	0.321	0.394	0.979
7 No. Vogtia	0.645	0.443	-0.700

*Variables underlined contributed most significantly to the linear relationship.

The third canonical variate, likewise independent of the first 2 and of less importance, consisted of a positive association between the number of Agasicles and internode length and the number of stems. We can conclude from this that adult Agasicles tend to occur more frequently in dense stands of alligatorweed with samller stems, and the latter condition is negatively correlated with the number of Vogtia and with Agasicles feeding. The Agasicles feeding and stem size association is in agreement with the first canonical variable but much smaller in magnitude. The positive correlation of Vogtia with stem size is expected since in small stems the full grown larvae may be as large in diameter as the stem itself and, therefore, not protected from parasites and predators or environmental factors.

It should be noted that 63.96% of the variation is explained by canonical variable 1, 30.92% by canonical variable 2, and only 5.12% of the variation is explained by canonical variable 3. The most important associations, therefore, are probably described by canonical variables 1 and 2.

In the second analysis, the same 4 plant characteristics i.e. plant height, internode length, internode diameter, and number of stems were used to compare with the number of Agasicles, Agasicles feeding damage and each of the 7 immature stages of Vogtia present.

In this correlation, 4 new canonical variables were formed (Table 8). The first 2 were significant at the .01

level of probability. The third was significant at the .10 level of probability and, therefore, will not be considered in this discussion. The fourth variate was not significant. The first variate incorporates 61.22% of the total variation and the second 29.87%.

Table 8. Canonical Variates in Analysis II.

Number of Canonical Variate Sets	Chi-Square	Degrees of Freedom
1	195.18961	36**
2	94.64266	24**
3	23.28067	14
4	5.74528	6

** indicates significance at the .01 level of probability

An inspection of the canonical coefficients for the individual variables (Table 9) reveals a positive association between stem diameter and internode length with the 5th instar Vogtia. This relationship, as explained in the first analysis, has been observed in the field in areas where alligatorweed was under severe stress. During temporary stress periods, the aerial stems may become small, with the stems making up the mat remaining large. In this case, the larvae can survive in the mat unless flooding occurs which may drown the larvae. Another relationship occurring in the first canonical variable is a negative association between Agasicles feeding and stem size. This relationship, also apparent in the first analysis, is a result of *Agasicles* damage producing stress in the alligatorweed which resulted in smaller, less thrifty plants.

The second canonical variate shows a negative association between *Agasicles* feeding and plant height. As discussed earlier, reduced plant height with increased *Agasicles* damage is a direct result of *Agasicles* attack. Since the plant suffers more damage in the top few internodes, the more severely attacked plants are much more prone to breaking over, and to dropping these upper internodes.

Table 9. Canonical Coefficients for Individual Variables, Analysis II

Variable	Can. Var. 1	Can. Var. 2
SET I		
Plant Height	0.036	<u>1.156</u>
Internode Length	<u>0.550</u>	0.200
Internode Diam.	<u>0.387</u>	-0.561
No. Stems	-0.220	0.578
% Leaf Area Missing	-<u>0.359</u>	-<u>0.855</u>
SET II		
No. *Agasides*	0.273	-0.195
1st Instar *Vogtia*	0.187	0.141
2nd Instar *Vogtia*	0.028	-0.114
3rd Instar *Vogtia*	0.021	-0.145
4th Instar *Vogtia*	0.237	-0.090

Table 9 continued.

Variable	Can. Var. 1	Can. Var. 2
5th Instar *Vogtia*	0.544	-0.075
Vogtia Prepupae	0.051	-0.147
Vogtia Pupae	0.119	-0.076

Nutrient levels and alligatorweed characteristics

In a similar program the same plant characteristics were compared with the physical and chemical parameters associated with water quality at each site. The second set of parameters were: pH, alkalinity, iron, turbidity, chlorides, phosphates, nitrates, hardness, depth of the water, and the lake or stream origin of sample (Table 10).

Table 10. Variables used in canonical correlations III (IN)

Variable	Mean	S.D.	Cases
SET I			
Plant Height	11.89	3.90	287
Internode length	2.225	1.321	287
Internode diameter	.1201	.0577	287
No. stems	51.21	21.85	287
SET II			
pH	7.02	0.99	287
alkalinity	74.14	74.21	287
iron	0.23	0.29	287
turbidity	36.13	20.15	287
chlorides	18.48	12.2	287

Table 10 continued.

Variable	Mean	S.D.	Cases
phosphates	1.32	1.75	287
nitrites & nitrates	3.68	1.35	287
hardness	99.21	120.45	287

These canonical variates produced four linear relationships which were significant at the .01 level of probability (Table 11). As in the first program, each of these relationships is independent of the others. The first and most important association is a negative correlation between water depth and plant height and a positive correlation between plant height and turbidity. Since larger coefficients occur between water depth and plant height those are likely the more important variates in this linear relationship. Therefore, as water depth increases, plant height tends to decrease. Secondarily, as turbidity increases plant height also increases. The latter relationship probably reflects nutrient pollution which would tend to produce larger, more vigorous stems (Table 12).

Table 11. Canonical variates in analysis III

Variates	Chi-square	D.F.
1	526.21	40**
2	233.11	27**
3	76.46	16**
4	24.03	7**

** Indicates significance at the .01 level of probability

The second canonical variable shows a second positive relationship between plant height and turbidity, independent from the first. In this case however, the major emphasis should be placed on the positive association between internode diameter and water hardness, where as water hardness increases, so does the diameter of the aerial stems.

Table 12. Canonical coefficients for individual variables, Analysis III

Variable	Can. Var. 1	Can. Var. 2	Can. Var. 3	Can. Var.4
SET I				
plant Ht.	-0.833	-0.701	-0.168	-0.784
internode L.	0.681	0.129	-0.145	-1.343
internode D.	-0.430	1.086	0.779	1.204
No. Stems	0.124	-0.230	1.022	-0.245
SET II				
pH	0.130	-0.038	0.861	-0.053
alkalinity	-0.150	-0.226	0.808	-0.697
iron	0.129	0.186	-0.216	0.563
turbidity	-0.773	-0.651	0.777	-1.003
chlorides	-0.042	-0.088	0.056	0.140
phosphates	0.053	0.450	0.899	0.375
nitrates, nitrites	-0.047	-0.113	-0.745	-0.117
hardness	0.005	0.981	-1.740	0.612
depth	1.376	0.369	1.281	0.306

Underlined coefficients contributed most to the linear relationship.

The third canonical variable indicates a negative relationship between the number of stems and water hardness. This, in conjunction with the second variable suggests that water hardness is normally associated with stems of larger diameter and of lower density as opposed to a larger number of stems of smaller size. Also important in this relationship is the positive association between water depth and stem density, indicating that as depth increases stem density increases as well. Another part of this association is a positive relationship between stem diameter and pH, phosphates and alkalinity, indicating that as these variables increase, the diameter of the stems increase similarly.

The fourth variable shows a negative relationship between turbidity and internode diameter similar to the second variable, and a positive relationship between turbidity and internode length. The latter relationship would be expected since a positive relationship has been shown between turbidity and plant height. Internode length and plant height are almost certainly related.

Comparison of lakes and streams

To determine if there was statistically significant difference between alligaterweed growths in lakes and streams a canonical discriminant analysis was utilized to compare the 287 samples and group them according to their origin (Cooley and Lohnes 1970). Three of the four plant characteristics were significant between the two groups at the .01 level of probability. These were: internode length, internode diameter and stem density. The samples were then weighted according to the relative importance of these three characteristics and reclassified through the use of the canonical discriminant function (Table 13).

Table 13. Computer reclassification of Lakes and Streams.

Original data set		
Lakes	Streams	
191	96	
Reclassified according to plant characteristics		
	Lakes	Streams
Lakes	67	29 = 70%
Streams	30	161 = 84%
Reclassified according to physical and chemical properties of the water		
	Lakes	Streams
Lakes	93	3 = 97%
Streams	0	191 = 100%

Using plant characteristics 67 of the 96 lake samples were classified correctly; 29 were reclassified as stream samples thereby producing an accuracy of 70 percent. The stream samples were reclassified with an 84 percent accuracy (161 of the 191 stream samples). Thirty of the stream samples were reclassified wrongly as lake samples.

The procedure of reclassification was repeated using the parameters which measured water quality, all of which were significant at the .01 probability level: PH, alkalinity, iron, turbidity, chlorides, phosphates, nitrates, hardness, and water depth. The result was an overall accuracy of 99 percent. Ninety-three of the 96 lake samples were reclassified correctly with only three appearing as stream samples (97% accuracy). The stream samples were reclassified with 100 percent accuracy (Table 13).

The author is cognizant of the fact that with the small number of sample sites these comparisions may not represent a true picture of lakes and streams in general; they are, however, valid for this study.

Analysis of variance of Plant Characteristics

Two analysis of variance tables were constructed for each of the variables representing plant characteristics; one which showed the statistical significance of the dependent variable with all independent variables included in the model, and the other an analysis of the dependent variable with only the independent variables representing the insect populations included in the model.

In each analysis, the sums of squares was broken down using partial sums of squares to show how each of the independent variables contributed to the variation of the dependent variable. In each case the F test was employed to determine statistical significance.

As shown in table 18 plant height was significant at greater than the .01 probability level in both analysis. The partial sums of squares indicate that iron, turbidity, water depth, and *Vogtia* were significant at .01 in contributing to the variation of plant height. Alkalinity was significant at the .05 probability level. In the second model which included only the [illegible] variables, both *Agasicles* and *Vogtia* were significant at .01 (Table 14).

Table 14. [illegible] for plant height

Source	DF	SS	MS	F	Prob F
Regression	12	22.69	1.97	27.14	0.0001
Error	274	19.92	0.07		
corrected total	286	[illegible]3.61			

Source	DF	Partial SS	F	Prob F
pH	1	0.116	1.59	0.205
Alkalinity	1	0.300	4.12	0.040
Iron	1	0.562	7.74	0.005
Turbidity	1	1.879	25.83	0.000
Chlorides	1	0.01	0.18	0.677
Phosphates	1	0.03	0.34	0.57
Nitrates	1	0.003	0.04	0.84
Hardness	1	0.06	0.81	0.63
Water depth	1	5.38	74.01	0.00
Lake or Stream	1	0.04	0.49	0.509
Vogtia	1	0.46	6.33	0.01
Agasicles	1	0.22	3.07	0.08

Table 14 continued.

ANOV for Plant Height with nutrient effects removed

Source	DF	SS	MS	F	Prob F
Regression	2	3.98	1.99	14.25	0.0001
Error	284	39.63	0.14		
Corrected Total	286	43.61			

Source	DF	Partial SS	F	Prob F
Agasicles	1	1.53	10.97	0.0014
Vogtia	1	3.12	22.34	0.0001

The analysis in which internode length was the dependent variable and with the same independent variables the analysis of variance indicated significance at the .01 level (Table 15). The partial sums of squares showed only one statistically significant independent variable, *Agasicles* (.01). In the insect only model both *Agasicles* and *Vogtia* were significant at the .01 probability level.

Table 15. ANOV for internode length

Source	DF	SS	MS	F	Prob F
Regression	12	149.96	12.50	9.79	0.0001
Error	274	349.84	1.28		
Corrected total	286	499.80			

Table 15 continued.

Source	DF	Partial SS	F	Prob F
pH	1	0.061	0.05	0.821
Alkalinity	1	0.670	0.52	0.524
Iron	1	1.351	1.06	0.305
Turbidity	1	0.509	0.40	0.535
Chlorides	1	1.082	0.85	0.639
Phosphates	1	0.696	0.55	0.532
Nitrates	1	0.253	0.20	0.661
Hardness	1	1.659	1.30	0.254
Water depth	1	0.341	0.27	0.612
Lake or Stream	1	0.448	0.35	0.561
Vogtia	1	2.892	2.26	0.129
Agasicles	1	8.304	6.50	0.011

ANOV for Internode length with nutrient effects removed

Source	DF	SS	MS	F	Prob F
Regression	2	81.65	40.82	27.73	0.0001
Error	284	418.15	1.47		
Corrected Total	286	499.80			

Source	DF	Partial SS	F	Prob F
Agasicles	1	11.32	7.69	0.0061
Vogtia	1	58.05	39.43	0.0001

The analysis of variance with internode diameter as the dependent variable indicated significance at the .01 probability level both with all independent variables included and with only the independent variables for insects included. The partial sums of squares with all variables included showed significance at .01 for water depth and Agasicles. The partial sums of squares with only the insect variables included resulted in Agasicles not being statistically significant and Vogtia significant at the .01 probability level (Table 16). The reversal in significance for Agasicles is probably due to the correlation of Vogtia with stem diameter (the simple correlation coefficient was .51).

Table 16. ANOV for internode diameter

Source	DF	SS	MS	F	Prob F
Regression	12	44.42	3.70	19.95	0.0001
Error	274	50.84	0.18		
Corrected Total	286	95.26			

Source	DF	Partial SS	F	Prob F
pH	1	0.001	0.00	0.95
Alkalinity	1	0.144	0.77	0.62
Iron	1	0.040	0.21	0.65
Turbidity	1	0.001	0.00	0.95
Chlorides	1	0.033	0.18	0.68

Table 16 continued.

Source	DF	Partial SS	F	Prob F
Phosphates	1	0.661	3.56	0.06
Nitrates	1	0.442	2.38	0.12
Hardness	1	0.540	2.91	0.08
Water depth	1	1.708	9.20	0.00
Lake and Stream	1	0.523	2.82	0.09
<u>Vogtia</u>	1	0.211	1.14	0.29
<u>Agasicles</u>	1	0.950	5.12	0.02

ANOV for internode diameter with nutrient effects removed

Source	DF	SS	MS	F	Prob F
Regression	2	15.76	7.88	28.16	0.0001
Error	284	79.49	0.28		
Corrected Total	286	95.26			

Source	DF	Partial SS	F	Prob F
<u>Agasicles</u>	1	0.592	2.11	0.1429
<u>Vogtia</u>	1	13.58	48.53	0.0001

Table 17 shows the analysis of variance using stem density as the independent variable with the same independent variables previously listed. Stem density was significant at the .01 probability level in both analysis. The partial sums of squares shows significance at .01 for the following variables: pH, alkalinity, nitrates, hardness, and water depth. Significance at .05 was indicated for phosphates, lake or stream variable, and *Vogtia*. The partial sums of squares with only insect variables included showed significance at .01 for *Vogtia* and no significance for *Agasicles* (Table 17).

Table 17. ANOV for Stem density.

Source	DF	SS	MS	F	Prob F
Regression	12	384.94	32.08	8.97	0.0001
Error	274	980.08	3.58		
Corrected Total	286	1365.02			

Source	DF	Partial SS	F	Prob F
pH	1	40.77	11.40	0.00
Alkalinity	1	27.51	7.69	0.01
Iron	1	6.66	1.86	0.17
Turbidity	1	7.06	1.97	0.16
Chlorides	1	0.10	0.03	0.86
Phosphates	1	14.88	4.16	0.04
Nitrates	1	64.42	18.01	0.00
Hardness	1	71.90	20.10	0.00
Water depth	1	53.29	14.90	0.00
Lake or Stream	1	14.43	4.03	0.04

Table 17 continued.

Source	DF	Partial SS	F	Prob F
Vogtia	1	18.72	5.23	0.02
Agasicles	1	5.21	1.46	0.23

ANOV for Stem density with nutrient effects removed.

Source	DF	SS	MS	F	Prob F
Regression	2	141.05	70.52	16.36	0.0001
Error	284	1223.97	4.31		
Corrected total	286	1365.02			

Source	DF	Partial SS	F	Prob F
Agasicles	1	2.777	0.64	0.5710
Vogtia	1	126.53	29.38	0.0001

The last ANOV table was constructed for the variable representing leaf area missing, in which case this was the dependent variable. Leaf area was significant at .01 in both analyses, i.e. in both the limited model and when all independent variables were included in the model (Table 18). The partial sums of squares indicated that the following independent variables were significant sources of variation at the .01 probability level: Alkalinity, iron, nitrates, *Vogtia* and *Agasicles*. Turbidity and phosphates were similarly significant but at the .05 level. The partial sums of squares in the limited model shows both *Agasicles* and *Vogtia* to be significant at the .01 probability level.

Table 18. ANOV for Leaf area missing.

Source	DF	SS	MS	F	Prob F
Regression	12	616.05	51.34	10.29	0.0001
Error	274	1366.48	4.99		
Corrected Total	286	1982.53			

Source	DF	Partial SS	F	Prob F
pH	1	0.54	0.11	0.74
Alkalinity	1	33.52	6.72	0.01
Iron	1	134.37	26.94	0.00
Turbidity	1	23.71	4.76	0.03
Chlorides	1	2.42	0.48	0.51
Phosphates	1	25.86	5.18	0.02
Nitrates	1	34.72	6.96	0.01
Hardness	1	0.05	0.01	0.92
Water depth	1	9.70	1.94	0.16
Lake or Stream	1	1.18	0.23	0.63
Vogtia	1	36.86	7.39	0.01
Agasicles	1	91.99	18.44	0.00

ANOV for leaf damage with nutrient effects removed

Table 18 continued.

Source	DF	SS	MS	F	Prob F
Regression	2	343.94	171.97	29.81	0.001
Error	284	1638.59	5.77		
Corrected Total	286	1982.53			

Source	DF	Partial SS	F	Prob F
Agasicles	1	288.82	50.06	0.0001
Vogtia	1	108.97	18.82	0.0001

In table 19 the overall effect of each of the independent variables on the plant characteristics as a whole is shown. Like the previous programs, F values were calculated using all independent variables in the first model and secondly with only the insect variables included. Pillai's Trace with the F statistic was used as a test for significance. When all variables were included only one independent variable lacked significance, chlorides. Variables with larger F values and therefore more important sources of variation were: Iron, turbidity, nitrates, hardness, water depth, and *Agasicles*. With only the insect variables included, both *Agasicles* and *Vogtia* were significant at greater than the .01 probability level.

Table 19. Overall effect of variables on alligatorweed

Variable	DF	F	Prob F
pH	5 and 270	3.15	0.0091
Alkalinity	5 and 270	3.07	0.0104
Iron	5 and 270	6.42	0.0001
Turbidity	5 and 270	10.54	0.0001
Chlorides	5 and 270	0.38	0.8624
Phosphates	5 and 270	4.76	0.0006
Nitrates	5 and 270	8.44	0.0001
Hardness	5 and 270	5.92	0.0001
Water depth	5 and 270	26.91	0.0001
Lake or Stream	5 and 270	3.98	0.0020
Agasicles	5 and 270	8.89	0.0001
Vogtia	5 and 270	3.57	0.0042

Overall effect of insects with nutrient effects removed

Variable	DF	F	Prob F
Agasicles	5 and 280	16.19	0.0001
Vogtia	5 and 280	15.08	0.0001

SUMMARY

Vogtia malloi was introduced into the United States in the spring of 1971 with populations successfully established in 1971 and 1972 at the following locations: Upper Legion Lake, Columbia, South Carolina, Twin Lakes, South Carolina, Garden's Corner, South Carolina, Black Lake, Melrose, Florida, Lake Alice, Gainesville, Florida, Lake Lawne, Orlando, Florida, and a roadside ditch, Fort Lauderdale, Florida.

Populations of *Vogtia* expanded randomly as alligatorweed in the release area became damaged and less desireable. Samples of the parasite populations at Lake Alice and Lake Lawne indicated that the *Vogtia* populations were not seriously reduced and only general parasites were observed.

Both *Vogtia* and *Agasicles* demonstrated their ability for surviving frost and cold temperatures. At Columbia, South Carolina both insects survived the 1972-73 Winter with below freezing temperatures recorded for 17 of the 28 days in the month of February. With this degree of cold tolerance it is probable that these insects can extend their range throughout the northern limits of alligatorweed infestations.

At Garden's Coner the *Vogtia* population was reduced but was not excluded even when *Agasicles* had completely defoliated the alligatorweed and almost destroyed it. When the Agasicles population subsided, as expected during the hot months of summer, the Vogtia population began to build up, keeping the alligatorweed under stress for the entire growing season.

While Agasicles populations remained low in south Florida, presumably because of high temperatures, the Vogtia population was apparently unaffected, and will therefore probably surpass Agasicles in its influence on alligatorweed growth in the southern regions.

The use of canonical correlations, in conjunction with a multivariate analysis has enabled us first to show the interrelationships which occured between Vogtia and Agasicles, between each of these insects and alligatorweed, and between the physical and chemical characteristics of the water and alligatorweed, and secondly, to determine the significance of these factors in controlling alligatorweed growth.

As expected, a significant relationship existed between Agasicles and plant height. Agasicles characteristically begins feeding on the upper leaves and items of alligator-weed resulting in shorter plants. Similarly, Agasicles adults occured less frequently in heavily damaged alligatorweed, as did Vogtia larvae, a probable result of the food supply being reduced.

In this study, as stem density increased Vogtia occurred less frequently and Agasicles occurred more frequently. Since alligatorweed may occur in relatively dense stands of stems with small diameters, this indicates the preference of *Agasicles* for the younger leaves, and with the positive correlation between *Vogtia* larvae and stem size, the inability of *Vogtia* larvae to survive in very small stems. This is also indicated by the tendency of both populations to occur in greater numbers with tall healthy plants.

As the depth of the water increased, aerial stems tended to be shorter and more numerous, and as turbidity, iron, and alkalinity increased plant height increased. Also, as water hardness, pH, and phosphates increased the plants tended to be larger. This simply indicates that alligatorweed grows better in shallow, fertile ponds as opposed to deep, clean water.

Samples from lakes and streams were more accurately seperated according to characteristics of the water than to plant characteristics, suggesting that a greater difference occurs between lakes and streams than between stands of alligatorweed growing in these areas.

The overall effect of the independent variables on the plant characteristics as a whole resulted in all variables, except chlorides, being significant at 0.01 The most important of these were: iron, turbidity, nitrates, hardness, water depths, and *Agasicles*, as indicated by larger F values.

The potential for seasonal control of alligatorweed has been clearly demonstrated by both *Agasicles* alone (Zeiger 1967), by *Vogtia*, and by *Vogtia* and *Agasicles* in combinations. However, the resiliency of alligatorweed in re-establishing itself is truly remarkable, and for this reason no attempt has been made to predict the final impact of these insects in reducing the overall area of infestation of alligatorweed.

In many areas, the mats of alligatorweed have increased over the years such that they now frequently occur 8-10 in. in depth. Under these conditions, herbicides may be required to facilitate insect presure if alligatorweed is to be reduced drastically in a short period of time.

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BIOGRAPHICAL SKETCH

John L. Brown was born November 17, 1944 in Weiner, Arkansas. He attended Weiner Public Schools from 1950 to 1962 and after graduation he enlisted in the U.S. Air Force. In 1967 he enrolled in the school of Agriculture at Arkansas State University. He received the Bachelor of Science degree in 1969, and enrolled at Iowa State University. He received the Master of Science degree in entomology in 1971 and transferred his studies to the University of Florida where he is completing the requirements for the degree of Doctor of Philosophy.

John L. Brown is married to the former Delena Y. Newmans and has two children, a son of 10 years and a daughter of 5.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

B. David Perkins
Assistant Professor of
Entomology

This dissertation was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1973.

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