flea beetles and moths will have damaged most of the leaves and stems. Damage by insects will be more predominant near the mat perimeter.

*August*—INTEGRATED—The effect of insect feeding on regrowth from previously treated mats will be severe. Plant height will vary because some alligatorweed stems will have shriveled and died.

*September*—BIOLOGICAL—Fall peak of insect activity will have reduced surface vegetation. Internodes will be void of leaves and dead. Plants of current seasons growth which have been pressed below the water line will not be affected by insect damage.

*September*—INTEGRATED—Regrowth will be reduced back to the water line by insects. The internodes below the water will be yellow and brittle because they will represent growth produced the previous season. Floating mats will be thin due to the combined pressures of chemical application and insect feeding damage.

*October*—BIOLOGICAL—Regrowth from attacked plants will be sparse. Insect populations will have decreased because the adults have left in search of alligatorweed with less damage. Insects that have remained will prevent mat replenishment.

*October*—INTEGRATED—Regrowth will be sparse. Internodes near the surface will be limp and void of chlorophyll. Deterioration of the mat will have advanced to the point that some mats will break free and float downstream. Mat fragments caught in the bend of the river will be rolled and inverted because of water pressure.

*November*—BIOLOGICAL—Frost will have killed surface vegetation. New leaves will be produced by stems pressed into the mat during the growing season. However, chilling temperatures will prevent any substantial growth. Insects may be found near the shore or under the cover of dried vegetation or floating on the surface. When first examined the insects will appear dead; but, when placed in the sun they will begin to revive.

*November*—INTEGRATED—Mats will be reduced by the combined pressures of herbicides and insect feeding damage. Large mats will have holes where portions of the mat have dropped out because of deterioration of internodes. Most of the alligatorweed infestation will be marginal.

## LITERATURE CITED


1. Maddox, D.M., L.A. Andres, R.D. Hennessey, R.D. Blackburn, and N.R. Spencer. 1971. Insects to control alligatorweed: An invader of aquatic ecosystems in the United States. Biosci. 21: 985-991.
2. Mohr, Charles. 1901. Plant life of Alabama. 6:1-921.
3. Weldon, L.W. 1960. A summary review of investigations on alligatorweed and its control. U.S. Department of Agriculture, Agricultural Research Service, Crops Research Division, CR 33-60, Sep. 41 pp.
4. Weldon, L.W. and R.D. Blackburn. 1968. Herbicidal treatment effect on carbohydrate levels of alligatorweed. Weed Sci. 16:66-69.


# Towards Integrated Control Of Alligatorweed


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## ABSTRACT

Under sponsorship of the U. S. Army Corps of Engineers a multifaceted research program is being conducted on major aquatic weed species in the United States. Alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] was an early target of this research due to the difficulty of controlling the weed chemically. Research in Louisiana, where alligatorweed is a problem in rice (*Oryza sativa L.*) growing areas and in canals and lakes, resulted in data on the use of four phenoxy herbicides. Included with this is information on the release of the alligatorweed flea beetle (*Agasicles hygrophila* Selman & Vogt) in the state and its subsequent impact on alligatorweed at several sites.


## INTRODUCTION

Virtually every type of water transportation in the Nation's larger inland waterways is affected by dense growths of aquatic plants. Included are small pleasure craft, commercial fishing fleets, petroleum industry vessels, and modern barge tows which move hundreds of important commodities. These plants also increase the chance of local flooding by impeding natural runoff and are detrimental to fish and wildlife in bayous, swamps, and marsh areas adjacent to navigable waterways. They affect agri-


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culture by increasing water loss through evapotranspiration and impeding water management in irrigation canals, thereby increasing production costs.

## CHEMICAL CONTROL OF ALLIGATORWEED

Preliminary studies on the chemical control of alligatorweed and waterhyacinths [*Eichhornia crassipes* (Mart.) Solms] in Louisiana were made in 1950 under a research contract with the New Orleans District of the U. S. Army Corps of Engineers and Tulane University (2). Since that time, phenoxy herbicides have been widely used for control of these two aquatic weeds. However, herbicide application for control of alligatorweed has been quite limited because relatively high herbicide levels are required, and the cost of retreatment that is usually necessary after a short period of time is substantial. To improve the control method, research studies were initiated with the University of Southwestern Louisiana in 1959 (1).

*Methods and Materials.* Field studies for the summer seasons of 1964, 1965, and 1966 were set out in Louisiana. Randomly selected plots 600 m² in surface area were sprayed with phenoxy herbicides using conventional ground equipment. The herbicides were applied in a water solution at a rate of 1.87 kiloliters (kl)/ha and 14 kg/sq cm. Eleven large scale plots, 0.2 to 0.4 ha in size, were sprayed by Corps of Engineers crews, using the same equipment and (2,4-dichlorophenoxy)acetic acid (2,4-D) herbicides used for the control of waterhyacinths. These plots were established in the canals of the Bonnet Carre Spillway near New Orleans.

*Treatment Results.* Field data for the summer seasons of 1964, 1965, and 1966 are presented in Tables 1, 2, and 3. The herbicides 2-(2,4,5-trichlorophenoxy)propionic acid (silvex), and the propylene glycol butyl ether esters (PGBEE) and the dimethyl amine (DMA) formulations of 2,4-D successfully controlled alligatorweed. Differences between herbicides were not significant. Rates and dates were highly significant, i.e., applications below 8 kg/ha did not produce satisfactory control, and late summer applications were more effective than early summer applications. Large scale field trials showed regrowth along the canal banks during the second year, and most canals were covered over by the end of the third year.

TABLE 1. PERCENT CONTROL FOR HERBICIDE TREATMENTS AT DIFFERENT RATES AND MONTHS OF APPLICATION FOR CONTROL OF ALLIGATORWEED FOR APRIL, MAY, AND JUNE 1964.

| Herbicide treatment[a] | Rate kg/ha[b] | Month of application | Percent control[c] |
|---|---|---|---|
| Silvex | 8.4 | April | 80[d] |
| | 5.0 | April | 55 |
| | 2.7 | April | 15 |
| 2,4-D (PGBEE) | 8.4 | April | 80[d] |
| | 5.0 | April | 70 |
| | 2.7 | April | 25 |
| 2,4-D (PGBEE) | 8.4 | May | 85[d] |
| | 5.0 | May | 45 |
| | 2.7 | May | 30 |
| 2,4-D (PGBEE) | 8.4 | June | 73[d] |
| | 5.0 | June | 40 |
| | 2.7 | June | 30 |
| Summary of treatment means | | | |
| Herbicides | | | |
| Silvex | | | 50[e] |
| 2,4-D (PGBEE) | | | 52 |
| Months | | | |
| | | April | 54[e] |
| | | May | 53 |
| | | June | 48 |
| Rates | | | |
| | 8.4 | | 79[d] |
| | 5.0 | | 42 |
| | 2.7 | | 30 |

[a] Applied in a water solution at 1.87 kl/ha and 14 kg/sq cm.
[b] Rate in kg active ingredient per ha.
[c] Percent control estimated from three replicates, by visual inspection of below water mat, 6 weeks after treatment (WSSA rating 1-10).
[d] Significant difference. P = 0.02.
[e] Nonsignificant difference.

## BIOLOGICAL CONTROL OF ALLIGATORWEED

Preliminary studies on the successful control of alligatorweed with the alligatorweed flea beetle have been reported in Florida (4, 7). There was some opposition to the introduction of the alligatorweed flea beetle into Louisiana for biological control of this weed because some economic uses existed, such as cover and food in crayfish ponds and grazing for cattle during the winter season. These uses, however, did not greatly conflict with the use of the alligatorweed flea beetle for control of the plant in canals and bayous.

*Methods and Materials.* The cooperative investigation of the biological control of alligatorweed was initiated be-

TABLE 2. PERCENT CONTROL OF HERBICIDE TREATMENTS FOR THREE LEVELS OF APPLICATION AND 2 MONTHS FOR CONTROL OF ALLIGATORWEED FOR MAY AND JULY 1965.

| Herbicide treatment[a] | Rate kg/ha[b] | Percent control[c] May | Percent control[c] July |
|---|---|---|---|
| Silvex | 8.4 | 70 | 100 |
| 2,4-D (PGBEE) | 8.4 | 50 | 100 |
| Silvex | 5.0 | 35 | 60 |
| 2,4-D (PGBEE) | 5.0 | 50 | 100 |
| Silvex | 2.7 | 35 | 60 |
| 2,4-D (PGBEE) | 2.7 | 20 | 60 |
| Summary of treatment means | | | |
| Herbicides | | | |
| Silvex | | 47 | 73[d] |
| 2,4-D | | 10 | 88 |
| Rates | | | |
| | 8.4 | 60[d] | 100[e] |
| | 5.0 | 43 | 80 |
| | 2.7 | 26 | 60 |
| Months | | | |
| May vs July | | 43 | 80[e] |

[a] Applied in water solution at 1.87 kl/ha and 14 kg/sq. cm.
[b] Rate in kg active ingredient per ha.
[c] Percent control estimated from three replicates by visual inspection of the below water mat, 6 weeks after treatment (WSSA rating 1-10).
[d] Nonsignificant difference.
[e] Significant. P = 0.05.

TABLE 3. PERCENT CONTROL FOR HERBICIDE TREATMENTS OF HERBICIDE COMBINATIONS FOR CONTROL OF ALLIGATORWEED FOR MAY, JULY, AND SEPTEMBER 1966.

| Herbicide treatment[a] | Rate kg/ha[b] | Month of application | Percent control[c] |
|---|---|---|---|
| 2,4-D (PGBEE) plus silvex | 4.5<br>2.3 | May<br>July<br>September | 25<br>40<br>100[d] |
| 2,4-D (DMA) plus silvex | 4.5<br>2.3 | May<br>July<br>September | 30<br>25<br>100[d] |
| 1,4-D(PGBEE) | 6.8 | May<br>July<br>September | 25<br>20<br>100[d] |
| 2,4-D (DMA) | 6.8 | May<br>July<br>September | 35<br>30<br>100[d] |
| **Summary of treatment means** | | | |
| **Combinations** | | | |
| 2-4-D (PGBEE) plus silvex | | | 55[e] |
| 2,4-D (DMA) plus silvex | | | 55 |
| 2,4-D (PGBEE) | | | 46 |
| 2,4-D (DMA) | | | 36 |
| **Months** | | | |
| | | May | 26 |
| | | July | 29 |
| | | September | 90[d] |

[a] Applied in water solution at 1.87 kl/ha and 14 kg/sq cm.
[b] Rate in kg active ingredient per ha.
[c] Percent control estimated from three replicates by visual inspection of the below water mat, 6 weeks after treatment (WSSA rating 1-10).
[d] Significant difference. $P = 0.05$.
[e] Nonsignificant difference.

tween the U. S. Army Corps of Engineers and the Agricultural Research Service (ARS) of the U. S. Department of Agriculture (USDA) in 1959. Exploration and investigation for insect enemies of the plant in South America were done by personnel of the Systematic Entomology Laboratory of the ARS.[2] ARS personnel conducted host specificity studies at the USDA research station in Argentina and at the USDA—ARS Biological Control Laboratory in California (3). Results of host specificity studies in Argentina indicated that an undescribed flea beetle, later named the alligatorweed flea beetle, was suitable for biological control of alligatorweed (2, 3, 4, 5, 6).

In December 1970, an official permit was granted by Louisiana authorities for the release of the insect in the state. The first release was made in February 1971, in the Cross Bayon Canal, about 8 km west of the New Orleans International Airport. Since that time, 15 releases have been made in Louisiana, with control of alligatorweed apparent in several areas of the state.

[2]Vogt, G. B. 1973. Exploration for natural enemies of alligatorweed and related plants in South America. pp. B3-B66. *In* Aquatic Plant Control Program, Technical Report 3. Biological Control of Alligatorweed, edited by E. O. Gangstad. Report sponsored by: Office, Chief of Engineers, U. S. Army, and published by: U. S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi. 167 pp.

*Treatment Results.* Release sites of the alligatorweed flea beetle in Louisiana are summarized in Table 4. Most of these sites have active populations of the alligatorweed flea beetle, and some measure of control has been obtained. The beetles are found to be most active during the spring and fall with a slowing of activity during the hot summer months. They have overwintered in the southern part of the state, and indications are that a stable population has been established. Although it is too soon to fully evaluate the degree of control, there is little doubt that the alligatorweed flea beetle will continue to supress excessive growth of alligatorweed growing in aquatic situations but terrestrial growth is much less affected.

## INTEGRATED CONTROL

As early as June 1968, Zurburg (8) suggested that the improved control of alligatorweed in Florida at the Ortega River release site might be related to the combined activity of the alligatorweed flea beetle feeding on the above portion of the mat and the effect of 2,4-D (incidentally applied for control of waterhyacinths) on the underwater portion of the mat. It was not until after permission was granted for the introduction of the alligatorweed flea beetle by authorities in Louisiana that this approach to the problem could be further studied in Louisiana.

Field observations have been made since 1970 to determine the effectiveness of the alligatorweed flea beetle to control alligatorweed. During the initial period of dispersion, populations increased slowly; consequently, feeding damage was minimal. However, by the fall of 1971 significant populations and feeding were apparent. As a result of the mild 1971 to 1972 winter, insects overwintered and large populations were found in most of the state in the spring of 1972.

In several widely separated locations in Louisiana during 1971 and 1972, attack by the alligatorweed flea beetle on alligatorweed was followed by increased competition from waterhyacinths and eventual replacement of the

TABLE 4. ALLIGATORWEED FLEA BEETLE RELEASE SITES IN LOUISIANA[a]

| 1971 Date of release | Number released | Origin of alligatorweed flea beetle | Release site |
|---|---|---|---|
| 19 February | 50 | Ortega River, Fla. | Cross Bayou Canal 1 |
| 03 March | 750 | Ortega River, Fla. | Jasmine Bayou 1 |
| 03 March | 750 | Ortega River, Fla. | Cross Bayou Canal 2 |
| 19 March | 150 | Lake Arthur, La. | Jasmine Bayou 2 |
| 15 April | 2000 | Lake Charles, La. | Cross Bayou Canal 3 |
| 16 April | 1000 | Lake Charles, La. | Jasmine Bayou 3 |
| 16 April | 300 | Lake Charles, La. | Bayou Rapides 1 |
| 17 April | 300 | Lake Charles, La. | Brushy Bayou |
| 17 April | 300 | Lake Charles, La. | Round-a-way Bayou |
| 26 April | 500 | Ortega River, Fla. | Warren Canal |
| 26 May | 300 | Lake Charles, La. | Bayou Rapides 2 |
| 27 May | 250 | Lake Charles, La. | Lake Bruin |
| 27 May | 550 | Lake Charles, La. | Logansport |
| 27 May | 1500 | Lake Charles, La. | Black Bayou Lake |
| 28 May | 150 | Lake Charles, La. | Chaplin Lake |

[a] Information supplied by W. E. Thompson, U. S. Army Engineer District, New Orleans, and L. V. Richardson, Louisiana Wildlife Fisheries Commission, for the estimated number of adult beetles at each site release.

alligatorweed by waterhyacinths. In these cases, herbicide treatment of waterhyacinths resulted in the elimination of both plants.

*Cross Bayou Canal.* Approximately 50 adult beetles were released at this site near Lake Pontchartrain on 19 February 1971. This location was selected as a release site for the alligatorweed flea beetle because of the lush growth of alligatorweed. The beetles also had access to large quantities of alligatorweed growing in the marsh area. Because of the slow increase in population an additional 2,000 beetles were released on 15 April 1971. This release resulted in a rapid increase in the population and in feeding damage (Table 5).

In July 1971, waterhyacinths intruded into the area and rapidly multiplied throughout the rest of 1971 and into the spring of 1972 to the point that by June 1972 the canal was completely blocked. The canal was sprayed 26 and 27 June 1972 by crews of the Louisiana Wildlife and Fisheries Commission, using 4.5 kg/ha of the DMA formulation of 2,4-D in a 0.5% spray solution. Spraying of waterhyacinths was done without any appreciable damage to the alligatorweed. By October 1972, only a small amount of alligatorweed remained in the area, and by the beginning of December 1972, alligatorweed was no longer present. Continuing surveys in the spring of 1973 indicated that almost no alligatorweed was present in the canal and along its banks.

In an evaluation of the causes leading to the severe reduction of alligatorweed on Cross Bayou, several factors were considered. The winter of 1971 to 1972 included 4 days below 0 C in January and 3 days in February. This cold weather killed a portion of the alligatorweed above the water and delayed its spring growth. In the spring of 1972 the alligatorweed flea beetle continued the stress which the weed had been under due to the cold weather earlier in the year (Table 5). The alligatorweed in Cross Bayou was less competitive with waterhyacinth, thus a plant replacement occurred making the use of 2,4-D necessary. Drift from this spray may have contributed to the disappearance of the alligatorweed in the summer of 1972.

TABLE 5. PERCENT CONTROL DATA FOR LOUISIANA LOCATIONS FOR BEETLE POPULATION AND ALLIGATORWEED MAT WIDTH AS RELATED TO HERBICIDE TREATMENT.

| Location of alligatorweed | Date of observation | Beetle population per sq m (adults) | Mat width (m) | Mat control (%) |
|---|---|---|---|---|
| Control canal | 05/20/71 | 0 | 15 | |
| | 06/26/72 | 0 | 17 | |
| | | | | 0 |
| Cross Bayou Canal, Louisiana[a] | 05/20/71 | 13 | 23 | |
| | 06/26/72 | 25 | 6 | |
| | | | | + 74 |
| Rice Irrigation Canal, Louisiana[b] | 07/14/71 | 11 | 21 | |
| | 07/16/72 | 18 | 3 | |
| | | | | + 78 |

[a] Sprayed with 2,4-D (DMA) for waterhyacinth control.
[b] Sprayed with 2,4-D (PGBEE) for alligatorweed control.

Alligatorweed has not reestablished on the canal due to the continued pressure of biotic and abiotic stresses.

*Rice Irrigation Canals.* Attempts to control rooted and floating mats of alligatorweed emerging from the banks of rice irrigation canals began in April 1968. Combinations of rapidly degradable phenoxy herbicides and water management were first successfully used in the 1969-70 season. These treatments, while not completely satisfactory in degree of control obtained, gave adequate control to minimize interference with irrigation water movement. In late October 1970, large scale spraying of irrigation canals was accomplished by applying 4.5 kg/ha of the DMA formulation of 2,4-D in 30.3 liters of water by commercial crop spraying aircraft. This application was timed to coincide with lowering water level in the irrigation system and earlier experience with the control of floating mats of alligatorweed by fall application of phenoxy herbicides. Results obtained earlier in this study in the control of rooted alligatorweed in the irrigation canals demonstrated the advisibility of an early spring application (late March) about 1 week prior to filling the canals with muddy water. In July 1971, very little alligatorweed was in evidence in the treated canals (approximately 16 ha treated). At this time, the alligatorweed flea beetle was introduced on alligatorweed along the canal bank and was noted to be feeding on the surviving alligatorweed. Beetle damage was moderate during this first summer and a population increase was observed. In the spring of 1972, the alligatorweed flea beetle damage to alligatorweed was very much in evidence and the remaining stand of alligatorweed was practically eliminated (Table 5).

In early March 1973, an examination of the canal banks in the treated areas revealed an occasional surviving plant of alligatorweed. However, extremely unfavorable temperatures in January and February 1973 reduced the alligatorweed flea beetle population almost to zero, necessitating a repetition of the 2,4-D treatment in the fall in certain areas. The alligatorweed flea beetle population reestablished itself in the spring of 1974.

## LITERATURE CITED


1. Gangstad, E. O. 1971. Aquatic plant control program, Hyacinth Contr. J. 9:48.
2. Hitchcock, A. E., P. W. Zimmerman, Henry Kirkpatrick, Jr., and T. T. Earle. 1950. Growth and reproduction of water hyacinth and alligatorweed and their control by means of 2,4-D. Contr. Boyce Thompson Inst. 16:91-130.
3. Maddox, D. M. 1968. Bionomics of an alligatorweed flea beetle, *Agasicles* sp., in Argentina. Ann. Entomol. Soc. Amer. 61:1299-1305.
4. Maddox, D. M., and M. E. Resnik. 1969. Determination of host specificity of the alligatorweed flea beetle, *Agasicles* n. sp., with radioisotopes. J. Econ. Entomol. 62:996-999.
5. Maddox, D. M., L. A. Andres, R. D. Hennessey, R. D. Blackburn, and N. R. Spencer. 1971. Insects to control alligatorweed; an invader of aquatic ecosystems in the United States. BioScience 21:985-991.
6. Selman, B. J., and G. B. Vogt. 1971. Lectotype designations in the South American genus *Agasicles* (Coleoptera: Chrysomelidae), with description of a new species important as a suppressant of alligatorweed. Ann. Entomol. Soc. Amer. 64:1016-1020.
7. Zeiger, C. F. 1967. Biological control of alligatorweed with *Agasicles* n. sp. in Florida. Hyacinth Contr. J. 6:31-34.
8. Zurburg, F. W. 1968. Some problems with aquatic weed herbicides. Hyacinth Contr. J. 7:33-34.