THE VALUE OF HERBICIDES IN SOUTHEASTERN AQUATIC HABITAT MANAGEMENT

WILLIAM P. BALDWIN, U. S. Fish and Wildlife Service
EDWIN W. BALL, U. S. Fish and Wildlife Service

Proc. Annu. Conf. Southeast. Assoc. Game & Fish Comm. 5:378-394

As a management feature on Southeastern National Wildlife Refuges many thousands of acres of marsh and wetlands have been diked for intensive waterfowl management, aquatic fur-bearers and fish. These impoundments (and portions of reservoirs and natural lakes) generally are improved waterfowl habitat. However, the plant succession on such areas is rapid, and of the vegetative species that invade, many are very undesirable. Management to improve waterfowl feeding conditions is concerned with finding the least expensive methods of keeping this habitat in the best stages of succession.

The value of herbicides in helping solve this problem has been the object of considerable investigation on our Southeastern Refuges, particularly during the past four years. No attempt has been made to evaluate all herbicides on all major vegetative species. Rather, efforts have been directed toward working on the most pressing problems of obnoxious plant control. This report reflects our principal experience with a dozen or so of these plants, and no attempt has been made to compare our results with the published accounts of other workers.

Operations have been of two types: 1) Rapid and total eradication of invading plants that (by nature of their rapid propagation) could offer terrific control problems if allowed to spread (ex., water hyacinth, alligatorweed); 2) Control of more slowly-spreading species (ex., cattails, maidencane). In some instances, successful and economical control was fairly certain, but for others investigations had to be made.

Ball has been responsible for investigating airplane application throughout the Southeast, as well as in a few other sections of the country. Baldwin has worked with ground application of herbicides on South Atlantic Refuges. The principal herbicide employed has been 2,4-D.

THE ROLE OF THE AIRPLANE

During the past three years, counting repeat treatments on some acreages, a total of 2,721 gallons of 2,4-D (principally in diesel-oil solutions), and 30,150 pounds of seed have been applied on 3,167 acres, by Ball in Service aircraft. The spraying of 2,4-D by airplane is gradually fitting into an accepted pattern as an effective technique of pest plant control. Not a "cure-all," the application technique is limited to certain plants and conditions. Three types of habitat definitely can be classified as unsuitable for this mode of application: 1) small areas, ten acres or less in size; 2) areas with numerous obstructions, such as dead timber; and 3) sites in close proximity to cotton and other crops possessing a high sensitivity to 2,4-D.

This last limitation in areas otherwise suitable for aircraft dispersal of 2,4-D is extremely serious. It is recognized generally that the drift from aircraft application can cause considerable damage to adjacent crops, resulting in litigation and compensation payments. It is of interest to note that one Federal Agency spraying the amine formulation of 2,4-D in 1950, was sued for alleged cotton damage as far as eight miles from the spray site. Some conception of potential drift of liquids can be secured by the knowledge that a water droplet one micron in size dropped from an altitude of ten feet, in a uniform wind of three miles per hour, takes 28 hours to reach the ground 84 miles distant. This is why aircraft spray equipment should be designed to yield large droplets somewhere in the 200 to 500 micron category. Even such large droplets, which theoretically reduce drift to between nineteen and seven feet under the above conditions, can be lifted by convection currents to great distances.

In order to minimize crop damage, spraying must be done on willow and similar species in early spring before susceptible crops emerge from the soil, or fall after crops have matured. Fall dormant sprays of brush are to be tried soon at Mattamuskeet National Wildlife Refuge in North Carolina. How successful spring and fall treatment of susceptible species will be is not known. It is probable that on those sites where complete eradication normally can be secured by one mid-summer treatment, two or three spring and fall applications will be required. Most reports indicate that 2,4-D kill for willow is about the same for spring and fall treatments, with less regrowth form fall operations. In treating plants like lotus, exhibiting a critical spraying period of June - August, aircraft is not recommended in cotton and bean country.

Inasmuch as the bulk of the cost of 2,4-D treatments by aircraft is for the 2,4-D itself, it is worthy of note that since its development there has been a substantial decline in the price, until this year. In 1949, the Service paid an average price of $4.80 per gallon for the ester formulation; in 1950, the Service paid an average price of $2.79 for the ester, and $2.85 per gallon for the amine form; this year all prices have advanced slightly, with ester costing $3.38, the amine at $3.40, and 2,4,5-T at $9.75 per gallon.

In analyzing the difference in price between the amine and the ester formulations, certain factors must be considered. The ester purchased in 1950 for $2.79 per gallon had 3.34 pounds of acid-equivalent per gallon, bringing the cost of one pound of acid equivalent to $0.75. The amine selling at $2.85 per gallon in 1950, contained four pounds of acid equivalent, making the cost of one pound of acid-equivalent $0.71. At this point the amine is slightly cheaper than the ester. However, it is general practice to boost application rates when the amine is used in place of the ester for comparable results on most species, and this factor usually favors the ester as being the cheaper of the two formulations.

It is believed generally that use of the ester has more potential hazards to crops than applications made with amine. The latest theory on this difference is not that the ester has greater volatility, but that micro-quantities of the ester have greater lethal effects on plants than the same quantities of amine. Use of the amine in preference to the ester offers no escape from crop damage.

Other than the cost and hazard differences between the two formulations, the ester has some decided advantages. The ester is relatively stable chemically, and can be stored one or more years without deterioration, while the amine is unstable and can experience precipitation of ingredients in long storage. The ester can be mixed with oil or water, whereas oil cannot be used with the amine. Oil in itself offers some degree of phytotoxicity, and there is evidence to show that non-polar molecules are more readily absorbed by the waxy cuticles of many aquatic plants than the highly polar molecules of water. Two other advantages of an oil diluent are that it does not wash off with a rain falling two to four hours after treatment, and more complete coverage can be obtained in extremely low volume treatments, such as that employed in aircraft spraying. Our experience with high-volume ground sprayers indicates that the use of oil as diluent (100 - 400 gallons per acre) seldom can be justified.

COST OF AIRPLANE APPLICATION OF 2,4-D

Tables 1 - 3 show the detailed breakdown of aircraft spraying for three years. The 1951 spraying was carried out with a Piper PA-18 airplane, with 125 h.p. Lycoming engine, and 85-gallon spray tank having output regulator. This was a great improvement over the airplane used in 1949 - 50, a Piper J5C, with 100 h.p. Lycoming engine, and 30-gallon spray tank with no output regulator. With the new plane it was possible to treat a flight-line with one pass, whereas with the old plane it was usually necessary to make three or four passes over each personnel marked flight-line to deliver the proper poundage and wetting.

Study of the data in these tables show that single application costs of 2,4-D by aircraft have ranged from $2.74 to $7.13 per acre. An application of 2,4,5-T formulation cost $7.45 per acre.

COST OF OTHER METHODS OF 2,4-D APPLICATION

In Table 4 are presented less-detailed but typical data on cost of applying 2,4-D by other methods. Non-power boat spraying, using two or three man crews, high pressure and high volume sprayers with 50 - 100 gallon tanks, cost $4.61 to $6.85 on open water vegetation. Along stumpy and shallow shorelines, with increasing difficulty of movement and application, the cost ranged from $7.80 to $15.50 per acre. Flooded timber impaired operation also, and costs ranged from $9.71 to $17.70 per acre. It should be realized that most of these operations represent sites where it was not desirable to employ aircraft.

Use of the Gulf Coast marsh buggy to eradicate inaccessible spot invasions of pest plants usually was more expensive than boat or airplane. While marsh buggy operations have been carried out more cheaply than the information on the table indicates, the $46.90 per acre treatment of water hyacinth represents one of the most difficult refuge jobs of plant eradication attempted. Hyacinths were growing in areas overtopped by sawgrass and willow, which prevented aircraft spray from reaching them, and the vegetation was so rough and inacessible that only one to one and one-half acres per day could be sprayed. However, this investment was worthwhile, since it reduced the threat of hyacinth ruining a huge impoundment.

Latest operations from truck-mounted sprayers, principally on dike brush, have shown typical operations with 2,4-D costing $4.85 per acre (Savannah Refuge, Georgia) and $6.60 per acre (St. Marks Refuge, Florida), and $9.40 per acre for 2,4,5-T formulations (St. Marks Refuge, Florida).

It could be pointed out that all discussions of per acre costs so far represent actual application costs for one treatment of an acre, and do not refer to cost of complete eradication. As will be discussed, the eradication costs vary with the

Table 1. Cost analysis of 2,4-D spraying by aircraft for 1949.

Refuge	Species	Acres	Lbs. Acid per Acre	Cost Materials ($)	Actual Spray Flight Time	Total Cost ($)	Cost per Acre	Total Flight Time[a]	Total Ground Time[b]	Cost Total Flight Time ($)	Cost Total Ground Time ($)	Total Cost ($)	Total Cost Per Acre ($)	Actual Spray Flight Cost Acre ($)
Lacassine,	Lotus	21.1	3.0	65.83	2:20	77.08	3.65	4:00	1:30	19.32	1.13	86.28	4.09	0.52
Louisiana	Primrose	47.0	3.0	146.17	4:50	169.35	3.60	6:50	2:00	32.84	1.50	180.51	3.84	0.50
	Hyacinth													
Savannah,	Primrose	130.0	2.0	417.30	9:25	462.70	3.56	10:25	46:00	50.23	34.50	502.03	3.87	0.35
Georgia	Waterlily	130.0	2.0	417.30	10:00	465.60	3.57	12:30	48:00	60.38	36.00	513.68	3.95	0.37
	Lotus													
	Alligator weed													
St. Marks,	Cattails	165.0	3.34	840.91	12:35	901.77	5.47	22:42	208:00	109.64	156.00	1106.55	6.71	0.37
Florida	Waterlily	165.0	3.34	840.91	11:00	894.04	5.42	18:07	89:00	87.42	66.75	995.08	6.00	0.32
		165.0	2.50	638.55	8:25	679.12	4.12	12:00	50:00	57.96	37.50	734.01	4.45	0.25
	Sagittaria													
Tishomingo, Oklahoma	Willow	300.0	3.34	1578.00	10:00	1626.30	5.42	19:40	36:20	95.15	27.23	1700.38	5.67	0.16
Tishomingo, U. S. Army Engineers	Willow	200.0	3.34		6:35			10:15						0.16

[a] Total Flight Time: Includes all flight time from airport to spray site plus actual spraying time. Does not include salary of Pilot.
[b] Total Ground Time: All ground time used in operation, including mixing 2,4-D, loading, guiding, etc. Aircraft used was Piper J5C, 100 h.p. engine, 30 gallon spray tank.

Table 2. Cost analysis of 2,4-D spraying by aircraft for 1950.

Refuge	Species	Acres	Lbs. Acid per Acre	Cost Materials ($)	Actual Spray Flight Time	Total Cost ($)	Cost per Acre	Total Flight Time[a]	Total Ground Time[b]	Cost Total Flight Time ($)	Cost Total Ground Time ($)	Total Cost ($)	Total Cost Per Acre ($)	Actual Spray Flight Cost Acre ($)
St. Marks, Florida	Waterlily	250	3.34	755.00	17:50	840.97	3.36	25:05	43:00	121.23	32.25	908.48	3.63	0.34
	Willow Sagittaria		3.34	755.00	16:35	835.18	3.34	20:09	32:00	97.08	24.00	876.08	3.50	0.32
Tishomingo, Oklahoma	Willow	300	3.34	1025.00	9:27	1070.88	3.57	15:02	45:00	72.45	33.75	1131.20	3.77	0.15
Lacassine, Louisiana	Lotus	50	2.0	94.00	6:43	126.36	3.70	7:43	8:00	37.19	6.00	137.19	2.74	0.65
Bull's Is., SC	Cattail	36	4.0	97.92	1:24	104.68	2.91	3:31	16:00	16:91	12.00	126.83	3.52	0.19
Crab Orchard, Illinois	Lotus	68	2.0	248.80	3:00	263.29	3.87	3:50	6:00	18.35	4.50	271.65	3.99	0.21

[a] Includes all flight time from airport to spray site plus actual spraying time. Does not include salary of Pilot.
[b] All ground time used in operation, including mixing 2,4-D, loading guiding, etc. Aircraft used was Piper J5C, 100 h.p. engine, 30 gallon spray tank.

Table 3. Cost analysis of 2,4-D, and 2,4,5-T spraying by aircraft for 1951.

Refuge	Species	Acres	Lbs. Acid per Acre	Cost Materials ($)	Actual Spray Flight Time	Total Cost ($)	Cost per Acre	Total Flight Time	Total Ground Time	Cost Total Flight Time [a] ($)	Cost Total Ground Time ($)	Total Cost ($)	Total Cost Per Acre ($)	Actual Spray Flight Cost Acre ($)
St. Marks,	Cattail		3.34	724.00	11:07	779.50	3.90	14:23	136	72.00	122.40	918.40	4.59	0.28
Florida [b]	Willow	200	2.10	640.00	4:00	660.00	3.30	5:06	24	25.50	21.60	687.10	3.44	0.10
	Sagittaria		2.10	640.00	4:06	660.50	3.30	6:06	24	30.50	21.60	692.10	3.46	0.10
	Total	200	7.54	2004.00	19.13	2100.00	10.50	25:35	184	128.00	165.50	2297.60	11.49	0.48
Cape Romain,	Cattail	25	3.34	90.50	1:06	96.00	3.84	1:30	12	7.50	10.80	108.80	4.35	0.22
SC			3.34	90.50	1:00	95.50	3.82	1:36	9	8.00	8.10	106.60	4.26	0.20
			3.34	90.50	1:06	96.00	3.84	2:00	9	10.00	8.10	108.60	4.35	0.22
	Total	25	10.02	271.50	3:12	287.50	11.50	5:06	30	25.50	27.00	324.00	12.96	0.64
Bull's Is., SC	Cattail	25	3.34	90.50	1:00	95.50	3.82	1:42	5	8.50	4.50	103.50	4.14	0.20
Savannah,	Primrose	55	3.34	199.10	2:00	209.10	3.80	2:30	8	12.50	7.20	218.80	3.99	0.18
Georgia	Waterlily													
Bombay Hook,	Willow													
Delaware	Maple													
	Ash	30	3.34	204.45	1:00	209.45	6.98	2:00	10	10.00	9.00	223.45	7.45	0.17
	Buttonbush			(2,4,5-T)										
Tennessee, Tennessee	Willow	220	3.34	796.40	6:18	827.90	3.76	12:06	110	60.50	99.00	955.90	4.34	0.14

[a] Cost of flight time does not include salary of Pilot.
[b] Aircraft used for first St. Marks spraying was Piper J5C. Aircraft used for all other treaments was Piper PA-18, 125 h.p. engine, 85 gallon spray tank.

Table 4. Typical 2,4-D applications costs — boat and marsh buggy[a].

Method[a]	Species	Location	2,4-D lbs. per Acre	Acres	Range of Cost per Acre ($)	Average Cost per Acre ($)	Date Applied	Remarks
Boat	Willow	Lake Isom, TN	4.0	20	–	7.80	7/10 - 14/51	
Boat	Willow	Santee, SC	5.0	4	–	9.19	6/7/51	
Boat	Cattail	Bulls Is., SC	3.34 - 26.75	15	5.10 - 26.65	15.50	4/26 - 28/49 6/27 - 29/49	Shallow pond edge, difficult boat work.
Boat	Water-lilies Primrose Alligator-weed	Savannah, GA	1.5 - 3.34	70	4.30 - 6.50	4.61	5/25 - 9/1/50	Open water, scattered beds.
Boat	Lotus	Savannah, GA	1.8	6	–	6.85	6/7 - 10/48	Open water, 7 beds.
Boat	Lotus	Reelfoot, TN	4.0	80	8.87 - 12.20	9.71	8/1 - 9/15/50	Flooded timber, difficult to treat.
Boat	Lotus	Lake Isom, TN	4.0	8	–	17.70	7/17 - 25/50	
Boat	Lotus	Santee, SC	3.34	15	–	4.83	6/29 - 7/3/51	Sunrise spraying to avoid drift to adjacent cotton.
Marsh buggy	Water hyacinth	Lacassine, La.	12 - 15	17	–	44.50	6/5 - 16/50	Fuel oil carrier.
Marsh buggy	Water hyacinth	Lacassine, LA	12 - 15	27	–	32.00	6/19 - 7/21/50	Watter carrier and cheaper 2,4-D
Marsh buggy	Water hyacinth	Lacassine, LA	–	2	–	46.90	Summer, 1951	All hyacinth in rough marsh; only 1 - 1½ acres treated daily.
Marsh buggy	Water hyacinth	Sabine, LA	4.0	12	–	13.25	Summer, 1951	Drought-drained marsh.

[a] Sprayer and pumps used were high-pressure, high volume Bean, Hardie, and Panama, with 50 - 100 gallon tanks. Boats were non-power units, oar propelled usually, with two or three man crew.

species, time, locale, and other features. Complete eradication does not occur often with one treatment.

THE EFFECT OF HERBICIDES ON UNDESIRABLE AQUATIC VEGETATION

In addition to the operations listed on the tables, considerable other herbicidal work on an operational basis has been carried out for which accurate cost data are not available. Also, many hundreds of plots and strips have been treated through the years with a variety of herbicides and concentrations. From all of this work examples will be presented with comments on the specific effects of certain treatments.

Willow *(Salix* spp.)

At Tishomingo Reservoir, Oklahoma, a 300 acre mud flat stand of willow (12 - 15') was treated by airplane July 29 and August 4, 1949. It was not flooded during this particular growing season. Observations the following spring revealed practically 100% kill; excellent volunteer stands of smartweed had matured throughout the dead willow. By late August, 1951, however, new invasion from willow seedlings was common as a result of severe flooding in the spring of 1951.

As continuation here, 300 more acres were treated April 6 - 14, 1950. For three weeks lethal symptoms closely resembling those obtained in the 1949 treatment occurred. At this point flood water enveloped the area, the water level remaining high until winter. Results in the spring of 1951 showed no kill.

At St. Marks Refuge, Florida, a March 27, 1950 and May 31, 1950, second treatment of 100 acres of willow *(Salix nigra* Marsh and *Salix caroliniana* Michx.) on exposed soil yielded a 95% kill. In 1951, an additional 200 acres sprayed April 24 - 26 yielded a 95% kill (to date).

On the Tennessee Refuge, for 220 acres of willow treated on area dewatered May 18 - 21, 1951, the typical 2,4-D symptoms of complete defoliation resulted, but with the start of a marked "wet spell" came a regrowth of willow foliage, reaching complete regrowth by this fall. On September 29 - 30, 1951, a second treatment was made.

From a comparison of these trials it is thought that for major success in willow control, the principle of complete dewatering during the spray and post-spray period has been demonstrated; likewise, that eradication can be secured by one to two applications of 2,4-D (3.34 acid lbs. per acre each treatment).

Strip studies at Savannah on drained and burned maidencane — willow have failed to yield complete eradication of willow with 90% Sodium T.C.A. up to 380 pounds per acre. To secure complete destruction with Ammate, required 600 pounds per acre, and with Polybor-chlorate, 1400 pounds. Cost of such treatment cannot compete with 2,4-D application for this species.

Buttonbush *(Cephalanthus occidentalis)*

Operational work through the years has failed to accomplish button bush eradication with 2,4-D, in water or on drained soils. In one series of tests it was killed on dike slopes by 5.5 pounds of 2,4,5-T acid per acre, but not by lesser amounts. The following maximum tests per acre also failed in 1951 plot studies (Savannah Refuge, Georgia) to secure 100% eradication — 500 pounds of 90% Sodium T.C.A., 625 pounds of Ammate, 1400 pounds of Polybor-chlorate. At Santee Refuge, South Carolina, however, fire-damaged bushes on drained plots succumbed to 110 pounds of 90% T.C.A. (per acre), and 435 pounds of Polybor-chlorate. The water relationships and tolerances of this species need investigation.

Cattails *(Typha* spp.)

The most extensive treatment of cattail by airplane was made at St. Marks Refuge, Florida, in three impoundments. The Picnic Pond area covers 40 acres, and prior to spraying, was dense *Typha latifolia* and a little *T. domingensis.* In winter, 1948 - 49, the area was drained and spray treatments made on May 10, June 13, and July 18. By fall a 70% kill and a good volunteer crop of wild millet *(Echinochloa)* had resulted. The area was again drained in late winter of 1949 - 50, and 2,4-D treatments made on March 27 and May 31, 1950. By fall the cattail had been practically eliminated, and the area was covered by a dense stand of wild millet, from volunteer and sown seed supplies.

The Mounds Pool area, 110 acres, received identical treatments as the Picnic Pond. Pest plants in this area included two cattials, bull-tongue *(Sagittaria lacifolia),* and white waterlily *(Castalia odorata).* The intial treatment practically eliminated *Sagittaria.* Although treatments of waterlily showed surface kills of 100%, a high percentage of regrowth occurred after each treatment in 1949, and by fall had started encroachment of some clearings in dead cattail. The species in 1950, however, was killed completely with the first treatment. It is believed that making the initial treatment a little earlier to coincide with *early* flower development, was the principal factor in effecting complete eradication of waterlily. The cattail, after five treatments in two seasons, exhibited 80 - 90% control.

Results in the Mounds Pool were definitely not as successful as the results in the Picnic Pool (where not a single cattail could be found). It was thought that the better soil conditions in Picnic Pool permitted a lush growth of wild millet, restraining weakened cattail growth; although Mounds Pool received heavy application of wild millet seed, there was little germination or natural growth.

It was the original plan to flood the pools soon after the last May treatment, but lack of rainfall kept both units dry. This resulted in the invasion of considerable *Spartina* grass. It is hoped that a period of flooding will control the undesired *Spartina,* even though the pools cannot be managed as drawdown sites for millet.

The St. Marks Refuge work indicates that five treatments over a two year period are needed for cattail eradication, total cost for five applications reaching $24.33 per acre, far below the cost of boat spraying or marsh buggy spraying of cattail. At St. Marks Refuge, *T. latifolia* succumbed more easily than *T. domingensis.*

A large series of experimental treatments of unburned, flooded cattail was made at Bull's Island, S.C., in April, 1949, and a second treatment in June - July. Spraying was done by boat in 1 - 3 ft. water on *T. domingensis, T. latifolia* and *T. angustifolia;* first flowering was just occurring *(T. domingensis)* when spraying started. Tests covered 2,4-D (3.34 - 25.74 pounds acid-equivalent per acre), 2,4-D and 2,4,5-T mixed (6.64 pounds), and 2,4,5-T (3.34 - 13.34 pounds). From this test several things were obvious.

1. There was poor correlation between the reaction by species with the amounts of 2,4-D. This problem was complicated by the varying stage of growth, water depth and distance from sprayer. In this complex, results from two sprayings were unsatisfactory, with complete eradication secured only on the second treatment with the most excessive concentrations of 2,4-D and 2,4,5-T. At this rate, cattail eradication would cost $50.00 to $100.00 per acre.
2. *T. domingensis* killed more easily than *T. latifolia* and that species more easily than *T. angustifolia*. The problem of treatment at the critical period of cattail growth (flowering to early fruiting) was difficult to arrange, since there was over a month's difference between this stage in the early *domingensis* and the late *angustifolia* that summer.
3. Attempts at "drifting" 2,4-D water sprays into inaccessible beds, 50 to 150 feet from boat, were complete failure. On such sites extensive labor and hose work throughout the beds increases cost.
4. Excessive concentrations of 2,4-D ester solutions falling in 6 to 12" water throughout cattail beds easily killed large-mouthed bass and blue-gill bream frequenting these sites. It did not occur in open water of the same depth, where slight wave action was noticeable.

In the same period at Bull's Island a supplementary series of small plots were treated by back-pack pump on another pond, on *T. latifolia*, growing in water. Effects of one treatment were as follows: 1) Maximum treatment of 16.7 pounds of 2,4-D acid per acre still left five per cent regrowth, a non-acceptable condition; 2) maximum treatments of 8.35 pounds of 2,4,5-T acid per acre still left a trace of cattail regrowth; 3) the water depth (6 - 24") was a major factor in determining amount of regrowth; 4) kerosene as a carrier provided no better kill than water solutions plus wetting agents.

The best control of cattail experienced by the writers occurred in 1947 at Bull's Island, South Carolina, on plot studies. Twenty-four 1/100 acre plots were treated by portable sprayers. On May 6, six plots of *T. domingensis* (5 - 7' tall, burned the previous winter to remove dead rough, 11 - 21 plants per square yard, on wet soil to 7" water) were treated with 2,4-D ester, acid-equivalent of 3.3 to 16.7 pounds per acre. Wetting was very thorough, 400 gallons of water to the acre. Results were as follows: 1) A trace of 1% regrowth; 2) lightest treatment just as successful as heaviest; 3) greatest regrowth, only 1%, in water plots; 4) clean marsh floor permitted wet soil plots to experience complete and rank competitive cover of giant foxtail *(Setaria magna)*, wild millet *(Echinochloa walteri)*, rice cutgrass *(Leersia)* and cordgrass *(Spartina patens)*. Control plot had even denser cattail by end of season. The following year all of the plots in series retained their identity, springing up to annual grasses in an otherwise solid pond of cattail.

Plots 7 - 12 were somewhat similar, but the tropical cattail was cut 4 - 12 inches *above* water (4 - 15" deep) and the butts sprayed in the same manner as above. Regrowth was 15 - 30%, with greatest amount from deepest water. Cutting above water, plus 2,4-D, gave poorer results than the approved method of *underwater* cutting (which usually yields 90% control on the first cutting).

The mature regrowth from plots 7 - 12 was sprayed a second time on July 1, but this gave 10 - 40% regrowth. However, concentrations as low as 0.75 pounds of

2,4-D acid per acre killed back all leaves on second treatment. Since this area had not been burned in the previous winter debris was abundant, which prevented the release of extensive germination of annual grasses on drained portions. In sites covered with water, the thinning of cattail did permit an increase in coontail and duckweeds.

The remaining 12 plots repeated the experiments with *T. latifolia*, and results were about the same.

The correlation between best kill and drawdown, plus abundant annual grass growth, also has been demonstrated on a larger scale by the most recent airplane treatments of Bull's Island and Cape Romain marshes, where studies on the value of discing and spraying are being made.

From the extensive observations on cattails, the program for most efficient eradication can be summed up as follows:

1. Drain in late winter, at end of maximum waterfowl use, and burn.
2. Spray drained marsh beds with average 2,4-D solutions (3 to 4 pounds of acid-equivalent per acre), using plenty of carrier to achieve thorough wetting.
3. Do not spray young plants, but commence operations at flowering stage or perhaps just before it.
4. If supplies of annual, 2,4-D resistant grass seeds are not in soil, sow area with quick germinating wild millet or Japanese millet, for competition and food.
5. Give cattail regrowth a second treatment about a month later, particularly after competitive grasses have made good growth.
6. Where cattail is growing in water that cannot be removed, or where airplane and boat application cannot achieve the thoroughness of leaf-wetting that appears necessary for cattails, as many as five treatments over two years may be necessary for eradication.

Maidencane *(Panicum hemitomon)*

This coarse grass, like giant cutgrass *(Zizaniopsis)* and cane *(Phragmites)*, has resisted well attempts at herbicidal control while growing in water. While the exact tolerance, water relationship has not been determined in our herbicidal work, we have concentrated on working out control methods on those areas where water can be removed through drainage or drought action. This permits fire destruction of rough prior to treatment and exposure of all foliage during spraying. The eradication of maidencane is necessary before many drawdown marshes, strategically located potholes or lake edges can be made to produce an abundance of waterfowl foods. Savannah Refuge studies on the plant's regrowth abilities show that "control" has not been accomplished until the last sprig has been eradicated. Fortunately, the plant does not reestablish readily by seeds.

While this June's work cannot be judged finally until next spring, it would appear that maidencane was eradicated at Savannah Refuge on burned "rice-field" ditches (where plowing could not be accomplished) by 500 pounds of 90% Sodium T.C.A. per acre but not by 380 pounds. It was not eradicated by 625 pounds per acre of Ammate or 1400 pounds of Polybor-chlorate, or reasonable mixtures of the three. This season's experiments at Santee Refuge, South Carolina supplemented the Savannah Refuge observations, where June minimum applications of 435 pounds of 90% T.C.A. were required for complete removal or 327 pounds total in two treatments. This effect was also achieved with 5½ tons of dry Borascu per acre, 2¼ tons of Polybor-chlorate, and 2¼ tons of Polybor-chlorate "88." With T.C.A. at $0.36 a pound, Polychor-chlorate at $0.31 a pound, and Borascu at $0.04, these operations are not economical to date. From less conclusive experiments it appears that the future control of maidencane by herbicides may be perfected by successive applications of moderate amounts of several herbicides. In line with this a large series of 1/10 acre plots at Savannah Refuge in 1950 revealed that multiple tractor-discings interspersed with two applications of 35 and 25 ponds of T.C.A. or Ammate yielded complete eradication, whereas five discings alone still permitted 1% residual stand in the following spring. No control of maidencane by 2,4-D has been observed.

A repeat of portions of this experiment starting in February, 1951, when the new cane on burned and drained marsh flats was only one-inch tall, revealed that ground sprays of various herbicides had very little effect at this early stage of plant growth.

As for giant cutgrass *(Zizaniopsis),* plot studies on well-drained pond edge show that the plant is more easily killed in this habitat than maidencane, reacting to T.C.A., Polybor-chlorate, Ammate, 2,4,5-T and even 2,4-D.

Lotus *(Nelumbo pentapetala)*

Reference to Tables 1 - 4 will indicate the numerous operations on this undesired species. Lotus offers no problems of control with 2,4-D and two pounds of the acid-equivalent per acre, in water or oil carrier, is all that is required for practically 100% control. On some of our operations we have had not one pad of regrowth, and only a few seedlings in successive years. In using the ester formulations in water solutions, tests of several wetting agents have indicated that these agents are not required, although actual foliage wetting certainly appears much more satisfactory when they are employed.

The only times when lotus eradication was not secured by one treatment were in 1) May applications (when large percentage of young plants were still under water), 2) in September when active blooming had ceased locally, and 3) where timber snags prevented proper approach of equipment. Treatment, therefore, should be during the late June to late July critical period of blooming-early fruiting.

Water-hyacinth *(Eichhornia crassipes)*

As with lotus, the control of water hyacinth with 2,4-D has not been as serious a problem as first anticipated; that is, moderate applications of 2,4-D will kill the plant, and heavy applications will make the rotting mats sink completely. Control operations have been carried out on our areas principally at Lacassine Refuge, Louisiana, and Okefenokee Refuge, Georgia.

On well-exposed hyacinth airplane application of three pounds of 2,4-D acid yielded 99% control. When protected by lush growth of sawgrass, hyacinth was not affected by airplane application. This necessitated the use of marsh buggy operations, with heavy applications of 2,4-D to insure absolute eradication. The high cost of this was pointed out earlier, and in Table 5, but was well justified in protecting the huge Lacassine Refuge impoundment.

White waterlily *(Nymphaea odorata),* Spatterdock *(Nuphar advena),* and Water-primrose *(Jussiaea grandifolora* and *J. diffusa)*

These plants are grouped since they represent water surface species that are fairly tolerant of 2,4-D, and require greater attention than lotus. Except for *Jussiaea diffusa,* which has been eradicated by single 2,4-D treatments, these plants, in flooded habitat, require four to six treatments over two (even three) years. This has been demonstrated particularly at Savannah Refuge, Georgia and St. Marks Refuge, Florida, with airplane, boat and portable sprayers.

Spot treatments by boat permits adjacent, unsprayed watershield *(Brasenia)* to spread into the treated zones. This competition aids in eliminating the undesired species. While water shield can withstand nominal exposure to 2,4-D, successive treatments by aircraft will eliminate this desired species along with the others.

While it may appear desirable to lower water on waterlily and primrose beds to expose more of the growth to 2,4-D, it was observed at Savannah Refuge, Georgia, that wholesale germination of white waterlily seeds will occur in the shallower and warmer water resulting from the drawdown and 2,4-D "thinning" of mature plants. In this manner the potential good effects of spraying could be counteracted. Such widespread and rapid germination of seeds has not been observed for lotus following spraying.

While tests have not been complete enough, it would appear that *Jussiaea grandiflora* was killed more easily on exposed soil than in flooded habitat, but multiple treatments were necessary under both conditions.

Results with white waterlily have been most conflicting. Generally, at St. Marks Refuge, Florida, this plant has been more resistant to 2,4-D than at Savannah Refuge, Georgia, because of racial, soil, or other habitat differences. On the other hand, at least one job on St. Marks Refuge waterlily achieved a 99% kill from the first treatment of the second season, when drastic drawdown and pond bottom exposure accompanied treatment.

A variety of tests with wetting agents failed to establish a marked increase in killing power through addition of such chemicals in water sprays, although the use of wetting agents certainly guarantees better coverage of waxy leaf surfaces.

Alligatorweed *(Alternanthera philoxeroides)*

It would be fruitless to list the large number of plot and operational studies that indicate our inability to destroy economically alligatorweed, or "pigweed," as it is known in some sections of the Southeast. When the plant is growing in water it has not been eradicated by successive treatments over four summers (Savannah Refuge). In this habitat, however, it can be "kept back" to pond shores and canal banks by three to six 2,4-D sprayings a summer. The alternative to this is extensive encroachment by the untreated plants to impede boat movement, fish production and waterfowl management.

On drained soil we have experienced, by 2,4-D application, total eradication only in a few instances, through 3 to 5 treatments in two (sometimes one) season. This has been on such a small scale and so exceptional that its occurrence on the

Table 5. Cost analysis of aircraft seeding for 1950 and 1951.

Refuge	Seed Species	Acres	Lbs. Seeded	Actual Seeding Flight Time[a]	Total Seeding Flight Time	Total Ground Time	Cost Total Flight Time ($)	Cost of Seeding per Lb. ($)[b]	Cost of Seeding per Acre[b]
1950									
St. Marks, Fla.	W. Millet	78.0	2,350						
	Smartweed	166.0	5,000	14:59	19:52	57:00	96.12	0.019	0.57
Wheeler, Ala.	W. Millet	100.0	3,000	3:51	4:20	16:00	20.77	0.011	0.33
Santee, S.C.	Ryegrass	40.0	2,000	2:39	4:15	12:00	20.53	0.015	0.74
Wheeler, Ala.	Ryegrass	40.0	2,000	3:03	3:30	12:00	16.90	0.013	0.65
Tennessee, Tenn.	Ryegrass	100.0	4,000	4:30	5:20	24:00	25.60	0.011	0.44
1951									
St. Marks, Fla.	Jap. Millet	167.0	5,000	4:18	6:48	21:00	34.00	0.009	0.26
	Smartweed	33.0	1,000						
Savannah, Ga.	W. Millet	77.0	2,300	2:06	2:24	8:00	19.20	0.008	0.25
Wheeler, Ala.	W. Millet	111.0	3,500	2:00	2:18	5:00	16.00	0.005	0.14

[a] 1950 Aircraft — Piper J5C. 1951 Aircraft — Piper PA-18.
[b] Cost of seed not included.

average operational basis cannot be predicted. Tests showed that excessive amounts of 2,4-D, use of wetting agents, or a variety of carriers did not insure any better control of the plant. Most recent tests (1951) at Savannah Refuge indicated that on drained soil, Ammate, Chloro-I.P.C., T.C.A., various forms of 2,4-D, King-o-cide, 2,4,5-T, diesel oil, nitrate of soda, and crushed limestone, did not promise certain economical control within one season's treatment. By control is meant elimination of every viable sprig and node.

With such a degree of eradication needed the principle of soil sterilization was investigated. Extensive plot studies (on continuous summer drawdown slopes) made at Savannah Refuge this year showed that on a 100 square foot basis the following herbicidal applications appeared to achieve complete eradication of alligatorweed (Table 6). These data are only relative and approximate, since soil type, soil moisture and rainfall obviously have much bearing on the effectiveness of soil sterilants.

Table 6. Herbicide application attempted for eradication of alligatorweed.

Herbicide	Method of Application	Amount Applied Per 100 sq. ft. (lbs.)
Polybor-chlorate	Dry	10 - 20
Polybor-chlorate	Dry	10 [a]
Polybor-chlorate	Water	10
Polybor-chlorate	Water	$<$ 10 [a,b]
Bozascu	Dry	20 - 30
Atlacide	Dry	20 [c]
Salt	Dry	75 [d]

[a] Followed by 2,4-D on regrowth.

[b] Polybor-chlorate, water or dry, in two applications up to a total of 7.5 pounds would not eradicate alligatorweed.

[c] Atlacide, water or dry, with or without 2,4-D later, did not eradicate alligatorweed at 10 pounds.

[d] The highest rate applied did not eradicate alligatorweed.

Two other series of soil sterilization plots followed by flooding indicate some interesting possibilities in pond management. One series of Polybor-chlorate (4/5/51) gave complete control of alligatorweed at 13 - 18 pounds per 100 square feet, and with Burascu at 14 - 45 pounds per 100 square feet. After flooding on May 15, a heavy volunteering of muskgrasses (Characeae) appeared by fall, with the only alligatorweed coming from lateral encroachment outside the treated spots.

The second series of plots treated with Polybor-chlorate on 5/1/51 and flooded 5/15/51 revealed that 8 - 13 pounds per 100 square feet killed all alligatorweed. Incomplete data indicated that it required less of the substance to react on damp flats than on dry flats, during drawdown. The same results were secured in similar tests on water primrose *(J. grandiflora)*, although this species appeared more sensitive to Polybor-chlorate than alligatorweed.

While the cost of large-scale application of any of the above soil sterilants would be prohibitive, the possibility of eradicating alligatorweed when it first gains entry in a fish pond or duck marsh is obvious, particularly considering that temporary soil sterilization represents the only one-treatment method of eradication for this insidious pest.

PRINCIPLES OF AQUATIC PLANT CONTROL

From our experience with herbicidal treatment of aquatic plants some general principles can be drawn. These do not apply to submerged aquatics. There are exceptions to each of these rules, but the generalizations would appear to hold true for Southeastern conditions.

1. Drain areas having undesired emergent marsh species in late winter prior to the season to be treated. This often can be made to coincide with a late January or February freeze, which will further assist in destruction of the pest plants. Dry and burn the wetland cover, for the following purposes: a) Fire removes the tremendous rough deposited by coarse marsh plants to allow better herbicidal contact with the growing tissues. b) It permits the better invasion of desired competitive annual plant growths after summer treatment. c) It permits better search by ground crews for low species like the alligatorweed. d) Better waterfowl feeding sites results the following winter.

   If 2,4-D treatment will not follow for several months the area can be kept drained or reflooded, depending on local seed supplies of pest plants. If reflooded for a few months, later draining will be necessary prior to summer herbicidal application.
2. When possible, make herbicidal application at the "critical period" of the plant's growth, which is usually in the flowering or fruiting stages. Avoid early spring treatment of young, vigorous marsh growths. When brush treatments must be applied in spring and fall, to avoid summer crop damage, several applications may be necessary to accomplish what normally can be done by one summer treatment.
3. If possible, keep water off of treated beds during and after spraying. A complete late summer drawdown seems best. This would apply particularly for operations on willow, cattail, maidencane, and alligatorweed.
4. After herbicidal treatment on drawdown areas, attempts should be made to secure quickly a stand of desirable plants to a) compete with damaged pest plants, b) blanket soil against seedlings of pest plants, c) provide abundant waterfowl food the following winter, d) provide a protective mulch through the following winter that will limit undesirable spring seedlings or permit a more thorough burn the second winter.

   On some of our coastal impoundments soil salinities appear too high to permit germination of desired annuals. Generally speaking, however, on most impoundments that have been in existence for a decade the impoundment soils possess abundant seed supplies of wild millet *(Echinochloa walteri, E. crusgalli)*, giant foxtail *(Setaria magna)*, fall panic-grass *(Panicum dichotomiflorum)* and smartweeds *(Polygonum spp.)*. These automatically cover drained areas denuded by average herbicidal applications. Some herbicides can cause temporary soil sterilization that inhibits desired seed germination.

   Where soils do not have abundant seed supplies of the desired species, sowing is recommended. Either wild millet, or the more rapidly germinating variety, Japanese millet (which is the variety usually supplied as "duck millet" by firms dealing in waterfowl food plants), is recommended for summer seeding, and Italian ryegrass is suggested for fall sowing (where winter flooding will not be experienced). Grasses are particularly valuable since, once established, they are resistant to additional 2,4-D applications in the summer.

5. In treating waterlilies and other pond surface growths (except alligatorweed), successive applications over several seasons will be necessary before eradication of the original plants can be expected. Lowering the water level in this habitat can permit widespread germination of waterlilly seeds in the warm shallows. Completely draining off the water may permit widespread germination of seeds from treated water primrose. Water manipulation must be handled carefully, for it is quite possible through improper manipulation to exchange one pest plant for another. Local conditions govern the practice.
6. Application of herbicides. Excessive amounts of 2,4-D are to be avoided since they seldom offer better kill. The economics of the problem suggest that the best results occur with applications of two to four pounds of 2,4-D acid-equivalent per acre for each treatment. While aircraft can treat an acre with as little output as two to four gallons of oil solutions, ground spraying of the larger species requires solution output of 100 to 400 gallons per acre. Under the latter conditions, therefore, the economy of using anything but water as a carrier is obvious. The use of oil in high-volume spraying is justified only in spot spraying of particularly obnoxious species (ex., water-hyacinth) where the acreage is not large. While wetting agents may be valuable for increasing the distribution of water solutions on waxy surfaces, it has been found with ester forumlations of 2,4-D that the wetting agents do not guarantee a better kill. However, with herbicides in powder form it may be desirable to use wetting agents, although our experience to date indicates no startling results from using them.
7. Coarse aquatic grasses, particularly maidencane, have shown greater resistance to Sodium T.C.A. than their upland counterparts (Johnson grass and Bermuda grass). In controlling maidencane, application of the drawdown principle appears most economical. While herbicidal control costs for such sites are still excessive, there is some promise that successive treatments with several herbicides is better and cheaper than using large amounts of one herbicide, or mixed solutions of several; also, that herbicides plus discing are cheaper than herbicides or discing alone.
8. For alligatorweed, which is in a class of its own in resisting eradication, the best herbicidal use has been demonstrated on drained soil. So necessary is it to destroy this plant when it first invades an impoundment that the use of soil sterlizing herbicides is recommended where water can be removed. In this manner colonies can be eradicated in one treatment, with soil sterilization usually a temporary condition. The use of soil sterilants particularly deserves investigation by field men responsible for controlling weed growths around and in fish ponds or display pools.
9. No plant control program should be planned on a one application, or even a one season, basis. The final results are never certain until the growing season following treatment. Although lotus often can be removed in one treatment, the destruction of cattails, waterlilies, etc. by herbicides is a multiple treatment job.