Aquatic Weed Control In the United States

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For the historical aspects of the aquatic weed control one refers to Dr. F. L. Timmons who, with his many abilities, has become historian of aquatic weed research in the United States. Fortunately as leader of the United States Department of Agriculture's Agricultural Research Service aquatic-noncrop weed investigation section he has been in a position to document salient facts of aquatic weed control.

Going back beyond the introduction of 2,4-D to compare the early arsenal of water weed killers with the herbicides available today, it seems a little shocking to see that we still use sodium arsenite, copper sulfate, and aromatic solvents. This is not because they are perfect herbicides and no new ones have come along, but rather an indication of changes in policy to prevent too-rapid introduction of herbicides into our waters. There is a great deal of research under way—work that reflects the cooperative action of many agencies. Federal, state, and industry workers are quite often directly involved in a single project because the multiple-use concept of water utilization requires multiple responsibility for finding answers.

Recent renewal of USDA-ARS activity in aquatic weed control indicates the expanding need for answers beyond those of early work with irrigation and drainage areas of the United States. The amount of work was increased tremendously in 1957 when the Ft. Lauderdale, Florida, facility was established and research personnel were shifted to other weed problem areas. ARS soon found itself deeply involved in all phases of aquatic weed control.

The U. S. Army Corps of Engineers, responsible for keeping navigible waters open, had long been battling water hyacinth. In 1958 a bill authorizing an extensive aquatic plant control program involving eight states released funds for joint research projects and was responsible for the movement of research people into the field of aquatics. Another agency, Tennessee Valley Authority, suddenly has found itself the major experimenter in Eurasian milfoil control, putting increasing manpower and hours into resolving the ever-expanding problem in the chain of TVA lakes.

U. S. public health and water pollution agencies are becoming involved either directly in monitoring programs or indirectly through grant-in-aid programs such as the work being conducted by Dr. John Lawrence at Auburn University in Alabama. This work is concerned with the relationship of weed growth and water pollution. Perhaps the catalyst in the whole resurgence of interest in aquatic weed work is the developing philosophies of the U. S. Food and Drug Administration. The concern over what is going into our waters is requiring far more complex tests now than ever before. We in industry have to account for residues in waters as well as in fish. We are now concerned with effects on fish production and the total food chain. We are doing research to investigate possible effects on crops irrigated with treated waters and may concern ourselves with stock watering and human consumption.

Submersed Aquatic Weed Species

Early aquatic weed control work was primarily with pondweed species in western irrigation canals. The species most frequently subject to test was sago pondweed (*Potamogeton pectinatus*).

Recently (that is, over the past ten years), aquatic weed research has also been oriented toward other submersed species. The rapid spread of Eurasian milfoil (*Myriophyllum spicatum*) throughout the United States, and the more regional problem of Florida elodea (*Hydrilla verticillata*) has caused a marked increase in the number of projects proposed and carried out.

The problem of Eurasian milfoil has been receiving the greatest amount of attention judging by the scale and number of agencies involved. TVA. U. S. Army Corps of Engineers, USDA, the U. S. Department of Interior, the Florida Game and Fish Commission, as well as many individual states, are working to control Eurasian milfoil.

The rapid spread of milfoil following its normal pattern of unobstrusive introduction, a 3- to 4-year period of establishment, and a sudden crisis situation, has been responsible for several crash programs attempting to stem the tide. Perhaps the most fortunate characteristic of milfoil is its susceptibility to 2,4-D, established early in the USDI research program conducted by Steenis in the late 1950's. Recent efforts have been directed toward developing new application methods and formulations. Ease of applying 2,4-D granules was improved by Amchem's Spreader Disc for helicopters and the West Point Products Aeriblower for shoreline boat application. Last year, based on previous test plot work, the dimethyl amine form of 2,4-D was applied large scale during the month of May with considerable success. Steenis (1) has been utilizing fluctuating tidal movement to minimize operational difficulties. In its efforts to control milfoil in 1969 the Engineers utilized both helicopter and boat blower systems for applying granular 2,4-D. In Florida a multiple-agency operation organized a large-scale test program and used everything from an airboat to a helicopter to apply a wide range of herbicides and formulations to control Eurasian milfoil which had become a potential hazard to its resort spring attractions. A number of materials were effective, but all are more expensive than 2,4-D. Although 2,4-D is a partial chemical answer to this particular species, milfoil spreads so fast that no single approach is adequate. The 15 papers presented at a one-day TVA conference on watermilfoil research and control gives an idea of the scope of research activity by personnel involved with the species.

Elser (2), responsible for directing the operational weed control work in Maryland, reports that the decline of tremendous acres of Eurasian watermilfoil in the Chesapeake Bay could be pathological. Two diseases, Lake Venice and Northeast (names for convenience as they have not yet been positively identified and classified) were generally found in the regions of large-scale milfoil decline. Elser reports that Suzanne Bayley of Johns Hopkins University determined that the Northeast disease organism is a filterable agent, possibly a virus. A small controversy exists in the minds of several researchers as to whether the "disease" is in reality a response to high salinity associated with salt water intrusion which occurred over a period of drought years.

The amount of work on other submersed species is generally related to problem size and rate of increase. Florida elodea is rapidly becoming a major weed problem in Florida waters. Blackburn (3) found that acrolein, aromatic solvents, copper sulfate and a diquat-copper sulfate mixture provided temporary control, but the diquat-copper sulfate is the only treatment not highly toxic to fish. Other work on elodea reported over the past few years shows copper sulfate, mixtures of copper sulfate and diquat, diquat plus endothall, and blackstrap molasses added to phenoxy compounds controlled this species. Ware (4) reported that 100 lb of copper sulfate per surface acre provided economical control of elodea. Larger crystals produced better control. Foret (5) used blackstrap molasses as a source of aconitic and itaconic acid and glucose. These materials added to phenoxy compounds increased control of elodea and other submersed speces. In the laboratory at Ft. Lauderdale where the nutritional and reproductive studies of Florida elodea simulate field conditions, Weldon (6) found that the WASM formulation of endothall doubled or quadrupled effectiveness in field trials.

Sago pondweed and other potamogeton species still constitute a severe problem in the waters of the western irrigation systems. The partially-satisfactory aromatic solvents with their inherent danger to fish are being used, but search for a better solution continues. New herbicides are constantly being screened and new application techniques have been developed to make the current materials more same. Work pertaining to nutritional requirements for establishment and the physiological aspects of temperature and planting depths is under way on several submersed weed species. Bruns (7) showed that acrolein applied at 0.6 ppmw volatilized as the treated waters moved downstream. Calculated losses were equal to 22% at one mile, 53% at 3 miles and 98% at 19 miles. Weed injury was still occuring at mile 18. Hathrop (8) reported that a low-rate long-contact period of acrolein application had been successful in the Columbia River Basin Project. Concentrations of 0.1 ppmw over a 48-hour period provided excellent control of sago pondweed in canals carrying 300 CFS and in laterals carrying 150 to 300 CFS.

Copper sulfate is being used in a similar manner to control higher plants as well as algae. Bartley (9) controlled both sago and leafy pondweed over several miles of ditch with daily applications of 0.5 ppmw copper sulfate. A 6- to 8-week treatment period was needed to produce the desired effect. Of importance here was the lack of copper build-up in canal-bottom soils. Apparently pondweeds extract copper efficiently from treated water. With a single dump application of 411 lb in a 411 CFS flow canal (standard algae control rate is 1 lb/CFS) Bruns (7) found that 95% of the copper in 23 miles of canal was sorbed by suspended particles which dropped to the bottom and re-released the copper. No build-up occurred. In neither test were fingerling trout injured.

Riemer (10) partially filled a void in the knowledge of the action of copper in his work dealing with the behavior of copper sulfate in small ponds. He verified the ability of plants to keep the copper suspended when he showed that a heavy bloom of algae reduced the amount of copper in the water. He also showed that larger granules which sink to the pond bottom permit less copper sulfate to get into solution than the theoretical expected amount, yet at the same time that part which goes into soluion mixes rapidly throughout the water system. Riemer's hypothesis that the copper applied as large granules may be adsorbed on the bottom muds possibly explains why Ware felt he had achieved more effective control with larger granules. Perhaps concentration at the stem-root zone permitted greater adsorption by the plant.

Much additional work on the control of submersed species is in the literature and more is yet to be reported. This work varies from cultural characteristics of individual species to broad-spectrum response to herbicides. Riemer (11) determined that under New Jersey conditions cabomba (*Cabomba caroliniana*) over-winters primarily as vegetative portions of the plant. No viable seed was produced either in the laboratory or in field experiments. In the laboratory test optimum growth occurred at pH 6.0 in aerated water with low levels of calcium.

In terms of new chemicals or new uses for old chemicals total water treatments of diuron, endothall dihydroxy aluminum salt, Fenac, and dichlobenil control submersed species. Walker (2) reported that diuron in gelatin capsules weighted with sand controlled cladophora and spirogyra in cold-water ponds for three months. Pierce (13) and Hambric (14) had excellent control of a wide range of submersed species with diuron. Pierce indicated that at 0.6 to 1.0 ppm myriophyllum, eleocharis, and acicularis were resistant. Most of the filamentous algae appeared susceptible. Hambric found that 2 lb/surface acre controlled a wide range of species, dispersal throughout the water system was excellent, and apparently there was immediate absorption with resultant kill since extensive water exchange did not reduce the effectiveness of the treatment.

In current Amchem research Fenac applied at the 1 to 5 ppmw needed to provide disappearance information for label purposes controlled many submersed aquatic species, particularly pondweed, and also the fringe growth of cattails (*Typhus* spp.) commonly found around ponds.

Dichlobenil studied more for the control of emersed than for submersed species was applied preemergence to Illinois ponds in December by Hiltebran (15). Rate of 16 to 20 lbs prevented the growth of *Potamogeton pectinatus*; lower rates did not control *P. foliosis*. Yeo (16) knocked down American and curlyleaf pondweed, small pondweed, elodea, cattail, and cladophora in four weeks with 10 lb/A.

Regarding endothall, Patterson (17) refers to the dihydroxy aluminum salt as a particulate carrier which brings the herbicide in direct contact with aquatic weeds. Cortell (18) confirmed the advantage of its direct and prolonged contact with the plant.

Although this is a paper dealing with aquatic weed control research in the United States, the work of Wile in Ontario and Thomas on Prince Edward Island should be included. In both instances the work was stimulated by use demands. Ontario Water Resources Commission maintains aquatic weed research studies for answering the many requests for assistance in maintaining provincial farm-ponds and recreation waters. Thomas, Fisheries Research Board of Canada, worked out the details for 2,4-D granular control where eelgrass (*Zostera marina*) had become a severe problem in maritime province oyster beds.

The association of aquatic weeds and high nutrient levels in polluted waters has stimulated interest in that relationship. Investigating the effects of pollution on aquatic growth and development, Denton (19) selected three species: alligatorweed (*Alternanthera philoxeroides*), parrrotfeather (*Myriophyllum brassiliense*), and water hyacinth (*Eichhornia crassipes*) growing in polluted and unpolluted waters. The plants were analyzed for ash, carbon, nitrogen, phosphorous, calcium, magnesium, potassium, and sodium. Samples of water and bottom muds were analyzed for the same elements. Plant ash varied with water hardness but the carbon content differed little with the environment. Plant nitrogen, magnesium, and sodium varied considerably with the concentration of these elements in the water and bottom soils. Riemer (20) analyzed 30 species of aquatic plants and their surrounding waters, checking 12 chemical elements. The data was recorded but not interpreted. Ryan (21) reported the effects of fertilization on the growth and mineral composition of anacharis, two myriophyllum species, and *Potamogeton* pulcher. In a two-year study the four species showed unlimited consumption of nitrogen, phosphorus and potassium when fertilized. Anacharis and *Potamogeton pulcher* fertilized showed significantly higher yields than in control pools. Unfertilized *Myriophyllum spicatum* produced the greater yield. *Myriophyllum heterophyllum* responded to fertiziation in 1967, but not in 1968. This effect of excess nutrients was evident at Ft. Lauderdale where it was found that high levels were toxic to hydrilla.

The current indication is that morework will be done on this aspect, stimulated in part by attempts to utilize aquatic vegetation as a feed supplement, and also the possibility of utilizing aquatic plants to trap excess nutrients in runoff water.

Otto (22) used nitrogen and phosphorous at two enrichment levels but did not increase the total vegetative mass of *Potamogeton nodosus* or *P. pectinatus.* The two species have low nutrient level requirements which are met primarily by the parent vegetative propagule.

Emersed Aquatic Weed Species

In the United States the most important emersed aquatic weed species are water hyacinth (*Eichhornia crassipes*) and alligatorweed, both serious problems in navigable waters. Research for controlling these weeds is also important because mats of them provide ideal mosquito-breeding conditions. The phenoyx compounds seem to offer the best control, 2,4-D for water hyacinth and 2,4,5-TP (silvex) for alligatorweed.

Among new chemicals, in the water hyacinth work by Weldon and Blackburn (23) 3 lb/A ametryne was very effective. Associated residual studies showed that at that rate ametryne remained in the water in the treated area for 32 days. The problem of drift to susceptible crops precipitated work with ametryne. To avoid the hazard of drift and also of volatility Ball shifted to an oil-soluble amine form of 2,4-D applied through the MICROFOIL boom for treating hyachinths in the Loxahatchee Reservoir, situated in the center of the vegetable growing area around Lake Okeechobee in Florida.

Alligatorweed is still included in test programs because we do not have a herbicide that is satisfactory in all situations. Weldon and his co-workers (24) found that 5 and 10 lb/A of granular dichlobenil controlled rooted emersed plants, but not floating ones. Spencer (25) reported that 12 lb/A of silvex plus 3 lb ai of amitrol-T maintained 40% control of alligatorweed after a 12-month period. In an all-out attempt to eradicate alligatorweed in a California test, Pryor (26) achieved complete kill with a drench of 1 qt of Vampam plus 1 gallon of weed oil in 25 gallons of solution per 100 sq ft.

Although a few years ago 8 lb/A of 2,4-D seemed to be controlling water chestnut (*Trapa natans*), resurgent and spreading infestations are now requiring further research. Results of a test program started in 1965 by Steenis and Elser (27) indicate that mixtures of 2,4-D and dicamba applied to immature developing seeds cause these to rot. Seeds treated at maturity are sterilized. Treatments made before flowering had no effect on the seed viability or development.

In the lily family a two-year test program conducted by Weldon and Blackburn (28) showed that 4 lb/A of dichlobenil applied in summer to early fall produced 90% control of frangrant white waterlily (*Nymphaea odorata*) and was more effective than in 8 lb/A rate applied during the winter. Taylor (29) agreed with Weldon and Blackburn on white waterlily, but suggested that 10 lb/A be used for the complete control of spatterdock (*Nuphar advena*). The best application time in the southerastern states was durin gthe period of active growth. Comes and Marrow (30) recorded 99% control of white waterlily three months after Aril treatment with 7.5 and 15 lb/A of dichlobenil. Riemer (31,32) investigated the effects on spatterdock of varying frequencies of defoliation, of a combination of defoliation plus 2,4-D, and of the effects of 2,4-D plus ETHREL (2-chloroethylphosphonic acid). He reported that defoliation depleted food reserves, the greater loss being associated with the greater number of prunings. Three trimmings plus 40 lb/A 2,4-D BEE provided complete kill with no regrowth the year following treatment. The addition of ETHREL to 2,4-D as a tank spray mix or as a separate application using 4 lb of 2,4-D plus 6000 ppm ETHREL provided complete knockdown. A later check of the plot area revealed that the rhizomes from the treated area were unhealthy and spongey-looking, while those from the check plts and 2,4-D along were healthy and sprouting.

Ditchbank Weed Control

Ditchbank weed control retains high research priorities because of the intensity of irrigation and drainage area problems. The USDA-ARS aquatic and noncrop weed control groups are working on the major weed species such as reed canarygrass (*Phalaris arundinacea*), carax and hardstem bulrush (*Scirpus acutus*). Much of the work is investigating physiological aspects. The growth habits of problem plants and their place in the succession of vegetation as well as their competitive characteristics are being studied quite intensively. Of patricular importance are the ecological studies which show changing weed populations.

Discussing the joint problem of reed canarygrass control and plant succession Hollingsworth and Comes (33) showed that applications repeated up to five times produced better kill of reed canarygrass than single applications of a higher rate. They also reported that amitrol-T was superior to amitrole alone. Plant succession favored establishment of bluegrass and redtop over a naturally-occurring weed mixture. Oliver (34) noted excellent control of annual broadleaf weeds and good grass tolerance with 0.25 lb/A of picloram and with a 1.4 lb/A of fenac on irrigation rights-of-way. The effectiveness of these materials suggested a 2-year weed control period might be possible. Kemper (35) controlled headstem bulrush with treatment rates of 2.2 and 4.4 lb/A methanearsonate. Spring treatments were superior to those in mid-summer and early fall. The spring treatment showed less than 10% regrowth in the second year. McHenry (36) verified Kemper's results but preferred mid-summer application. In McHenry's test, 1 lb/A of DSMA was second to the 2 lb rate of a low olatile ester of 2,4-D. 2,4-D is an effective treatment, but drift is an inherent danger to susceptible crops.

Herbicide Residues

The question of pesticide residues is becoming the most critical aspect of aquatic weed control. With chemical methods the concern is the herbicide itself. With mechanical methods it is the re-release of nutrients into the water, creating more favorable environments for weed re-establishment. We must know the degradation and disappearance time of any herbicide placed in water, and also residues in fish and bottom organisms which make up the biological food chain.

Averitt (37) recorded a decreasing herbicide concentration over a 22-day period when 2,4-D dimethylamine sale was applied to Louisiana waters. Initial concentrations went from 189 and 269 ppm to 19 and 10 ppm. Daly, Funderburk and Lawrence (38) showed a differential disappearance of paraquat, diquat, and 2,4-D BEE applied to Lake Seminole for the control of Eurasian water milfoil. There was only a trace of paraquat and diquat after 24 hours but the 2,4-D formulation lasted through the 7-day sampling period. All materials controlled the weed. Paraquat residue was higher in soil and milfoil than in the water. The 2,4-D formulation prevented reinfestation for a much longer time. This data in part verifies the earlier work of Frank (39) who found that 1.33 ppm initial concentration in a still pond was reduced to 0.019 in 19 days and 0.001 ppm ibn 36 days.

The USDA-ARS group is most active in this aspect of aquatic weed work, having endothall, dichlobenil, 2,4-D, amitrole, TCA, ametryne and acrolein under test either as direct application to water or as indirect application associated with ditchbank spraying. Dyes have been used to study channelling as well as stratification of substances introduced in to canal waters. The dilution factor is of most concern in moving waters. Dyes have also been used by Steenis and others in determining flow currents associated with using diquat and 2,4-D amine salts in back coves of Chesapeake Bay tidal flats.

The second aspect of herbicide residues associated with aquatic weed control pertains to those waters used for crop irrigation. Two USDA facilities, both in the Western Irrigation Region, are studying the effects on crops of known quantities of herbicides applied in fixed volumes of irrigation through both sprinkler and furrow methods. The crops being studied represent the crop grouping established by the U. S. Food and Drug Administration and include sugar beets, beans, corn, wheat, and potatoes. These experiments are generally carried through to yield to determine cumulative effects as well as immediate formative effects. At the present time acrolein, silvex, 2,4-D, fenac, amitrol-T, picloram, and pyriclor have been tested either by Bruns at Prosser, Washington or by Hodgeson at Bozeman, Montana.

Biocontrol of Aquatic Weeds

Because of the lack of specialists, it appears that aquatic weed research people are having to wear several hats. Many are becoming involved in herbicide disappearance studies, fish production and tolerance studies, plant succession studies, application techniques, and mechanical and biological control studies. The pressing need to know complete answers is producing a group of well-rounded aquatic weed biologists.

In line with this philosophy is the biocontrol work under way at the USDA station at Ft. Lauderdale, Florida with snails; a tilapia study in California; and a manatee and beetle program in Florida.

Reviewing the animals which were under study as aquatic phytophagous agents Butler (40) referred to insects, molluscs, fish, ducks, and manatees. He commented that the list was small but felt that this was a new approach offering hope in resolving this annoying public problem.

Florida is "where the action is" at the present time. In this state the snail, the flea beatle, and the manatee have been utilized to control submersed weeds and alligatorweed. Blackburn and Andres (41) indicate that the snail *Marisa cornvarietis* L. is quite hardy, surviving in a temperature range of 48 to 110°F, can live in polluted waters, and can tolerate a salinity of 2500 ppm. The snail feeds quite actively and is indiscriminate in its eating habits. This is an advantage in that it will keep all vegetation down. Marisa also feeds on disease-bearing snails without transmitting diseases harmful to man, an additional benefit. The disadvantage is that marisa could feed on aquatic crops, such as rice, waterchestnut, and watercress. Perhaps the greatest problem will be producing enough snails to be of value in the area where they will adapt. Field tests show that fairly high populations are needed — 8000 per acre stocked in Florida cleaned up ponds and kept them clean over a two-year period.

The so-called mighty mite of biocontrol is the flea beetle (*Agasicles* n. sp.) with its single-minded food habit. It apparently lives only on alligatorweed. This insect, imported through the USDA-ARS Entomological Department from Argentina, has been released in the United States at several locations. Zeiger (42) reported successful introduction to Florida waters. He indicates the two characteristics needed — survival and rapid adaptation — were met with apparent satisfactory control of alligatorweed. Blackburn and Andres suggest that the beetle might not be the final answer since it does not prove effective in the Savannah, Georgia, program.

Manatees, although capable of removing weeds in confined canals at a rate of ½ miles section per 5000 lb of manatee over a three-week period, present problems. They are difficult to move about, weighing 384 to 2170 younds, and their rate of reproduction is very slow. The seacow cannot tolerate waters below 65°F so will always be limited to areas meeting this temperature requirement.

Mechanical Weed Control

The primary obejction to mechanical control in the past has been the fact that the methods used frequently spread species which propagate vegetatively. The early collection and compressing of weed masses also returned the nutrients to the water, ultimately supporting a greater weed population. This is apparently changing. Bryant (43) discussed a new and more efficient harvester system which transports the weed mass to the shore and hauls it away. He also noted that a Wisconsin state law now requires weed removal in any weed-cutting operation. The Water Witch uses high pressure to blast weeds from swimming areas, but makes no provision for weed collection and site removal.

Perhaps in the final analysis mechanical weed control will become more popular when it becomes part of an integrated herbicidal-mechanical program such as is in effect at the Winter Park, Florida, recreational lakes. The Ft. Lauderdale research group has worked cooperatively with the administrators of a chain of lakes there, utilizing a combination mechanical-chemical operational program with considerable success.

CONCLUSION

This has been an attempt to survey the reported literature over the past few years and to utilize my own observations of research work under way. That it is incomplete is obvious since within the score of this paper it is impossible to document work reported. Secondly, any attempt to put into one paragraph the objectives of programs under way or planned would do a great injustice. The Fish Pesticide Laboratory of Columbia, Missouri, a modern facility designed to study the interactions of pesticides, water, sediments, vegetation, and aquatic animals, is just beginning to get into the problem. Once it becomes adequately staffed many of the vague generalizations made by non-qualified individuals can be tested and either verified or proven wrong.

Another project just beginning to produce results because of the nature of the aquatic plant studies originally set up is at Cornell University, now under the guidance of Dr. Hugh F. Mulligan. At the present time their facilities are being utilized to study the effects of eutrophication on plankton, algae, and several common submersed species.

U. S. Army Engineers are deeply involved in the operational aspects of aquatic plant control. They are faced with both the need for immediate action and for long-range planning, and can initiate work that might at present be considered "far out". The Corps is primarily an operational agency in aquatic growth removal, but is in a position to encourage and finance basic research by other agencies or individual workers. Investigations are under way with the Laser beam to kill water hyacinth, high frequency sound irradiation to disintegrate plant tissue, the experimental use of biocontrol agents, and the development of new application techniques.

To sum it all up, one must say that there is a tremendous amount of aquatic weed research under way. More importantly, understanding of aquatic weed control is progressing to the point of our realizing the necessity of a total environment concept. Research is no longer a shotgun or hit-or-miss concept involved with only a single aspect of the problem. The realization that our natural resources will not last forever at the rate we are using or destroying them is making us all conscious of the need to act as part of a total environment rather than for individual needs alone.

REFERENCES

1. Steenis, J. H. 1969. Tidal dispersal of 2,4-D for controlling Eurasian watermilfoil in Chesapeake Bay. Proc. NEWCC 23:375.
2. Elser, H. J. 1968. Observations on the decline of watermilfoil and other aquatic plants, Maryland 1962-1967. Proc. NEWCC 22:487.
3. Blackburn, Robert D. and Lyle W. Weldon. 1969. Control of *Hydrilla verticillata*. Proc. SWC 22:317.
4. Ware, F. J. and J. D. Jorman. 1967. The results of selected aquatic herbicides on elodea in South Florida. Proc. SWC 20: 290-293.
5. Foret, J. A. 1967. Response of *Elodea canadensis* to treatment with phenoxy herbicides and organic acids. Proc. SWC 20:288-289.
6. Blackburn, Robert D. and Lyle W. Weldon. 1969. A new approach to aquatic weed control. Proc. SWSS 22:315.
7. Bruns, V. F., J. F. Nelson and C. C. Coutant. 1968. Behavior reactions and effects of acrolein and copper sulfate in irrigation water. WSWS Res. Prog. Rept. 22:94-95.
8. Hattrup, Alan R. 1967. New innovations for low rate acrolein applications to the Columbia Basin project carriage system. WWCC Res. Prog. Rept. 21:115.
9. Bartley, T. R. 1967. Evaluation of copper sulfate for control of pondweed in irrigation canals. WWCC Res. Prog. Rept. 21:116-118.
10. Riemer, D. N. and S. S. Toth. 1967. Behavior of copper sulfate in small ponds. Proc. NEWCC 21:534-537.
11. Reimer, D. N. and R. D. Ilnicki. 1968. Reproduction and overwintering of cabomba in New Jersey. Weed Sci. 16 (1):101-102.
12. Walker, Charles R. 1966. Aquatic weed control summary. NCWCC Res. Rept. 22:110-112.
13. Pierce, Phil C. 1967. Results of field testing diuron as an effective herbicide for the control of vascular aquatics. Proc. SWC 20:327-333.
14. Hambric, Robert N. 17969. Testing diuron as an economical herbicide in recreational lakes. Proc. SWSS 22:321-323.
15. Hiltebran, R. C. 1967. Aquatic weed control summary. NCWCC Res. Rept. 24:44-45.
16. Yeo, R. 1969. Personal correspondence. (U.S.D.A., Univ. Calif., Davis)
17. Patterson, William G. 1969. The 3M concept of aquatic weed control. Proc. SWSS 22:324-327.
18. Cortell, J. M. 1969. Field evaluations of new controlled release aquatic herbicides. Proc. NEWCC 23:385-389.
19. Denton, Jerry B. 1967. Certain relationships between the chemical composition of aquatic plants and water quality. Proc. SWC 20: 354-362.
20. Riemer, D. N. and S. J. Toth. 1967. A survey of the chemical composition of aquatic plants in New Jersey. Bulletin 820. (New Jersey Agricultural Exp. Sta.)
21. Ryan, James B. 1969. The effects of fertilization on the mineral composition of pond water. Proc. NEWCC 23:350-358.
22. Otto, N. E. 1969. Effects of nitrogen and phosphorus on pondweed productivity. WSWS Res. Prog. Rept. 23:99-100.
23. Weldon, L. W. and R. D. Blackburn. 1967. The control of floating aquatic weeds with ametryne. Prod. SWC. 20:312.
24. Weldon, L. W., H. T. DeRigo and R. H. Blackburn. 1968. Control of alligatorweed with dichlobenil. Proc. SWC 21:287-291.
25. Spencer, Sam L. 1967. The effect of herbicides on seven species of aquatic plants in the Mobile delta. Proc. SWC 20: 319-326.
26. Pryor, Murry R. 1969. Alligatorweed control with vapam (SMDC). WSWS Res. Prog. Rept. 23:101.
27. Steenis, J. H. and H. J. Elser. 1967. Waterchesnut control with mixtures of 2,4-D and dicamba. Proc. NEWCC 21:550-551.
28. Weldon, L. W., R. D. Blackburn and W. C. Durden Jr. 1969. The control of fragrant water lily with dichlobenil. Proc. SWSS 22:316.
29. Taylor, James. 1969. Personal correspondence.
30. Comes, R. D. and L. A. Morrow. 1968. Control of white waterlily (*Nymphaea tetragona*) with dichlobenil. Proc. WSWS 22:92-93.
31. Reimer, D. N. and W. W. MacMillan. 1967. Effects of defoliation on spatterdock (*Nuphar advena*). Proc. NEWCC 21:556.
32. Reimer, D. N. 1969. Further studies on the control of spatterdock (*Nuphar advena*). Proc. NEWCC 23:380-385.
33. Hollingsworth, E. B. and R. D. Comes. 1966. Control of reed canarygrass. WWCC Res. Prog. Rept. pp. 99-100.

34. Oliver, Floyd E. 1967. Preemergence control of annual weeds on irrigation rights of way—Columbia Basin project, Washington. WWCC Res. Prog. Rept. pp. 112-113.

35. Kemper, Harold M. 1968. The seasonal response of hardstem bulrush to methanearsonates. WSWS Res. Prog. Rept. 22:91-92.

36. McHenry, W. B., L. L. Bushman, and N. L. Smith. 1968. Seasonal response of hardstem bulrush to MSMA, Pyriclor, 2,4-D and dalapon + TCA. WSWA Res. Prog. Rept. 22:92.

37. Averitt, William K. 1967. An evaluation of the persistence of 2,4-D amine in surface waters in the state of Louisiana. Proc. SWC 20:342.

38. Daly, R. W., H. H. Funderburk, Jr. and J. M. Lawrence. 1968. Persistence of diquat, paraquat and 2,4-D BEE when used for eurasian water milfoil (*Myriophyllum spicatum*) control. Proc. SWCC 21:299.

39. Frank, P. and R. D. Comes. 1967. Herbicidal residues in pond water and hydrosoil. Weeds 15 (3):210-213.

40. Butler, J. M. Jr., Frederick F. Ferguson, Louis A. Berrios-Duran. 1968. Significance of animal control of aquatic weeds. Proc. SWC 21:304-308.

41. Blackburn, Robert D. and Lloyd A. Andres. 1968. The snail, the mermaid, and the flea beetle. Science for better living. pp. 229-234. USGPO, Washington, D. C.

42. Zieger, C. F. 1967. Biological control of alligatorweed with *Agasicles* n. sp. in Florida. Proc. SWC 20:299-303.

43. Bryand, C. Brate. 1969. Aquatic weed harvesting. Weeds Trees and Turf 8 (10):14-17.