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Waterways Experiment  
Station

*Aquatic Plant Control Research Program*

# **Relationships Between Fish and Aquatic Plants: A Plan of Study**

*by K. Jack Killgore, Eric D. Dibble, Jan Jeffrey Hoover  
Environmental Laboratory*

*WES*

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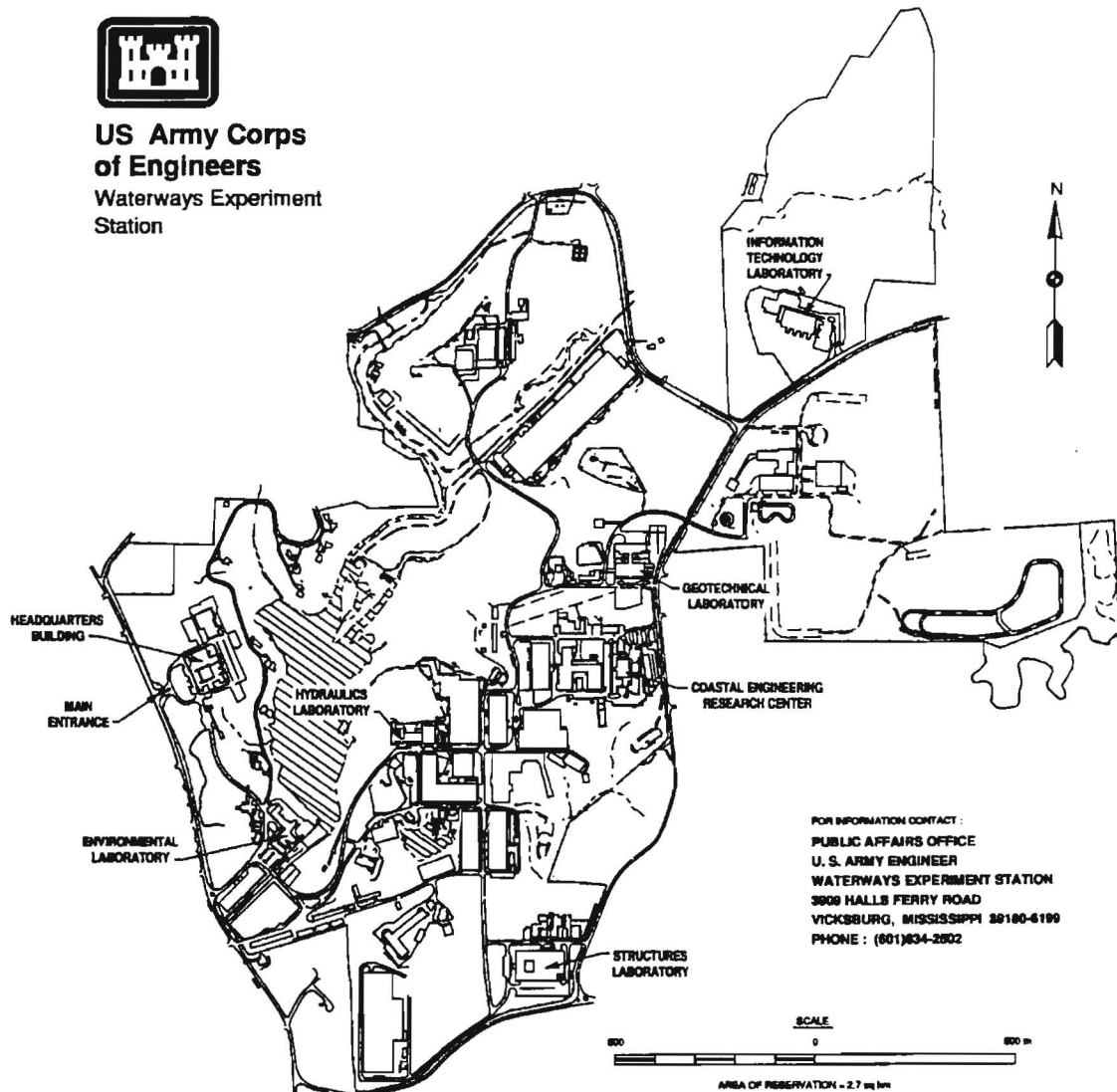
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# Preface

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The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32806. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the APCRP. Technical Monitor during this study was Ms. Denise White, HQUSACE.

This report was prepared by Mr. K. Jack Killgore, Mr. Eric D. Dibble, and Dr. Jan Jeffrey Hoover, Aquatic Ecology Branch (AEB), Environmental Resources Division (ERD), EL, WES. Mr. Larry Sanders, AEB, coordinated the workshops. The study was supervised at WES by Dr. Ed Theriot, Chief, AEB, and Dr. Conrad J. Kirby, Chief, ERD. Dr. John Harrison was Director, EL.

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# 1 Introduction and Purpose

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The influence of aquatic plants on species composition, abundance, and size of fishes is an important consideration when managing aquatic plants. Numerous studies reviewed in this document show that aquatic plants structure fish populations and influence angler success. The habitat value of plants to fishes and the continuing emphasis on environmental consequences of Corps of Engineers aquatic plant control projects requires that fish/plant interactions be thoroughly understood.

The structural heterogeneity of aquatic plant beds contributes to high numbers of many species of fish that associate with these complex habitats. Sunfishes, for example, have a high affinity to plants and are often the dominant group of fishes in vegetated waters. Many phytophilic fishes are exploitable and, thus, provide an important recreational and commercial resource. As a result, aquatic plants are not only a vital habitat component of aquatic systems but also a source of revenue and recreation for many people.

The interaction between fish and aquatic plants is highly variable, which impedes the formulation of specific fisheries management strategies for vegetated water bodies. This variability is evident on both an ecoregion and a microhabitat scale. Relationships between aquatic plants and fish vary by differences in aquatic systems (river vs. lakes), plant forms (floating vs. submersed), composition of the fish community (sunfishes vs. minnows), and geographic areas (Southern States vs. Pacific Northwest). As a result, the fishery management potential in vegetated habitats is poorly understood.

Questions often arise regarding the amount of aquatic plants necessary to support a viable sport fishery and the relative value of different plant species for spawning, foraging, and predator avoidance by fishes. Competition by water users (e.g., real estate, boating, fishing) confounds this problem. Although there are numerous studies that recommend optimum plant levels to maximize fish production, aquatic plant managers still have problems implementing and justifying control strategies that benefit the fishery. Until functional relationships between plant and fish abundance are determined, the effects of aquatic plant management on fishes will remain subjective and speculative.

The purpose of this document is to describe a plan of study (POS) for fish/plant interactions based on an objective evaluation of the deficiencies in information on fish/plant interactions. The POS will be used to document the need for future research, to serve as a basis for prioritizing and designing studies on fish/plant interactions in different geographic regions of the United States, and to provide documentation for developing a new technology area in the Aquatic Plant Control Research Program (APCRP).

The objectives of this document are to (a) summarize literature on fish/plant interactions, (b) identify specific research areas that address information deficiencies, and (c) describe a POS to quantify relationships between aquatic plants and fish for broad applicability within geographic regions.

## 2 Literature Review on Fish/Plant Interactions

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### Introduction

Anthropogenic effects on our nation's aquatic systems are ever increasing the need for controlling plant growth and abundance to maintain viable fisheries. Millions of dollars are spent annually to manage aquatic plants in our nation's rivers, streams, lakes, and reservoirs (Dunst et al. 1974; Koegal, Livermore, and Bruhn 1977; Durocher, Provine, and Kraai 1984), yet little is known about certain ecological interactions between plants and the fish that inhabit them.

Historically, aquatic plants have been an important component in the evolution of freshwater ecosystems (Gray and Taylor 1988). Aquatic plant distribution and abundance continue to be important factors in the ecology of our lakes, streams, rivers, and reservoirs (Wetzel and Hough 1973; Carpenter and Lodge 1986; Hinkle 1986; Kimmel and Groeger 1986; Duarte 1987; Evans et al. 1987; Engel 1988; Boes, Van Ballegoijen, and Uunk 1991). Many of the mechanisms regulating eutrophication in lakes and reservoirs are unclear (Phillips et al. 1978); however, submerged plants are a principal component in the process and are often replaced by dense phytoplankton populations (Balls, Moss, and Irvine 1989; Irvine, Moss, and Balls 1989).

Submerged aquatic plants, both exotic and native, serve as contributors of autochthonous organic carbon to lakes, impacting biochemical cycles and productivity in freshwater systems (Goulder 1969; Carpenter and Lodge 1986; Watkins, Shireman, and Haller 1983; Polunin 1984; Scheffer, Achterberg, and Beltman 1984; Duarte 1987, Schramm, Jirka, and Hoyer 1987, Engel 1988, Stevenson 1988; Irvine, Moss, and Balls 1989). In addition, aquatic plant beds decay and supply organic detritus for the aquatic food web (Adams and Prentki 1992, Carpenter and Lodge 1986, Duarte 1986), serve as important substrate and cover for invertebrates (Krecker 1939; Wohlschlag 1950; Pardue 1973; Gilinsky 1984; Morin and Kimball 1984; Whitfield 1984; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Engel 1988; Miller et al. 1989; Chilton and Margraf 1990; Hargeby 1990),



and have important interactive roles with fish (Flemer and Woolcott 1966; Hall, Cooper, and Werner 1970; Werner and Hall 1979; Heck and Thoman 1981; Savino and Stein 1982; Anderson 1984; Mittelbach 1984; Spencer and King 1984; Whitfield 1984; Wiley et al. 1984; Osenberg et al. 1987, Cook and Bergersen 1988, Engel 1988, Rozas and Odum 1988).

The key to effective management of fish and plant populations is thoroughly understanding the relationships between physical habitat (aquatic plants and their impacts) and fish production (critical factors affecting growth, recruitment, and survival). In a practical sense, fishery and aquatic plant managers should look to agriculture for models because agricultural research has gained enough understanding about plant-animal relationships to supply data necessary for successful crop management and pest control programs.

To understand relevant interrelationships between plants and fish, a new approach in the study of aquatic systems is needed. Researchers must first define and then classify fish habitat created by aquatic plants; develop innovative, precise, and accurate sampling schemes; identify and understand the function of these habitats; develop modified management plans incorporating the information collected; and finally, but probably most importantly, initiate an interdisciplinary exchange of data and cooperation between fishery biologists, aquatic plant managers, aquatic ecologists, botanists, and limnologists.

The intent of this study was to review previous studies on aquatic fish/plant interactions and provide the biologist with basic information that can determine availability of critical habitat and factors that impact growth, recruitment, and survival of fish populations.

## **Classification of Aquatic Plant Habitats**

Fish habitat is classified at regional system (macro) and local (micro) levels (Table 1). Each type of classification makes assumptions about factors that structure fish communities. There are, however, many issues that confound classification schemes. Habitat is a multivariate combination of discrete levels of environmental variables (Baker, Killgore, and Kasul 1991). Emphasis of particular variables is usually subjective, and the many factors that determine species composition and distribution of aquatic plants are vague and difficult to predict. Macrophyte growth, composition, and distribution are frequently dependent on limiting factors in the chemical composition of sediments and water (Barko et al. 1982, 1984, Barko, Adams, and Clesceri 1986; Langeland, Linda, and Haller 1985; Sutton 1990), and to a lesser extent, elevation, morphometry of the water body, and substrate particle diameter (Jackson and Charles 1988). In addition, water transparency, depth, and chlorophyll *a* concentrations tend to be associated with macrophyte abundance (Canfield, Maceina, and Shireman 1983, 1984).

Fish assemblages and their habitat have been delineated successfully by a regional classification, i.e., stream and river drainage systems (Hocutt and Wiley 1986; Rohm, Giese, and Bennett 1987; Lyons 1989). This type of regional classification has been greatly improved using Geographic Information Systems (GIS). A recent effort, called E-Map, is an example of using the GIS to delineate fish habitat on a regional scale allowing approximately 800 lake and stream sites to be evaluated annually<sup>1</sup> (Whittier and Paulsen 1992). An excellent source of information on regional distribution of fishes is "Zoogeography of North American Freshwater Fishes" by C. H. Hocutt and E. O. Wiley (1986); this document provides specific distributional data by region and drainage basins and discusses reasons why a particular community structure has formed within that region.

Classification at the system level includes characterizing relative abundance and distribution of emergent, floating-leaved, and submersed plants in lake littoral zones from aerial photography (Canfield et al. 1990), and using plant biomass to delineate differences in aquatic plant habitats (Maceina et al. 1984; Duarte 1987; Hoover, Killgore, and Morgan 1988; Pine, Anderson, and Hung 1989, 1990; Sliger et al. 1990). Attempts to quantify phytoplankton at the systems level are more common than quantifying macrophyte beds because the latter have patchy distribution within a lake, and the biomass within patches is highly variable (Downing and Anderson 1985).

The classification of stream substrate described by Bain, Finn, and Boone (1985b) is one approach for habitat analysis at the microlevel, and similar studies are needed in classifying important spatial parameters in aquatic plants. Although past research focused on differences between structured versus nonstructured or vegetated versus nonvegetated habitats (Werner et al. 1977; Watkins, Shireman, and Haller 1983; Mittelbach 1984; Gregory and Powles 1985; Layzer and Clady 1987; Paller 1987; Cook and Bergersen 1988; Hoover, Killgore, and Morgan 1988; Morgan, Killgore, and Douglas 1988; Miller et al. 1989; Todd and Rabeni 1989), others have made an attempt to quantify additional parameters at the micro level and determine their importance to fish (Table A1).

Plant microhabitats have been delineated by measurements of plant stratification in the form of canopy, midcanopy, and lower stem strata (Morin and Kimball 1984, Whitfield 1984, Engel 1988); stem and plant densities (Savino and Stein 1982, Anderson 1984, Downing and Anderson 1985); taxa; and differences in emergent versus submergent (Scheffer, Achterberg, and Beltman 1984; Durocher, Provine, and Kraai 1984; Holland and Huston 1984; Whitfield 1984; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Engel 1988; Hoover, Killgore, and Morgan 1988; Nichols, Schloesser, and Geis 1988; Miller et al. 1989; Canfield et al. 1990).

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<sup>1</sup> Personal communication, 1992, F. H. McCormick, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring Systems laboratory, Cincinnati, OH.

Shade created by dense structure has been quantified and may be important to fish by allowing better visibility in foraging and predator avoidance (Helfman 1979,1981). However, in other investigations, shade was measured and did not appear to affect habitat preferences by bass or bluegills (Lynch and Johnson 1989). Even the size of interstitial spaces in aquatic structures has been measured to evaluate the value of important fish habitat (Johnson, Beaumier, and Lynch 1988; Lynch and Johnson 1989; Walters, Lynch, and Johnson 1991). These studies show the use of structural habitat by largemouth bass is correlated with body size; smaller fish (<300 mm total length (TL)) used smaller (40 or 350 mm) interstitial spaces than did larger (>300 mm TL) fish.

## **Fish Distribution, Diversity, and Abundance**

### **Fishes that inhabit aquatic plant habitats**

Based on data collected from radiotelemetry and other types of fish movement studies, many fish prefer and inhabit areas of aquatic plants that provide complex structure. Submersed vegetation in a Colorado reservoir was preferred by northern pike (*Esox lucius*) and was the key factor in their distribution and habitat use (Cook and Bergersen 1988). Young-of-year (YOY) northern pike also prefer submerged vegetation over emergent vegetation and showed a tenfold increase in preference for vegetated areas over nonvegetated areas (Holland and Huston 1984). The strong preference for aquatic plant habitats by northern pike appeared not to be related to food, and the overall production of the YOY pike was best in these areas (Holland and Huston 1984).

Brown bullheads (*Ictalurus nebulosus*), banded killifish (*Fundulus diaphanus*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*) have been sampled in heavily vegetated sites (Killgore, Morgan, and Rybicki 1989). Representative species from the Percidae, Cyprinidae, Cyprinodontidae, and Centrarchidae families prefer complex, species-rich, macrophyte beds over lesser complex and depopulate beds (Poe et al. 1986). Janecek (1988) provides an excellent summary of fishes inhabiting vegetated areas in the Upper Mississippi River System.

Larval fish abundance and species composition is much higher in macrophyte beds than in open water (Floyd, Hoyt, and Timbrook 1984; Paller 1987). Some work on the drift of larval fish in streams and rivers has been conducted (Floyd, Hoyt, and Timbrook 1984, Armstrong and Brown 1983), yet relatively little is known about freshwater fish larvae in littoral areas of lakes and reservoirs. Difficulty in sampling these habitats is a contributing factor to lack of study.

## Effects of plant density on fish abundance

Evaluation of aquatic plant control programs has provided aquatic biologists system-scaled experiments on the gross effects that plant removal has on fish populations. Therefore, much of the available literature on fish abundance in association to plants is related to plant control studies (Prowse 1971; Strange, Berry, and Schreck 1975; Terrell 1975; Terrell and Terrell 1975; Ware et al. 1976; Bailey 1978; Colle, Shireman, and Rottman 1978; Lembi et al. 1978; Mitzner 1978; Rottmann and Anderson 1978; Haller, Shireman, and DuRant 1980; Shireman and Maceina 1981; Savino, Stein, and Marschall 1985; Bettoli, Morris, and Noble 1991).

Plant density is important in determining species composition and abundance of fishes. High fish densities (15,000 to 98,000/ha) have been estimated from collections made in intermediate densities of vegetated areas (Barnett and Schneider 1974; Borawa et al. 1978; Shireman, Colle, and DuRant 1981; Killgore, Morgan, and Rybicki 1989), and as plant density increases, aquatic plant beds support higher numbers of smaller fish (Barnett and Schneider 1974). Experiments in controlled environments suggest that intermediate plant densities maximize foraging success by largemouth bass (Anderson 1984). Many investigators suggest that moderate levels (10 to 40 percent coverage) of plant density are optimal for fish production, commercial fishing, and for stabilizing water quality in freshwater systems (Hestand and Carter 1978; Crowder and Cooper 1979a, 1979b; Wiley et al. 1984). Janecek (1988) summarized suggested optimal vegetative levels for selected Upper Mississippi River fishes (Table 2).

Sunfish (*Lepomis* spp., *Pomoxis* spp.) populations increase with aquatic plant abundance (Ware and Gasaway 1977; Shireman, Colle, and DuRant 1981) and decrease in number with a reduction in plant coverage (Forester and Lawrence 1978, Noble 1981), sometimes immediately (Borawa et al. 1978). Likewise, largemouth bass (*Micropterus salmoides*) production increases with an increase of aquatic plant abundance (Borawa et al. 1978; Moxley and Langford 1982; Durocher, Provine, and Kraai 1984) and decreases with reduction in plant abundance (Ware and Gasaway 1976). Natural senescence in aquatic macrophytes decreases abundance of fishes due to the reduction of invertebrates (Whitfield 1984). Even reductions of plant communities due to boat disturbance can decrease species composition and abundance (Murphy and Eaton 1981). Juvenile largemouth bass inhabit vegetated areas (Barnett and Schneider 1974, Moxley and Langford 1982), and there appears to be a significant relationship between YOY largemouth bass survival and recruitment, and the availability of submerged vegetation (Aggus and Elliot 1975; Haller and Sutton 1975; Shireman et al. 1984).

Removal of plants in aquatic systems also affects abundance of pelagic species. Reduction of aquatic plants increased numbers of shad (Bailey 1978, Maceina and Shireman 1985); the increase of plant abundance has been shown to decrease standing crops of shad (Noble 1981). Usually, as macrophytes increase, the plant mass shifts primary productivity at the

expense of phytoplankton and reduces food resources available to planktonic feeders (Sills 1964, Prowse 1971, Wiley et al. 1984, Noble 1986).

The effects of plants on catfish are inconclusive. Wiley et al. (1984) and Noble (1981) showed increases in the number, recruitment, and survival of catfish after plants were removed with grass carp. However, Borawa et al. (1978) reported the opposite trend. Even though data supplied from plant removal literature is extensive, care must be taken in reaching conclusions on plant effects on fish. Since most field investigations only indirectly address the mechanisms regulating fish/plant interactions, many of the results from this literature are inconclusive and contradictory (Evans et al. 1987). For example, most data suggest that plant removal has major impacts on fish populations. Other studies suggest that plant reduction has little effect on fish populations and that factors other than aquatic plants may have greater impact (Bailey 1978, Noble 1986). Unfortunately, few long-term studies on fish populations before and after removal of aquatic plants have been conducted (Bettoli, Noble, and Betsill 1992).

## **Functional Uses of Aquatic Plants By Fishes**

### **Importance of understanding microdistribution**

Functional (behavioral) response of an organism to its habitat determines its niche and its relationship to the environment. Understanding the mechanisms that regulate distribution and habitat choice in fish is essential to determining reasons why fish utilize aquatic plant habitats. Observed phenotypic differences of fish among microhabitats indicate that individual fish specialize on one habitat (Layzer and Clady 1987, Rosenzweig 1991). Previous works have demonstrated some general distribution patterns and habitat partitioning by fish (Werner et al. 1977, Gorman and Karr 1978, Hubert and Lackey 1980, Mittelbach 1984, Probst et al. 1984, Martin-Bergmann and Gee 1985, Pringle et al. 1988, and Todd and Rabeni 1989). Recently, the role of learning in fish behavior has been addressed in the literature (Kieffer and Colgan 1992), suggesting fish learn to choose specific habitats to improve foraging and predator avoidance (Milinski and Heller 1978; Ehlinger 1989; Colgan, Gotceitas, and Frame 1991; Kieffer and Colgan 1991).

Unfortunately, specific behavioral data needed to determine the causal mechanisms regulating habitat use by fish and important interactions between fish and their habitats are sparse (Howick and O'Brien 1983, Kieffer and Colgan 1992). However, explanations have been presented which state why fish may use the complex habitats located in aquatic plant beds. Fish may use plant habitat to avoid predators (Hall and Werner 1977; Laughlin and Werner 1980; Power, Mathews, and Stewart 1985; Mittelbach and Chesson 1987; Schmitt and Holbrook 1985), to forage on

epifauna (Werner et al. 1977; Laughlin and Werner 1980; Devries, Stein, and Chesson 1989), to improve visual acuity of environment with the shade created by plant canopies (which may help both foraging and predator avoidance behaviors) (Helfman 1979, 1981; Diehl 1988), and to create optimal spawning and nesting sites (Tester 1930, Vogeles and Rainwater 1975, Mesing and Wicker 1986, Quinn and Dittman 1990, Hoff 1990).

## **Plant habitats and food**

Aquatic plants supply structurally complex habitat (Engel 1983, 1984, 1985) and increase nutrients for the food web that promote increased diversity and stability in macroinvertebrate and aquatic faunas (Rosine 1955; Boyd 1971; Stenseth 1980; Watkins, Shireman, and Haller 1983, Engel 1984; Schramm, Jirka, and Hoyer 1987). Epiphytic algae on plants increase productivity and cover in littoral areas. Plants affect environmental conditions of water by resistance of mixing and gradients in dissolved oxygen (DO), pH, and temperature form in and around plant beds, which fluctuate differently than in open areas (Van, Haller, and Garrard 1978; Bowes, Holaday, and Haller 1979).

Aquatic plants supply important habitats containing food resources for both juvenile and adult fish. Leaves and stems of aquatic plants provide support and cover for macroinvertebrates (Pardue 1973; Pardue and Nielsen 1979; Keast 1984; Engel 1985; Goldsborough and Robinson 1985; Beckett, Aartila, and Miller 1992), and plant beds supply additional nutrients to support a diverse group of benthic macroinvertebrates (Scott and Osborne 1981, Gilinsky 1984, Miller et al. 1989). The spatially complex habitats of aquatic plant beds contain about twice as many macroinvertebrates as nonvegetated areas (Gerking 1957). The reported high abundances of macroinvertebrates on and below macrophyte beds (Andrew and Hasler 1943; Rosine 1955; Quade 1969; Watkins, Shireman, and Haller 1983; Morin and Kimball 1984; Scheffer, Achterberg, and Beltman 1984; Engel 1985; Lodge 1985; Schramm, Jirka, and Hoyer 1987; Hanson 1990) may serve as potential forage bases for smaller and younger fishes. Many fish feed on the macroinvertebrates present in aquatic plant habitats (Flemer and Woolcott 1966; Keast 1985a, 1985b; Hoover, Killgore, and Morgan 1988). The distribution of macroinvertebrate populations is site specific; they inhabit only particular aquatic plant species (Scheffer, Achterberg, and Beltman 1984; Hargeby 1990). Habitat-associated differences in the diet of fish frequently reflect this distribution (Keast and Webb 1966; Keast 1985a; Hoover, Killgore, and Morgan 1988; Layzer and Clady 1991).

## **Availability of cover and predation effects**

Predators are important in structuring aquatic communities (Hall, Cooper, and Werner 1970; Connell 1975; Hall et al. 1979; Power, Mathews, and Stewart 1985; Sih 1987; Hunter and Price 1992, Power 1992).



Size-dependent predation operates in littoral areas of freshwater systems, and the structurally complex habitats provided by plants can reduce predator risk for prey (Keast 1985a; Charnov, Orians, and Hyatt 1976; Werner et al. 1977, 1979; Werner, Hall, and Werner 1978; Reynolds and Eaton 1983; Gilinsky 1984; Werner and Gilliam 1984; Mittelbach and Chesson 1987). Prey fishes may avoid predators by using plants as interference and refuge. The spatial distribution of prey organisms in relation to refuge and a predator may be either chance (Huffaker 1958) or may be a behavioral response by the prey to choose a habitat (Giles and Zamora 1973; Ware 1973; Charnov, Orians, and Hyatt 1976; Stein and Magnuson 1976, Stein 1977). Predators maximize energy gain by selecting optimal food items (Anderson 1984), and prey minimize predator risk (mortality) by modifying microdistribution and behavior in the presence of a predator (Stein 1977, Wildhaber and Crowder 1991).

Aquatic plants are important to fish because their structures supply cover from predators and habitat for food resources. Moderate densities of plants increase habitat heterogeneity, which influences community stability (Stenseth 1980) and determines the extent of interactions between fish and their prey (Glass 1971; Smith 1972; Murdoch and Oaten 1975; Crowder and Cooper 1979a, 1979b, 1982; Saiki and Tash 1979; Savino and Stein 1982; Gilinsky 1984; Johnson, Beaumier, and Lynch 1988). Aquatic vegetation densities, spatial configuration, and growth forms can affect prey vulnerability to predation (Watkins, Shireman, and Haller 1983). Yet, fish-foraging probability is significantly enhanced by feeding in the submerged aquatic vegetation. The same plant beds not only afford protection from predators but also can provide a rich foraging habitat (Rozas and Odum 1988). Seasonal variation in the growth of exotic plants may be important by increasing forage and refuge habitat for juvenile fish populations in late fall and winter when native macrophytes are seasonally absent (Nichols, Schloesser, and Geis 1988). Too much structure or too many plants can reduce interactions between fish and prey, leading to a reduction of fish production (Dunst et al. 1974, Smith and Crumpton 1977, Diehl 1988). An intermediate level of plant density and structure appears optimal (Killgore, Morgan, and Rybicki 1989; Glass 1971; Savino and Stein 1982; Crowder and Cooper 1979a; Colle and Shireman 1980).

Aquatic plant beds serve as protective habitats for macroinvertebrates and other fish prey species. Because of their spatial complexity in providing refugia, aquatic plant beds decrease predation effects, thus increasing both species richness and density of most macroinvertebrates (Gilinsky 1984). The total macroinvertebrate biomass and abundance is unaffected by differences in fish biomass (Hanson and Leggett 1986). However, high fish densities forced into refuge habitats by predators can precipitate fierce forage competition for resources and significantly reduce invertebrate size and abundance (Mittelbach 1981, 1988).

## Plant habitats and factors affecting growth

Vegetation in aquatic systems impacts growth and condition in fish. Based on a survey of 300 systems, growth of largemouth bass decreased as vegetation abundance increased (Engel 1985). Others have reported similar results in the relationship of increased plant abundance and the growth rates of largemouth bass (Colle and Shireman 1980, Noble 1986, Maceina et al. 1991). The opposite appears to be true in the growth and condition of smaller centrarchids. Since bluegill and other small centrarchids use vegetation as a food source (Gerking 1962, Engel 1988), the increase of vegetation tends to increase growth rates and conditions in bluegill, crappie, and redear sunfish populations (DiCostanzo 1957; Bailey 1978; Colle and Shireman 1980; Wiley et al. 1984; Maceina and Shireman 1985; Savino, Marschall, and Stein 1992). The decrease or lack of vegetation is correlated with reduced size (Evans et al. 1987). Too much vegetation can actually decrease growth rates in these fish (Colle and Shireman 1980, Shireman et al. 1984, Colle et al. 1986), but control of plant densities can maintain optimal growth and condition (Cope et al. 1970).

The availability of plants and the structure they provide may affect growth rates by altering foraging behaviors in both prey and predatory fish. The exposure to predators strongly determines smaller and younger fish's feeding behaviors, which affect foraging rates (Ware 1973), and the amount of exposure to a predator is directly related to structural habitat availability and its complexity (Smith 1961; Macon 1966; Danehy, Ringler, and Gannon 1991).

The use by juvenile and smaller prey fishes of such habitats to avoid predation can increase foraging competition (Goldberg and Barton 1992), thus reducing food intake and retarding growth (Mittelbach 1988). The size that younger fish reach in their first year of growth is critical for over-winter survival (Gutreuter and Anderson 1985), which influences fish recruitment and production.

Larger, predatory fishes' growth and condition also may be influenced by aquatic plants. Habitat complexity caused by aquatic plant abundance regulates piscivory in the littoral zone of lakes (Bettoli, Noble, and Betsill 1992). Prey-capture rates tend to decline monotonically with an increase of structural complexity (Crowder and Cooper 1979a), and foraging efficiency by predatory fish decline as the habitat becomes more spatially complex (Glass 1971, Stein and Magnuson 1976, Vince et al. 1976, Van Dolah 1978, Cooper and Crowder 1979, Saiki and Tash 1979, Heck and Thoman 1981, Savino and Stein 1982, Johnson, Beaumier, and Lynch 1988).

For bass and other large predators, the increases in visual barriers provided by plant stems may decrease foraging success (Savino and Stein 1982) by increasing search, handling times, and swimming velocities but reducing encounter, attack, and capture rates (Glass 1971, Crowder and



Cooper 1979b, Anderson 1984). Thus, in high densities of aquatic plants with additional spatial complexity, larger fish may expend more energy in searching and capturing prey items, and less successful captures. This may result in a loss of caloric intake normally allocated towards growth or reproduction. However, largemouth bass may modify their foraging tactics from actively pursuing prey to ambushing them, thus minimizing energy costs required for prey capture (Savino and Stein 1982; Killgore, Morgan, and Rybicki 1989).

### **Reproduction and survival of larval fish**

Much of the data on spawning success comes from studies conducted on largemouth and smallmouth bass, as well as other centrarchids. Bass and sunfish select nesting sites that are protected from wave action (Tester 1930, Kramer and Smith 1962, Miller and Kramer 1971, Summerfelt 1975) and keep their immediate nest sites cleared of vegetation (Tester 1930, Hubbs and Bailey 1938, Watson 1955, Latta 1963, Mraz 1964, Summerfelt 1975), yet they choose nest sites with some type of vegetation or complex structure nearby (Tester 1930, Vogeles and Rainwater 1975, Carpenter and McCreary 1985, Messing and Wicker 1986). However, too much vegetation can hinder spawning adults by decreasing availability of nest sites (Colle and Shireman 1980).

Correlation of nesting success and recruitment with years of high water was observed (Hulsey 1959, Von Geldern 1971, Meals and Miranda 1991), suggesting that inundated vegetation supplies optimal areas for nesting and important cover for survival of larval and juvenile fishes. Nesting success is improved by increasing the available complex structure that spawning fish use for protection (Vogeles and Rainwater 1975, Johnson and Bagwell 1979, Hoff 1990), and the increase of submerged vegetation in areas lacking other types of structure, i.e., timber or coarse substrate, may improve survival of larval fish and the year's recruitment (Kramer and Smith 1962; Bryant and Houser 1971; Miranda, Shelton, and Bryce 1984; Meals and Miranda 1991).

Few studies directly address habitat use by larval and juvenile fish, but data do suggest aquatic plant beds provide complex structure needed for larval fish to avoid predation (Aggus and Elliot 1975) and can serve as important nurseries for larval fish (Gregory and Powles 1985). Light traps showed that early life stages of darters and pumpkinseed sunfish selected shallow, macrophyte-dense areas; perch demonstrated an early ontogenetic shift in these habitats. The prolarvae preferred shallow, high-density macrophyte areas while postlarvae preferred deep, low-density macrophyte zones (Gregory and Powles 1985).

# **Sampling Strategies**

## **Quantification of fish/plant relations**

Before effective management strategies can be put into practice, information is needed on the earlier life stages of fish, the behavior of fish, and their interaction with their habitat. Fisheries management has focussed on harvestable fish and neglected interactions between behavior of small fish and their environment. In the past, fishery management not only lacked empirical data to support sound management practices but also lacked sampling methods to properly assess the questions related to fish/plant interactions. The fundamental reason for a lack of data on important fish/plant interaction is the difficulty in sampling and measuring fish in aquatic plants (Gregory and Powles 1985). New and innovative sampling methods are required in furthering the understanding of their relationships. A number of studies have successfully used a variety of sampling techniques for quantifying fish and their habitat in aquatic vegetation (Table 3).

## **Measuring plants and microfauna**

Both direct and indirect methods have been used to sample plant species and composition of their macroinvertebrate fauna. Some of the direct techniques include using modified dredges for sampling and estimating plant biomass in littoral habitats (Sliger et al. 1990) and by manually clipping sections of plant stems (Gerking 1957). Gerking (1957) suggested differences of benthic macrofauna and phytomacrofauna can be distinguished by collecting plant sections near the substrate and separating them from samples located higher on the plant stem.

Where water conditions are favorable, samples have been directly taken by divers either with the aid of SCUBA or snorkel gear. Transect and quadrat sampling has been successfully conducted by divers to sample submerged vegetation and the macroinvertebrate fauna that inhabit them (Kautsky, Widbom, and Wulff 1981; Pringle 1984; Machena and Kautsky 1988). These methods have proved to be the most precise and efficient way of sampling biomass and estimating standing crop of macrophytes (Downing and Anderson 1985).

Duarte (1987) suggests that sampling aquatic vegetation with divers is time-consuming and cumbersome; alternatively, indirect methods such as the use of a fathometer for sampling aquatic vegetation may be more efficient (Maceina and Shireman 1980; Maceina et al. 1984; Duarte 1987; Pine, Anderson, and Hung 1989). Biomass sampling has been used to define differences in plant distribution, abundance, and species composition (Forsberg 1959; Edwards and Moore 1975; Cassani and Caton 1985; Smart and Barko 1988). An indirect estimation of biomass with echosounder tracings may serve as a good tool for quantifying effects of plant management operations (Pine, Anderson, and Hung 1989). In addition, the

use of aerial videography (Lukens 1967) as a remote sensing tool and of automated positioning systems (Harvey, Patterson, Pickett 1988) serves as a promising approach in quantifying macrophytes at the system level (Jennings, Dewey, and Voh 1991).

### **Measuring fish in plant habitats**

Shallow, structurally complex plant habitats are often primary spawning and nursery grounds for fish, and since these habitats are very difficult to sample, more attention is needed on sampling methods. Under suitable conditions, a diver team can rapidly census fish populations and measure species composition and abundance in habitats that are impossible to sample with traditional methods (Northcote and Wilkie 1963, Keast and Harker 1977, Dibble 1991). Divers with cameras have been used to quantify salmon populations (Ellis 1961). The relative abundance of littoral zone species can be efficiently determined along shoreline microhabitats in rivers, lakes, and reservoirs (Goldstein 1978, Slaney and Martin 1987, Zubik and Fraley 1988, Dibble 1991). However, in conditions where fish are selecting the most dense cover, visual methods by divers may be hindered (Heggenes, Brabrand, and Saltveit 1990).

Modified electroshocking equipment has been devised to sample specific microhabitats (Bain, Finn, and Booke 1985b). This sampling method is effective for site-specific sampling, yet it was designed for systems without high densities of vegetation. However, with slight innovation such equipment may be applicable for precise and accurate sampling of fish in dense vegetation (Dewey, Holland-Bartels, and Zigler 1989; Dewey 1991). In addition, this technique avoids sampling biases that typically prevent traditional electrofishing equipment from measuring natural behaviors in fish because a time delay can be allowed between disturbance (setting up the device) and the sample.

Nets have also been modified to sample fish in aquatic plant habitats. Tow nets for ichthyoplankton have been specially modified to sample larval fish in the shallow, congested habitats where traditional nets could not be easily used (Meador and Bulak 1987). The use of popnets and dropnets has been an effective sampling method for determining fish distribution, diversity, and abundance in dense vegetated and congested areas that traditional methods (i.e., seining and electrogear) are unable to sample (Wegener, Holcomb, and Williams 1973; Freeman, Greening, and Oliver 1984; Larson, Johnson, and Lynch 1986; Serafy, Harrell, and Stevenson 1988; Dewey, Holland-Bartels, and Zigler 1989; Morgan, Killgore, and Douglas 1988; Espegrin and Bergersen 1990). Since the popnets tested in pools and reservoirs proved to be accurate in sampling small fish associated with complex habitats (Larson, Johnson, and Lynch 1986), it is probably one of the better methods used to measure habitat use by juvenile fish. Light traps also appear to be a useful method for determining larval fish abundance in habitats that are difficult to sample by other means (Faber 1981, Gregory and Powles 1985).

Small areas of vegetation can be blocked off with nets, and rotenone applied (Lambout 1959). However, sample accuracy decreases with increase in plant density (Shireman, Colle, and DuRant 1981). This loss of accuracy is due to the difficulty in fish retrieval (Shireman, Colle, and DuRant 1981); similar problems have plagued electrosampling procedures in heavy vegetation (Layher and Maughan 1984, Killgore, Morgan, and Rybicki 1989). Zippen depletion estimation has been used to improve this type of sampling (Dewey 1991).

In addition, explosives have been used in sampling the abundance of fish populations (Averett and Stubbs 1962, Ferguson 1962, Bass and Hitt 1980, Metzger and Shafland 1986), but may not work efficiently in areas of soft, muddy substrate typically found under aquatic plants (Layher and Maughan 1984, Bayley and Austen 1988).

## **Management Goals**

### **Plant control**

Much attention has been focussed on controlling aquatic plants and the effects of control programs on freshwater systems (Table 4). Aquatic plants maintain diversity and ecosystem stability in aquatic systems (Odum 1969, Boyd 1971, Engel 1985, Gregg and Rose 1985), and the maintenance of specific plant density and plant configuration should be a major goal in management. Maintaining intermediate densities appears to be an important aspect of aquatic plant beds affecting the abundance, diversity, and growth of fish (Ware and Gasaway 1977; Savino and Stein 1982; Durocher, Provine, and Kraai 1984; Wiley et al. 1984; Engel 1985, 1988, 1990; Killgore, Morgan, and Rybicki 1989). It is especially important for the survival and recruitment of juvenile fishes (Aggus and Elliot 1975, Hall and Werner 1977, Gregory and Powles 1985, Gotceitas and Colgan 1987, Gutreuter and Anderson 1985, Mittelbach 1988, Meals and Miranda 1991, Cushing and Jia 1992).

Colle and Shireman (1980) predicted that the condition of largemouth bass would significantly decrease in systems with 40 percent or greater coverage of aquatic plants. The creation and maintenance of edges also may increase the availability of important forage and refuge habitat (Werner et al. 1977, Werner, Hall, and Werner 1978; Engel 1984). Based on these predicted benefits, moderate plant densities and plant edges, if maintained, should increase the growth and condition of harvestable fish and supply enough food and cover for the strong recruitment and survival of younger fish.

## **Fisherman's perspective and cost**

There appear to be a number of sportfishing benefits (Surber 1961) to controlling aquatic plants. The fisherman's perspective and cost (Bryant 1970, Stott et al. 1971, Shireman, Colle, and Canfield 1986) are important factors to consider when prioritizing management goals (Surber 1961, Berry et al. 1975, Wiley et al. 1984). In a fisherman survey, only 55 to 62 percent thought aquatic plants posed a problem, and 84 percent of these people suggested that only a partial amount of the plants be removed; only 11 percent felt more emphasis should be placed on plant control (King, Raymong, and Buntz 1978). However, economic losses of fishing revenue have been recorded and are predicted with substantial increases of submersed vegetation in lakes and reservoirs (Berry et al. 1975; Strange, Berry, and Schreck 1975; Colle et al. 1985, 1986, 1987; Borawa et al. 1978). Fishing effort has been shown to increase as much as 241 percent after much of the shoreline vegetation was removed (Mitzner 1978).

## **Summary**

Many of the topics covered in this review represent recent theoretical works that directly apply to relationships between fish and their plant habitats. In addition, there has been extensive work in the area of plant management and indirect impacts on fish populations. However, the literature offers little empirical data to bridge the difference between theoretical predictions and management application.

More emphasis needs to be placed on the early life stages of fish when the relationship between plants and fish may be most important. More work is needed to better understand predator-prey relationships, and how both predatory and prey fishes use complex aquatic plant habitat. To understand these trophic interactions in reference to plant habitats, more attention should be directed towards well-designed behavioral studies, new ways of sampling, and experimental manipulations (McAllister and Peterman 1992) required to examine causes for distribution and habitat use. Additional effort should be directed to better define and quantify meaningful habitat parameters in aquatic plants. Finally, an interdisciplinary approach is required for a thorough understanding of fish/plant interactions. Cooperative studies must be conducted among fishery biologists, aquatic plant managers, aquatic ecologists, botanists, and limnologists.

# **3 Workshops on Fish/Plant Interactions**

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## **Background of Workshops**

Two workshops were held to discuss data requirements, study designs, and research priorities concerning fish/plant interactions. The first workshop was held in New Orleans, Louisiana, in June 1992. Researchers from Federal, State, and academic institutions who are currently working with fish and aquatic plants were invited to present the results of their studies on fish/plant interactions and help develop work units in the new technology area (Table 5). The results of this workshop were used to define research topics and prepare for the second workshop.

The second workshop was held in Seattle, Washington, in July 1992 with the Field Review Group (FRG) and Program Managers Office of the Aquatic Plant Control Research Program (Table 6). The purpose of this workshop was to solicit input from the FRG on the importance of this topic to the overall program, to identify potential work units in the technology area, and to discuss the objectives and approach of each work unit.

## **Conclusions of the Workshops**

Participants of both workshops fully supported the need for this research. Many ideas were expressed and various research areas were identified. The major conclusions are presented below.

- a.* Six work units in the new technology area were identified (Table 7). The objectives, approach, and interrelationships are discussed in Chapter 4 of this document.
- b.* Participants were briefed on current negotiations for a memorandum of agreement between WES and Bass Anglers Sportsman Society (BASS). BASS has expressed interest in WES's research on habitat

value of aquatic plants for fishes. This exemplifies the importance of the new technology area.

- c. All participants fully supported a comprehensive literature review. They indicated that a document summarizing fish/plant research would help in developing research priorities and preparing environmental assessments of plant control operations. It was noted that the literature review should distinguish between a lack of data for a subject area and deficiencies in data for a subject area. Ultimately, the literature review will help justify funding requirements.
- d. The effect of herbicides on fishes was noted as an important public relation concern that often creates controversy in operational treatment of problem aquatic plants. Coordination of research between the Chemical Control and Fish/Plant Technology areas in APCRP was suggested.
- e. Selection of target fish species was briefly discussed. Community-level studies were preferred, but recreational fishes such as largemouth bass, bluegill, and crappie, should also be a major component of the research. The group emphasized that there should be a rationale for selecting target species and accounting for geographic variation in ichthyofaunal assemblages. An example was migratory fishes such as salmonids in the Columbia River.
- f. Angler attitudes should be addressed in the technology area. Several ideas were expressed by the participants:
  - (1) Anglers are generally concerned how plant control operations affect the numbers of exploitable fishes either by direct mortality from treatment (mechanical harvester, herbicides) or habitat alteration.
  - (2) Aquatic plant managers need to know which plant habitats attract fishermen. Creel surveys would be one method of evaluating this question.
  - (3) Environmental concerns should be considered in aquatic plant management practices of the Corps of Engineers.
- g. Sampling gear and sampling strategy were noted as an important consideration. Consistency in the sampling design between researchers was emphasized in order to ensure continuity and minimize bias.
- h. There was consensus among the participants on objectives and approach presented for each work unit (see Chapter 4). Most discussion centered on the Habitat Classification and Management Strategy work units. Comments included:



- (1) Structure of the plants (spatial configuration and density) should be emphasized more than species of plants in the habitat classification of aquatic plants. However, the establishment of exotic plants in a water body may have substantial effects on the composition of the native plant populations and should be considered in the initial classification scheme.
  - (2) The classification should incorporate regional differences in growing season, plant density, and possibly invertebrates and periphyton associated with the plant bed.
  - (3) The high variability in field data is problematic when evaluating cause and effect. The group agreed that well-defined studies with large sample sizes will be necessary to reduce the variability, but this problem will remain characteristic of aquatic plant research.
  - (4) The Management Strategies work unit needs to be better defined. Management strategies should be a series of demonstration projects that apply the results of the other work units to plant control operations. Benefits should be a separate component and used for cost justification of fishery habitat enhancement and plant control operations.
- i.* Considerable discussion ensued on the form of technology transfer, particularly by the FRG. In addition to technical reports containing quantitative multivariate relationships, a mechanistic model that relates the functional aspects of fish/plant interactions to plant control operations was suggested. For example, an aquatic plant manager can choose several spatial configurations of the plant bed and evaluate the response by largemouth bass according to feeding rates, reproductive success, and growth. Usable products should be in the form of fish/habitat relationships using response variables (e.g., growth and abundance of fish, harvest) that can be reasonably assessed. It is important to know which management strategies work, and why they work, so that successful management practices can be repeated.



## **4 Description of the Technology Area**

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### **Background of Technology Area**

The purpose of this section is to describe an approach to develop quantitative relationships between aquatic plant habitats, fish abundance, and fish community structure for broad applicability within geographic regions and to discuss how fish/plant interactions can be used to develop fishery management strategies in vegetated water bodies. The literature review and the two workshops, which were the initial step in developing the technology area, served as a basis for prioritizing and designing studies on fish/plant interactions.

The technology area will have three primary requirements. First, results of each work unit must have a broad geographic application because the APCRP is a national research program. To meet this requirement, study sites will be selected in different regions of the United States where the Corps of Engineers is experiencing problems with fish/plant interactions. Secondly, a habitat-based approach is needed because aquatic plant managers directly modify habitat complexity through plant control programs. In addition, a habitat-based approach provides a common theme that researchers can use to compare study designs and results of individual projects. The final requirement is to have standardized collection methods to assess the composition and abundance of plants and fishes. This requirement is necessary to ensure that the results of work units are comparable when developing management strategies.

### **Organization of Work Units**

The information gathered through the literature review and input obtained from the two workshops were used to identify six work units for the technology area:

- a.* Classification of Aquatic Plant Habitats for Fish.

- b.* Fish Distribution, Diversity, and Abundance in Vegetative Habitats.
- c.* Reproduction of Fish in Aquatic Plant Habitats.
- d.* Food Web Interactions.
- e.* Growth and Conditions of Fishes.
- f.* Strategies for Fisheries Management in Vegetated Water Bodies.

The interrelationships of the work units are graphically displayed with a flow chart (Figure 1). The flow chart divides the technology area into three components:

- a.* What are the types of fish habitats in plant beds? The habitat classification and the fish distribution, diversity, and abundance work units will address this question. The literature review and input from the workshops clearly showed that the quality of the habitat directly influences species composition and relative abundance of fishes. These two work units must be conducted concurrently because habitat type and fish association are intricately related. Therefore, the first step in this research is to develop a classification scheme of aquatic plant habitats and describe the distribution, diversity, and abundance of fishes within each habitat. Both work units are more descriptive than causative evaluations, but the information derived from each is necessary to develop study designs for subsequent work units.
- b.* Why are the fish in those habitats? The next step is to evaluate why fishes use specific plant habitats. This question addresses functional use of habitats by fishes and will include the work units on reproduction, feeding, and growth. As the work units suggest, fish use plants for three primary reasons: reproducing, feeding while avoiding predators, and maintaining adequate growth rates and condition. The functional value of plants to fishes is an essential element in understanding the complex interactions of biotic and abiotic factors that regulate population maintenance and community structure. By studying functional processes in specific plant habitats, management strategies can be better developed because knowledge on spatial structure and relative abundance of plants will be part of the results. Both controlled and field studies will be used to verify and expand the understanding of functional value. Behavior interactions will be a key component of these studies. The results will allow researchers to show mechanistic responses of fish populations given different scenarios in plant habitat and fish species associations.
- c.* How should plant beds be managed as fish habitat? The final work unit will interrelate the results of the previous work units, evaluate limiting factors that influence fish/plant interactions, identify

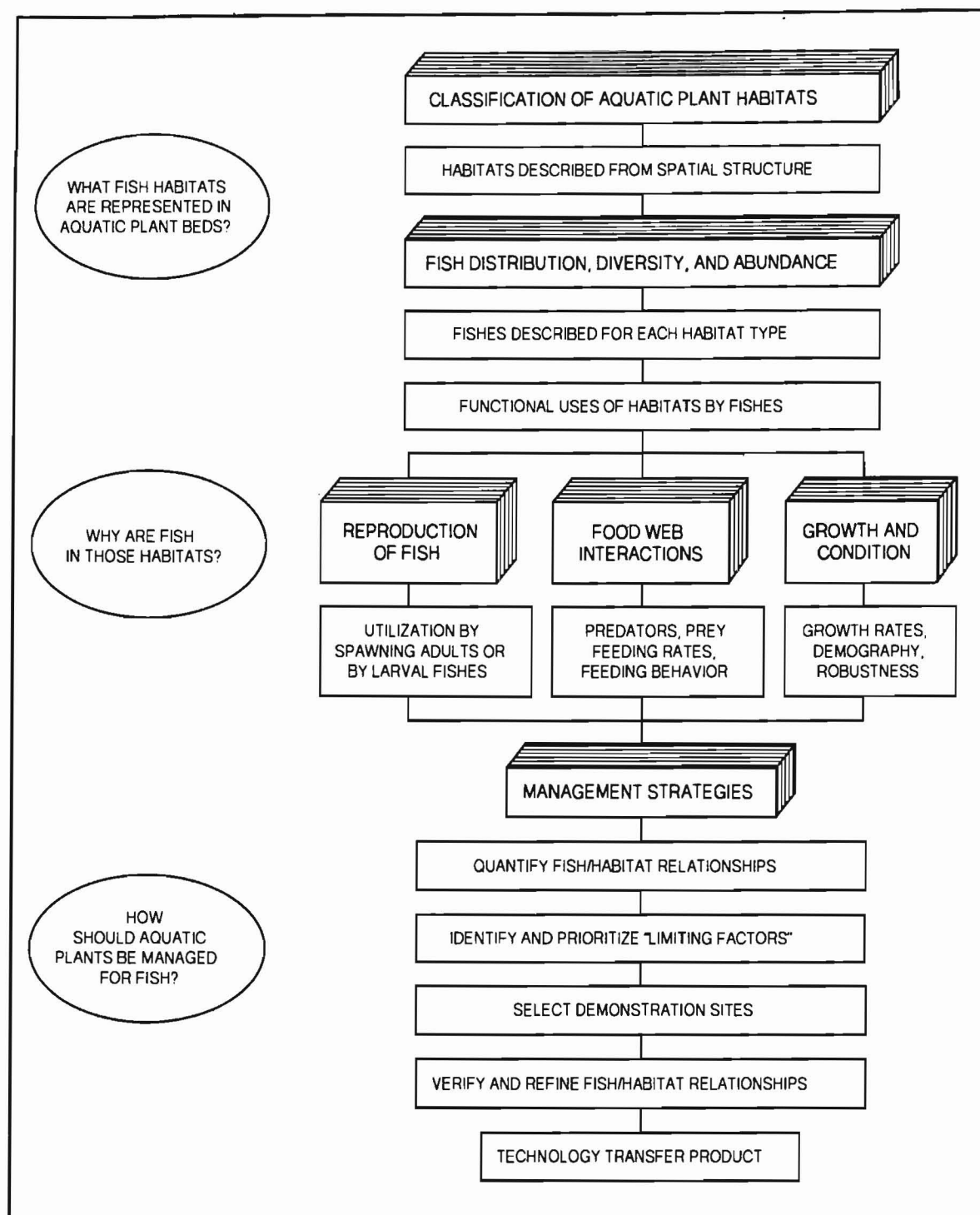


Figure 1. Organization of the technology area on fish/plant interactions. Circles represent research questions, boldface rectangles denote work units, and simple rectangles denote essential steps within each work unit.

causative factors for habitat use, and determine how aquatic plants should be managed for fish. Demonstration sites will be selected, and different management strategies will be applied. The results of the demonstration studies will ultimately be used to produce the technology transfer products that Corps of Engineers Districts can use to simulate and predict the outcome of different plant management strategies on fish.

## **Description of Work Units**

### **Classification of aquatic plant habitats for fish**

The purpose of this work unit is to develop a standardized system of classifying habitats created by aquatic plants. Aerial photography and biomass sampling are commonly used to evaluate aquatic plant beds. This work unit will consider these and other types of mapping techniques to determine their feasibility in distinguishing aquatic plant habitats. Relevant habitat variables that can be used to characterize plant beds and can be correlated with measures of the fish community (e.g. abundance and growth of sport fishes) will be identified. Emphasis will be placed on variables and techniques to describe the configuration and relative abundance of plant beds within a water body since these variables are directly influenced by plant control. Once individual habitats are defined, post-hoc analysis of the variables will be conducted to determine the adequacy of the habitat classification, and any modification of the classification matrix will be made as necessary.

### **Fish distribution, diversity, and abundance in vegetative habitats**

Determining standardized system for collecting fish in vegetated habitats will be the initial objective of this work unit. As shown in the literature review, there are a variety of methods used to collect fish in plants including seining, electroshocking, rotenone, enclosure traps, light traps, and underwater observation techniques. Sampling gear recommendations will consider the biases and limitations of each gear type. Although study design is at the discretion of the researcher, fish-collecting techniques in subsequent work units will follow the guidelines developed in this work unit.

Once aquatic plant habitats have been defined in the first work unit, field studies will be conducted to quantify the composition and abundance of the fish community in each habitat. The primary objective will be to relate biological response variables (i.e., fish distribution, abundance, and diversity) to independent habitat variables created or regulated by aquatic plants (e.g., trophic status, water chemistry, plant biomass, and

distribution). Data will be collected at various locations across the United States to account for different types of water bodies, plant and fish assemblages, and geographic areas. Numerical relationships between fish and aquatic plants will be evaluated and developed using various analytical techniques including regression models, multivariate techniques (e.g., classification and ordination), and community indices (e.g., species diversity).

### **Reproduction of fish in aquatic plant habitats**

Reproduction of fish in each aquatic plant habitat will be measured. Variables will include spawning periodicity, fecundity, nest density, survival rates, and richness and abundance of larvae. Both direct (underwater techniques) and indirect (e.g., light traps for larval fish) observations will be made in representative habitats. Correlations between nesting success and recruitment will be evaluated in water bodies where the population structure of fishes is regularly assessed by resource biologists. Ontogenetic shifts in habitat use will be determined by sampling over the entire reproductive season. The results of this work unit will describe the overall importance of aquatic plants to survival of embryos and larvae and provide a comprehensive list of species that use individual plant habitats for reproductive purposes.

### **Food web interactions**

The purpose of this work unit is to determine relationships between aquatic plant habitats and foraging of individual species. The foraging environment of fishes is dependent on the complexity of the habitat, availability of food, and the influence of predators on foraging strategies. Foraging strategies are usually a behavioral response to the surrounding environment. The interaction of these factors makes it difficult to determine the importance of one plant habitat from another. Therefore, one approach will be to simulate distinct plant habitats in controlled environments (e.g., ponds) and measure the behavioral response of fishes relative to the presence of predators. These results may indicate that certain plant habitats optimize foraging success. Field experiments will also be conducted that correlate invertebrate assemblages with stomach contents of fishes in different plant habitats. If certain invertebrate food items are actively selected and if the habitat preferences of these food items are determined, then management can focus on specific plant configurations that optimize the habitat of commonly eaten invertebrates. The trophic state of the water body will be a primary consideration in establishing the composition and availability of food resources.

## **Growth and condition of fishes**

Fishes of commercial or recreational value will be emphasized in this work unit. Two approaches will be used. First, growth of different age classes of fish will be compared between unvegetated and vegetated water bodies. These data will provide an objective evaluation on impacts of problem aquatic plant species that rapidly colonize unvegetated water bodies on fish growth. The second approach will be to compare growth rates of individual species among the predetermined plant habitats. Because of the difficulty in determining a fish's foraging history in large water bodies, pond studies will be emphasized. Response variables will include condition factors, relative weight indices, and absolute growth between years or seasons.

## **Strategies for fishes management in vegetated water bodies**

This work unit will compile the results of the descriptive and functional studies into quantitative relationships between fish and aquatic plant habitats. Factors that limit the distribution and abundance of fishes will be identified and discussed. Demonstration projects will apply these relationships to reduce impacts of plant control on fish communities and to enhance fish habitat in areas with aquatic plants. Demonstrations will consist of modifying spatial configuration and density of plant beds at different field sites. In addition, experimental ponds at the Lewisville Aquatic Plant Research Facility will be used to demonstrate behavioral response of fishes to varying degrees of plant removal. The results of these demonstrations will be used to verify and refine fish/plant relationships and to compile a set of recommendations on distribution and abundance of plant beds for fishery management purposes.

## **Funding Sequence of the Work Units**

The sequence of funding of each work unit is shown in Table 7. As noted previously, classification of aquatic plant habitats (Work Unit 1) and the fishes associated with each habitat (Work Unit 2) will be determined concurrently. The functional value of plant habitats will follow and include studies on reproduction, trophic dynamics, and growth and condition of fishes. The last work unit on management strategies will compile information from the previous work units, demonstrate fish/plant relationships emphasizing limiting factors, and produce workable models that plant managers can use to simulate and predict impacts of plant control operations.

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**Table 1**  
**Different Approaches in Habitat Classification**

Criteria Used for Classification	Reference
<b>Regional Level Classification</b>	
Assemblage characteristics	Hawkes, Miller, and Layher (1986) Hughes et al. (1986) Larson, Johnson, and Lynch (1986) Rohm, Giese, and Bennett (1987)
Ecosystem characteristics	Bailey (1983) Whittier, Huges, and Larsen (1988)
Regional water quality	Heiskary, Wilson, and Larsen (1987)
Stream characteristics	Lyons (1989) Pflieger, Schene, and Haverland (1981)
Stream hydrology and geology	Fausch, Hawkes, and Parsons (1988) Hocutt and Wiley (1986)
<b>Macro-Level Classification</b>	
Biomass and standing crop	Maceina and Shireman (1980) Maceina et al. (1984) Pine, Anderson, and Hung (1989) Schloesser and Manny (1984) Shireman and Maceina (1979) Sliger et al. (1990) Duarte (1987)
Percent of plant cover	Canfield et al. (1990) Durocher, Provine, and Kraai (1984) Edwards (1983) Edwards and Twomey (1982a, 1982b) Edwards et al. (1982a) Edwards, Gebhart, and Maughan (1983) Hamilton and Nelson (1984) Inskip (1982) Krieger, Terrell, and Nelson (1983) Maceina and Shireman (1980) McMahon and Terrell (1982) McMahon, Terrell, and Nelson (1984) Stuber (1982) Stuber, Gebhart, and Maughan (1982a,b,c) Trial et al. (1983) Raleigh et al. (1984) Raleigh, Zuckerman, and Nelson (1986) Williamson and Nelson (1985)
Plant abundance	Jennings, Dewey, and Voh (1991) Lukens (1967) Nichols et al. (1988)
Plant distribution	Harvey, Patterson, Pickett (1988) Rybicki et al. (1987) Scheffer, Deredelijkheid, and Noppert (1992) Shireman and Maceina (1979) Stent and Hanley (1985)
Plant species composition and water quality	Canfield et al. (1983) Jackson and Charles (1988)
<i>(Continued)</i>	

**Table 1 (Concluded)**

Criteria Used for Classification	Reference
<b>Macro-Level Classification (Continued)</b>	
Stream characteristics and hydrology	Hamilton and Nelson (1984)
Submersed vegetation and sediment type	Barko et al. (1982) Modde, Ford, and Parsons (1991)
<b>Micro-Level Classification</b>	
Dominant species	Scheffer, Achterberg, and Beltman (1984)
Emergent versus submergent vegetation	Jackson and Charles (1988) Lodge (1985) Morgan, Killgore, and Douglas (1988)
Light intensity and shade	Helfman (1979, 1981) Johnson, Beaumier, and Lynch (1988) Lynch and Johnson (1989)
Plant density	Anderson (1984) Downing and Anderson (1985) Killgore, Morgan, and Rybicki (1989) Petrell, Bagriall, and Smerage (1991) Savino and Stein (1982)
Plant strata	Engel (1988) Morin and Kimball (1984)
Species richness	Poe et al. (1986)
Submergent versus emergent and floating	Holland and Huston (1984) Schramm, Jirka, and Hoyer (1987)
Substrate and interstice size	Bain, Finn, and Booke (1985a, 1985b) Johnson, Beaumier, and Lynch (1988)
Vegetation distance from shore and depth	Cook and Bergersen (1988)
Vegetated versus nonvegetated areas and depths	Gregory and Powles (1985) Layzer and Clady (1987) Hoover, Killgore, and Morgan (1988) Miller et al. (1989) Mittelbach (1988) Paller (1987) Todd and Rabeni (1989) Watkins, Shireman, and Haller (1983) Werner et al. (1977) Whitfield (1984)

**Table 2**  
**Optimum Vegetation Cover for Selected Upper Mississippi River**  
**Fishes<sup>1</sup>**

Species	Cover, %	Reference
Gizzard shad	>30	Williamson and Nelson (1985)
Rainbow trout	>22 <sup>2</sup>	Raleigh et al. (1984)
Brown trout	>35 <sup>2</sup>	Raleigh, Zuckerman, and Nelson (1986)
Brook trout	>25 <sup>2</sup>	Raleigh (1982)
Northern pike	>80	Inskip (1982)
Common carp	30-55	Edwards and Twomey (1982a)
Common shiner	20-70	Trial et al. (1983)
Creek chub	>30	McMahon (1982)
Smallmouth buffalo	>30	Edwards and Twomey (1982b)
Bigmouth buffalo	25-75	Edwards (1983)
Black bullhead	25-30	Stuber (1982)
Channel catfish	>30	McMahon and Terrell (1982)
White bass	25	Hamilton and Nelson (1984)
Green sunfish	35-80 <sup>2</sup>	Stuber, Gebhart, and Maughan (1982b)
Warmouth	>45 <sup>2</sup>	McMahon, Terrell, and Nelson (1984)
Bluegill	15-30	Stuber, Gebhart, and Maughan (1982a)
Smallmouth bass	25-50 <sup>2</sup>	Edwards, Gebhart, and Maughan (1983)
Largemouth bass	40-60 <sup>2</sup>	Stuber, Gebhart, and Maughan (1982c)
White crappie	25-80 <sup>2</sup>	Edwards et al. (1982b)
Black crappie	25-85 <sup>2</sup>	Edwards et al. (1982a)
Yellow perch	25-50 <sup>2</sup>	Krieger, Terrell, and Nelson (1983)
Walleye	25-45 <sup>2</sup>	McMahon, Terrell, and Nelson (1984)

<sup>1</sup> Table has been adapted from Janecek (1988).

<sup>2</sup> These fish may use other forms of cover in addition to vegetation. The values given are for all cover combined.

**Table 3**  
**Methods Used to Quantify Plants and Fishes in or Near Vegetated Habitats**

Method	Reference
<b>Plants</b>	
Aerial photography	Berry et al. (1974) Durocher, Provine, and Kraai (1984) Lukens (1967) Martin et al. (1986) Jennings, Dewey, and Voh (1991)
Automated system	Harvey, Patterson, Pickett (1988)
Direct plant measurements	Petrell, Bagnall, and Smerage (1991) Pine, Anderson, and Hung (1989)
Divers	Downing and Anderson (1985) Engel (1988) Machena and Kautsky (1988) Whitfield (1984)
Fathometer	Duarte (1987) Maceina et al. (1984) Maceina and Shireman (1980) Shireman and Maceina (1979) Stent and Hanley (1985)
Line transect (boat)	Jackson and Charles (1988) Schloesser and Manny (1984)
Plant removal	Killgore, Morgan, and Rybicki (1989) Canfield et al. (1990) Holland and Huston (1984) Morin and Kimball (1984) Schramm, Jurka, and Hoyer (1987) Poe et al. (1986) Scheffer, Achterberg, and Beltman (1984) Nichols, Schloesser, and Geis (1988) Sliger et al. (1990)
<b>Fishes</b>	
Combination of shocker and net	Hoover, Killgore, and Morgan (1988) Killgore, Morgan, and Rybicki (1989)
Divers	Dibble (1991) Goldstein (1978) Keast and Harker (1977) Northcote and Wilkie (1963) Rodgers et al. (1992) Slaney and Martin (1987) Zubik and Fraley (1988)
Drop/throw nets	Barnett (1973) Freeman, Greening, and Oliver (1984) Wegener, Holcomb, and Williams (1973)
Stationary nets	Meador and Bulak (1987) Whitfield (1984)
<i>(Continued)</i>	

Table 3 (Concluded)	
Method	Reference
Fishes (Continued)	
Explosives	Averett and Stubbs (1966) Bayley and Austen (1988) Bass and Hilt (1984) Ferguson (1962) Layher and Maughan (1984) Metzger and Shafland (1986)
Grid shocker	Bain, Finn, and Booke (1985a)
Hose pump/net	Paller (1987)
Light and minnow trap	Gregory and Powles (1985) Layzer and Clady (1987)
Popnets	Serafy, Harrell, and Stevenson (1988) Dewey, Holland-Bartels, and Zigler (1989) Espegrin and Bergersen (1990) Morgan, Kilgore, and Douglas (1988)
Radio telemetry	Cook and Bergersen (1988) Todd and Rabeni (1989)
Rotenone	Durocher, Provine, and Kraai (1984)
Seine	Freeman, Greening, and Oliver (1984) Holland and Huston (1984)
Seine/angling	Mittelbach (1984)
Shocker	Engel (1988)
Shore observations	Savino and Stein (1982)

**Table 4**  
**Topical Emphasis of Plant Control Studies**

Topics	Reference
Angler-oriented plant control and sport fisheries	Berry et al. (1975) Colle (1982) Surber (1961) Wiley et al. (1984)
Comparison of bio/chemical control	Buck, Baur, and Rose (1975) Hestand and Carter (1978) Osborne, Richard, and Small (1983) Shireman and Haller (1983)
Comparison of chem/bio/mechanical control	Shireman et al. (1984)
Effects on fish by plant removal	Bailey (1978) Bettoli (1987) Bettoli, Morris, and Noble (1991) Colle, Cailteux, and Shirman (1989) Mikol (1985) Ware et al. (1976)
Effects on ichthyofauna and macrophytic insects	Haag and Buckingham (1991) Krzywosz, Krzywosz, and Radziej (1980)
Efficiency of plant control and economics	Osborne (1985) Koegal, Livermore, and Bruhn (1977) Shireman, Colle, and Canfield (1986) Singh et al. (1969) Stott and Robson (1970) Stott et al. (1971)
Environmental effects by chemical control	Gallagher (1970) Hinkle (1985)
Environmental effects of control by grass carp	Bailey (1972, 1975) Bain and Boltz (1992) Beach et al. (1976) Bettoli, Noble, and Betsill (1992) Shireman and Maceina (1981) Thompson and Hartwig (1973) Van Zon, Van Der Zweerde, and Hoogers (1978)
Plant control by grass carp	Avault (1965a, 1965b) Klussmann (1988) Pine, Anderson, and Hung (1990) Rowe (1984) Sutton (1985) Ware et al. (1976)
Plant control and control programs	Gangstad (1971) Opuszynski (1972) Reinert, Hinman, and Rodgers (1988)
Plant control and restructuring littoral zones	Dawson, Castellano, and Ladle (1978) Engel (1984) Hestand and Carter (1977)
Plant control with fertilizers	Smith and Swingle (1941)
Plant control by water level manipulation	Hestand et al. (1973) Lantz et al. (1964)
Plant control by mechanics	McGehee (1979)
Water quality and plant control	Blackburn (1975) Canfield, Maceina, and Shireman (1983) Shireman et al. (1985) Wiley (1978)



**Table 5**  
**List of Participants of the Workshop Held in New Orleans,**  
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**Table 6**  
**List of Attendees for the Workshop Held in Seattle, Washington,**  
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**Table 7**  
**Funding Sequence for the Fish/Plant Interaction Technology Area**

Work Unit	FY 94	FY 95	FY 96	FY 97	FY 98	FY 99
1. Classification of Aquatic Plant Habitats for Fish	-----	-----				
2. Fish Distribution, Diversity, and Abundance in Vegetated Habitats	-----	-----	-----	-----		
3. Reproduction of Fish in Aquatic Plant Habitats	-----	-----	-----	-----		
4. Food Web Interactions	-----	-----	-----	-----		
5. Growth and Condition of Fishes	-----	-----	-----	-----		
6. Strategies for Fisheries Management in Vegetated Waters					-----	-----

# REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words) <p>This report describes a proposed new technology area in the Aquatic Plant Control Research Program on fish/plant interactions. A plan of study (POS) is presented based on a comprehensive literature review of relationships between fish and aquatic plants, and input from two workshops held with State, Federal, and university researchers. The POS discusses the need for future research according to deficiencies in the literature and serves as a basis for prioritizing and designing studies on fish/plant interactions in different geographic regions of the United States.</p> <p>The purpose of the first two work units (Classification of Aquatic Plant Habitats for Fish; and Fish Distribution, Diversity, and Abundance in Vegetated Habitats) is to describe species composition and abundance of fishes associated with specific aquatic plant habitats. Once the habitat classification is completed, studies will be initiated to evaluate why fishes use specific plant habitats. This question addresses functional use of habitats by fishes and will include work units on reproduction, feeding, and growth. The functional value of plants to fishes is an essential element in understanding the complex interactions of biotic and abiotic factors that regulate population maintenance and community structure of fishes. The last work unit on management strategies will interrelate the results of the</p> <p style="text-align: right;">(Continued)</p>				
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descriptive and functional studies to determine how aquatic plants should be managed for fish. Demonstration sites will be selected, and different management strategies will be applied. The results of the demonstration studies will be used to produce the technology transfer products that Corps of Engineers Districts can use to simulate and predict the outcome of different plant management strategies on fish.