Propagation and Establishment of Native Aquatic Plants in Reservoirs

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U.S. Army Corps of Engineers, Lewisville
Aquatic Ecosystem Research Facility

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CONTENTS

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ABSTRACT

The role of plants in aquatic systems is significant. Aquatic plants provide valuable fish and wildlife habitat, serve as a food source for waterfowl and other aquatic wildlife, improve water clarity and quality, reduce rates of shoreline erosion and sediment re-suspension, and help prevent the spread of nuisance exotic plants. Typically, three different situations occur in large multipurpose reservoirs: 1) low abundance of vegetation, 2) low species diversity, or 3) remediation following control of nuisance exotic plant species such as hydrilla (*Hydrilla verticillata*). Because reservoir hydrodynamics, herbivore populations, and seed bank are vastly different from natural lakes, techniques have been developed to improve the chances of success in aquatic plant introduction programs in reservoirs.

In this document, we present an approach for accelerating community succession using native aquatic plant founder colonies. By ensuring that propagules, such as seed or plant fragments, are present in sufficient numbers when conditions are suitable for natural establishment, the time required for vegetative colonization to occur is shortened. Recommendations for production of suitable propagules include their growth requirements, operation of production facilities, and selection of different propagule types by species. Recommendations for establishment of these propagules in reservoir ecosystems includes site selection, season of establishment, planting techniques, defining individual phases of an establishment project and monitoring and adaptive management after species are introduced.

Example schematics, material selection, and placement of protective exclosures necessary for initial establishment are discussed. Growth requirements and individual autecology for four submersed, two floating-leaved, and nine emergent species found to work best in the full range of environmental conditions present in Texas' reservoirs are provided.

INTRODUCTION

The role of plants in aquatic systems is significant. Aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996), serve as a food source for waterfowl and other aquatic wildlife, improve water clarity and quality (James and Barko 1990), reduce rates of shoreline erosion and sediment re-suspension (James and Barko 1995), and help prevent the spread of nuisance exotic plants (Smart et al. 1994). These desirable qualities make efforts to establish native aquatic plants in our inland waters worthwhile.

Typically, three situations occur in large multipurpose reservoirs that qualify for restoration through establishment of native aquatic plants: 1) low abundance of vegetation, 2) low species diversity, or 3) remediation following control of nuisance exotic plant species such as hydrilla *Hydrilla verticillata*. In the first two situations, restoration involves establishment of desirable species of aquatic plants; in the latter, we must additionally address control of invasive exotic species (not covered in this manual).

Aquatic plant communities may take hundreds or even thousands of years to develop in natural lakes (Doyle and Smart 1993). The average age of the 670-plus reservoirs managed by the Corps of Engineers is just over 40 years; there has simply not been sufficient time in these manmade systems for natural introduction and establishment of native aquatic plants to occur. Time is not the only limitation: an absence of propagule sources, harsh abiotic conditions, and biotic pressures all contribute to reducing the likelihood that aquatic plants will become established in any given reservoir.

Reservoirs are often constructed in areas that lack natural lakes, and may be remote from populations of aquatic plants. As a result, many reservoirs have no aquatic plant seed bank and receive only limited inputs of seed and other plant propagules from their watersheds or other sources. These reservoirs are often first colonized by nuisance exotic weeds, frequently a result of accidental introduction by boaters. Many exotic species are adapted for exploiting disturbed conditions and may quickly spread to become problematic (Smart and Doyle 1995). Once established, exotic plant species can hamper establishment of native plants, regardless of subsequent propagule availability.

Abiotic conditions unfavorable to plant establishment may include excessive water-level fluctuations, high turbidities, and shifting sediments. Newly established plants are especially vulnerable to changing water levels that may place them in water too deep or turbid to allow for adequate light penetration or so shallow as to expose them to turbulence or desiccation, or cover them with sediments (Smart and Doyle 1995).

Biotic disturbances are caused by a number of aquatic and semi-aquatic organisms. Fish and other animals that feed or root in sediments easily dislodge seedlings and other small plants. In addition, grazing by turtles, crayfish, insect larvae, mammals, and waterfowl has been shown to impair establishment and/or growth of submersed aquatic plants (Lodge 1991; Dick et al. 1995; Doyle and Smart 1995; Doyle et al. 1997). Because of their mobility and widespread distribution, aquatic omnivores are often present in numbers sufficient to prevent, or at least delay, succession and establishment of aquatic vegetation. Additionally, grass carp *Ctenopharyngodon idella* have been used to control aquatic weed infestations in some systems, and their continued presence may prevent establishment of most aquatic plant species for many years (Smart et al. 1998). This manual is a revision of an earlier version (Smart and Dick 1999).

CHAPTER 1

Founder Colony Approach

1.1 Founder Colony

We present an approach for accelerating succession in aquatic plant communities by overcoming one major impediment: availability of propagules. Continual provision of propagules ensures they are present when conditions are suitable for natural establishment, greatly shortening the time required for vegetative colonization to occur. The approach utilizes ***founder colonies*** (Figure 1) as propagule sources: these are small colonies of aquatic plants established in strategic locations within the reservoir. Once established, founder colonies spread in two manners, including expansion (vegetative spread from the founder colony itself) and colonization (formation of new colonies from fragments, seeds, etc.; Smart et al. 1996, 1998).

1.2 Objectives of Founder Colony

Establishment of founder colonies faces the same impediments as natural establishment, and relies on planting of robust propagules (such as mature transplants) into protected sites (Smart et al. 1996, 1998). This manual describes techniques for producing aquatic plant propagules and for establishing these propagules in reservoirs.

Many techniques we present here result from research conducted on seven Texas reservoirs over 8 years. Although the techniques have not been rigorously tested in multiple systems and may not be universally applicable due to differences among plant species, among regions of the country, among reservoirs, and even within reservoirs, they are believed to be the most effective techniques currently available. Annual variations in climate and hydrology are likely to affect the outcome of any plant establishment efforts. These techniques are certainly not the only means of establishing aquatic vegetation, and we continue to develop and evaluate new methodologies at a number of reservoirs in several southern states. Likewise, we have thus far attempted to establish relatively few species on a large scale or in multiple situations, and we continue to evaluate establishment of additional species. Some of these new techniques and new species will prove successful while others may not.

CHAPTER 2

Propagule Production

2.1 In-house Propagule Production

Each restoration project requires many individuals and may consist of multiple aquatic plant species. Even on the scale of founder colony establishment, plant numbers required can be quite high. Because acquisition of large numbers of appropriate propagules in a timely manner can be difficult, we have developed methods for producing transplants and other propagules, tailored for each specific project.

Although commercial suppliers may be used to provide some plant materials needed for restoration projects, local propagule production may be preferred for several reasons. Currently, only a limited selection of aquatic plant species (particularly submersed plant species) is readily available from commercial sources. Additionally, propagule types offered commercially are seldom suited to the demands of plant community establishment in large water bodies: for the most part, stem fragments, seeds, root crowns, or dormant perennating organs (e.g., tubers and winter buds) are the life stage sold commercially. These propagules require near-ideal conditions for successful establishment, and in the harsh environment of reservoirs, only a small percentage is likely to persist.

Another concern regarding dependence upon commercial supply is that such propagules are often only available seasonally, possibly at the wrong time of the year for a particular restoration project. One reason for this is geographic location of commercial suppliers or collectors. As an example, northern suppliers generally must wait until spring thaws occur, which may be beyond the period for optimal establishment in southern reservoirs. In other cases, propagules may be readily available in the spring, but hydrologic conditions (e.g. spring flooding) may dictate planting at a later date. Plant material, even dormant propagules, may not survive holding for extended periods.

Species locality is also an issue of concern. Although a particular species may be found throughout the U.S., there may be genetic variability among plants from different regions, due to differences in environmental (climatic or geological) conditions. Because a northern variety may not do well in southern climates, finding source plants locally (or as locally as possible) is highly preferred

Because finding local plant stocks and cultivating desired species are the most likely means of acquiring suitable plants for restoration projects, this chapter is intended to guide those who choose to produce their own propagules. We cover general requirements and considerations for culturing a variety of aquatic plants, including submersed, floating-leaved, and emergent growth forms. Additional information on 15 North American species is provided in Appendix A.

2.2 Plant Growth Requirements

The key to growing any plant is to provide conditions that allow the plant to fulfill its nutrients requirements and sustain a rate of photosynthesis sufficient to provide for respiration and growth. All plants have a basic need for water and an environment that provides appropriate temperatures. Beyond these basic requirements, photosynthesis by aquatic plants depends on adequate levels of light and a continual supply of inorganic carbon (dissolved carbon dioxide or bicarbonate), while nutrient uptake depends on a supply of critical nutrients. Table 1 indicates sites of nutrient uptake and photosynthesis for terrestrial and aquatic plants of different growth forms. These facts must be considered in development of plant culture methods and facilities.

Unlike terrestrial plants, submersed aquatic plants conduct photosynthesis in an aqueous environment. This is important for several reasons. First, water limits light penetration and must be sufficiently clear to transmit adequate light to the leaves. Second, dissolved nutrients are present, particularly phosphorus, and excessive growth of algae can cause problems by reducing light penetration to submersed plants. Third, diffusion of carbon dioxide in water is slow compared to the atmosphere and the concentration of carbon dioxide can be greatly reduced in water, particularly at pH levels greater than 8.3. Therefore, a continual supply of inorganic carbon must be provided. Furthermore, algae will compete with submersed plants for inorganic carbon.

Successful culture of rooted submersed aquatic plants depends on our ability to provide adequate levels of light via water to the shoots (Smart and Barko 1985), adequate nutrients via the sediment to roots, and adequate levels of inorganic carbon via the water to shoots (Smart and Barko 1985). Because non-rooted submersed aquatic plants must obtain all of these resources (nutrients, light, and carbon) via the water, they are quite difficult to grow under artificial conditions due to competition with algae. For this reason, we do not at this time recommend culture of coontail *Ceratophyllum demersum* and prefer to collect plants of this species from existing natural populations.

<u>Water quality requirements</u>

In general, water suitable for raising freshwater fish is adequate for growing plants. While floating-leaved and emergent plants are not as susceptible to light limitation due to leaves emerging above the water's surface, a reliable source of high-quality water is required for growing submersed aquatic plants. Ideally, water should be clear and low in nutrients (particularly phosphorus). Clear water allows adequate light penetration. Under low light conditions, some plants will produce weak root systems. Nutrient-rich water often leads to algal blooms that can interfere with plant production by limiting light and competing for inorganic carbon. Municipally treated water is not recommended unless chlorine is removed. Additionally, treated water also often contains relatively high levels of phosphorus.

For tank cultures, lake water can be polished or treated to improve quality; one method is to use a vegetated pond to reduce turbidity and remove most dissolved phosphorus from the water column. Water is pumped directly from this pond to the culture facilities. A second method is to pump lake water into a holding tank where it is treated with aluminum sulfate (approximately 12 oz per 1,000 gal) to flocculate clays and suspended material and to remove phosphorus by sorption onto precipitates. The resultant flocculent is allowed to settle and clear surface waters are pumped to culture tanks. For a large-scale plant-production system, a 6-ft deep, lined water supply pond may be used as a reservoir. Lake water is pumped into the pond, treated with aluminum sulfate, and mechanically filtered with sand filters (Dick et al. 1997). The pond liner (synthetic rubber) prevents nutrients and clay minerals from being released or suspended from the soil into the water column. This system provides an abundance of high-quality water.

Additional requirements for water used to grow submersed aquatic plants include a source of inorganic carbon and a balanced chemical composition including calcium, magnesium, and potassium ions (Smart and Barko 1984, 1985). Periodic replacement of part of the water will maintain favorable levels of alkalinity, dissolved inorganic carbon, and dissolved ions. Alternatively, additions of sodium or potassium bicarbonate and calcium (as either a sulfate or chloride salt) can be used to maintain adequate levels of these constituents. In unlined, earthen ponds, sediment respiration provides an abundant and continuous supply of carbon dioxide to support the photosynthesis of submersed aquatic plants. However, in lined ponds or tanks, carbon dioxide availability may be a factor limiting growth of submersed aquatic plants; floating-leaved and emergent species acquire carbon dioxide directly from the air, and are therefore not of concern. Consequently, aeration of tank cultures is helpful for submersed species. A regenerative blower or compressor aeration system will supply the air, and vigorous bubbling of atmospheric air through air stones usually provides adequate mixing in addition to supplying carbon dioxide.

Sediment/substrate

Submersed aquatic plants will grow in a variety of substrate types, ranging from pure sand to heavy clays. However, for optimum production, a fine-textured substrate with a low to moderate organic content (10-20 percent) is ideal for most species. Sandy substrates are unsuitable as a culture medium because they are generally infertile and added nutrients will diffuse into the water column, causing algal problems. On the other hand, highly organic substrates can be inhibitory to plant growth by fouling the water column (Barko and Smart 1983, 1986). When available, we recommend using fine-textured sediments from ponds or lakes in which aquatic plants are known to grow. If the growth potential of sediments is in doubt, small-scale trials should be conducted to determine sediment suitability for supporting aquatic plant growth. Heat or chemical sterilization may be required if seeds of undesirable species are present in such substrates.

Because suitable natural sediments may not always be available, the use of commercial potting soil or topsoil may be necessary. For relatively small-scale efforts, bagged soils may be practical. In selecting a soil for aquatic use, the lowest priced product will often be the most suitable as it will generally contain the fewest additives. Avoid the use of products that contain non-soil additives such as vermiculite or perlite. For large-scale projects, local topsoil may be purchased in bulk after ensuring their suitability (by conducting small-scale plant growth trials).

Containers

Production of propagules suitable for transplanting into lakes requires growing plants in pots. We recommend using commercial nursery pots with drain holes in the bottoms. Holes allow movement of dissolved nutrients into the sediment substrate where they can be taken up by the roots. Various sizes and shapes of commercial nursery pots are available, but we have had the most success with quart- (4-in diameter) and gallon-sized (6-in diameter; nominal sizes) pots for growing a wide variety of aquatic plant species. For economy, acquisition of blow-molded plastic pots permits reuse at least several times.

Nutrients

To ensure adequate distribution and reduce the likelihood of damaging propagules, nutrients in the form of fertilizers should be mixed into substrates prior to filling pots.

For short-term (single growing season or less) cultivation of submersed aquatic plants, an initial fertilization of the potting medium is usually sufficient. Often, addition of nitrogen is required to achieve optimum growth (Smart et al. 1995). Ammonium sulfate (21% nitrogen) at rates of 1/2 oz per gallon of potting medium is sufficient to support growth during this period. When other compounds are used as a source of nitrogen, they should always be added as an ammonium salt, not as nitrate or urea, which are rapidly lost from anaerobic sediments by diffusion and de-nitrification.

Longer-term cultivation of submersed aquatic plants may require periodic addition of nitrogen and/or other nutrients. This may be facilitated by initially adding ammonium sulfate to the water at a rate of 0.5 oz per 1,000 gallon prior to adding plants. Because excess levels of nitrogen can be inhibitory to the growth of submersed aquatic plants, residual concentration (following uptake by the plants) should never be allowed to exceed 0.25 oz per 1,000 gallon.

Floating-leaved and emergent growth forms generally produce more biomass than submersed growth forms and have proportionately greater demands for nutrients. Therefore, more fertilizer (0.25 oz nitrogen per gallon of medium) should be added to the substrate. Complete fertilizers, such as 10-5-5 (or similar N-P-K ratios) with micronutrients, should be amended to the substrate at a rate of 2.5 oz per gallon (or comparable, dependent upon fertilizer composition). Because these forms have their photosynthetic and carbon uptake surfaces in the air rather than the water, excessive algal growth generally does not interfere with their growth. In fact, once they develop a canopy of leaves, these plants may shade out algae. Long-term growth of cultures of these growth forms can be sustained by adding 2.5 oz of fertilizer per 1,000 gallon of water. Although these growth forms generally are not well adapted to absorb nutrients from the water, transpiration drives a movement of water (and dissolved nutrients) into the root mass. For this reason, pots with ample drain holes will facilitate water exchange.

2.3 Production Facilities

Production of aquatic plant propagules requires adequate facilities, but these need not be complicated or expensive; small ponds or tanks may be used to grow aquatic plants. To minimize transportation costs and inevitable damage that occurs during transport of plant materials, production facilities should be located as close as possible to the restoration site. In this regard, in-lake production, if possible, is sometimes the most economical means of propagule production. In the following section, we provide guidelines on the suitability of various facilities for plant production.

Small ponds

Properly designed ponds offer excellent sites for culturing aquatic plants. Although any pond that has a reliable water source (and water depth) will suffice, those in which drainage and filling are easily accomplished serve best. This allows the grower to manipulate water levels for cultivation needs such as planting, weeding, fertilizing, and harvesting. Because the objective is to produce robust, potted transplants, we want to restrict growth (as much as possible) to the containers. Earthen, pond-bottom sediments allow growth of endemic vegetation and encourage the escape of cultivated plants. These situations are undesirable because plants growing wild in the pond compete with potted plants, and hence reduce the growth, and interfere with maintenance and harvesting operations. For these reasons, lined ponds are preferred.

Segregation of plant species within a lined pond can be critical for successful cultivation of many species. Cross-contamination by faster or earlier growing species can reduce production of slower or later growing plants. Because many aquatic plants spread vegetatively from fragments, care must be taken when selecting species for polyculture within a single pond. Isolating fragment-spreaders (or prolific seed producers) in their own pond is highly recommended. A second option is to construct enclosures for these species. Fine-mesh shade cloth fencing will serve to prevent spread by fragmentation of all species of aquatic plants discussed in this manual.

Raceways or Pools

Raceways are excellent vessels for growing aquatic plants. The advantages of raceway culture include: accessibility, water quality management, and segregation of species. Many sizes and shapes of fiberglass and plastic pools or tanks are also available commercially at relatively low cost. While these are generally manufactured for aquaculture of fish and invertebrates, or for livestock watering, some models are well suited for culturing aquatic plants. When selecting tanks, make sure the tank depth is suitable for the species of plants to be cultivated. Another consideration is raceway or tank dimension. Easy access is critical to good plant cultivation. A width of about 4 ft is the maximum for easy access to plants without having to enter the tank. For many species of submersed and floating-leaved plants, we recommend raceways or tanks in the range of 24-in to 36-in deep by 48-in wide by appropriate length (up to 16 ft). For ease of operation, tanks should be accessible from both sides. Shallow tanks (12 in or less) are suitable for emergent species.

Construction of custom tanks or raceways may be desirable and cost-effective on many projects. For long-term cultivation, concrete vats can be made to size for specific plant types. Permanent plumbing, including filling and drainage piping, can be included in such structures. Water control structures can be used to maintain an optimal level when staff are not able to inspect facilities every day. Less expensive, custom tanks can be constructed from available building materials (lumber or concrete blocks) and pond liner material (Figure 2). Construction of raceways using standard dimension lumber can reduce cost and material waste.

Shelters

Greenhouses, hothouses, and cold frames can be incorporated into tank designs to extend the growing season for many plant species. Some degree of protection may be needed for plants in northern areas, where water in tanks may freeze surface to bottom. An advantage to moderating temperatures (and possibly photoperiod) is early-season production of plants (i.e. mature transplants can be produced, ready for transplanting as soon as project conditions allow). Without temperature or light control, or both, most native plants will remain dormant until temperatures rise in the spring, reducing the transplant window during a particular season.

Excessive solar heating can be a serious problem, especially in aboveground tanks. Hot, sunny days may cause excessively high temperatures within tank cultures, and plants may suffer high mortality. Because excessive light can also damage submersed aquatic plants, we recommend covering tanks with a light grade (30 percent reduction of sunlight) shade cloth for some species. This will reduce both light intensity and temperature. Shading is not necessary for floating-leaved or emergent species.

In-lake Production

In-lake cultivation may be preferred for some projects, especially when available culture facilities are located some distance away from the project. Transportation of mature transplants over long distances can be logistically difficult and stressful to the plants. In these cases, construction of plant production nurseries within the project water body is recommended.

A simple design that illustrates the basic components of an in-lake nursery is shown in Figure 3. A large but movable container (such as a kiddie pool) for holding and stabilizing the pots, and a protective exclosure to prevent grazing (and other disturbances) are required. Pots are filled with lake sediments, planted with propagules (from local or other sources) and plants allowed to grow within the protection of the fencing. When plants are mature, they are moved to designated sites and transplanted. Empty pots are refilled with sediment substrate and a subsequent crop is started to ensure a continued supply of mature transplants (or other propagules) throughout the growing season. If water level fluctuates significantly during the growing season kiddie pools and exclosures may be moved up or down gradient to maintain optimum water depth. Due to the possibility of contamination, in-lake production is not recommended if exotic nuisance species are already present.

In-lake Harvest

Although the majority of this manual describes methods of establishing native aquatic plant propagules employing protection from herbivory at various life stages of the plant, there are cases where a simpler method can be employed by using selected species that are resistant to herbivory. Water willow *Justicia americana* can often be planted without the need for protective measures. Source plants can be harvested and transplanted from within the target lake or from a nearby waterbody. If suitable stands of water willow can be located, they can provide good source material with low investment. Plants can be dug up, separated, and placed in a covered washtub or ice chest to reduce desiccation. Plants with fist-sized root clumps are a good size to target but even bare-root stalks can be utilized. A very efficient method for this species is to place whole stems horizontally on moist substrate held in position with weighted wire mesh. Stems will root at the nodes and mesh may be removed in several weeks. Care should be taken when harvesting plants "in the wild" to leave sufficient plants to enable recovery and to keep disturbance to a minimum. It is also best to harvest plants early in the day when temperatures are lower. When harvesting plants from external sites, care must be taken to ensure against the introduction of invasive aquatic species.

2.4 Propagule Types

Many commercial suppliers sell aquatic plant propagules. These propagules may be appropriate for planting in lakes and reservoirs or for starter material in plant production facilities but some caution should be used to make certain that plant materials purchased are the correct species or ecotype for the area planted and that the purchased materials are not contaminated with exotic species such as hydrilla. If local or regional populations of a particular species are available, harvesting from these populations to obtain starter propagules may be a better option; however; care should be taken not to overharvest plants from a particular location and to insure plants are not contaminated with invasive, exotic species.

Stem fragments, daughter plants, root crowns, tubers or winter buds, or seeds (usually dependent upon species) may be used as starter materials for aquatic plant cultures. Appendix A lists the types of propagules recommended as starter materials for producing transplants of 15 aquatic plant species. We suggest planting more pots than needed for a project because, as with any nursery operation, some plants will not survive. After a culture of a particular species is established, plants not required for the current plantings can be used as a source for the next generation of cultivation.

Stem Fragments

Many aquatic plant species spread vegetatively from stem fragments. These species have apical meristems at the terminal ends of the shoots. To propagate new plants from stem fragments, cut healthy stem tips to a length of 6 to 8 in. When selecting material, remember that the greater the density of leaves along the stem the better, as most nodes can produce roots as well as leaves and branches. Plant the cuttings about 4 in deep in the potting medium, making sure that apical meristem is at least 6 in above the substrate. For faster development, several cuttings should be planted per pot. Established plants readily regenerate new meristematic tissues after cutting, so once the culture is actively growing, cuttings can be taken to plant additional pots.

Rosettes

Some aquatic plant species grow in a rosette form that produces daughter plants with roots along stolons. To propagate these species, daughter plants should be clipped from the parent and planted directly into pots. Daughter plants have a basal meristem and care must be taken not to excessively cover this growing area when planting. A relatively dense, fine substrate is important for these species because they are buoyant and, without sufficient anchoring, are easily dislodged from the potting medium. A layer of coarse sand or fine gravel can be placed over the substrate after planting to help anchor the plants. Once plants are established, additional plantings can be made by removing daughter plants as they appear on stolons or by dividing established plants.

Dormant Perennating Structures

Many aquatic plants perennate by producing tubers or winter buds that survive winter or dry periods in a dormant state. Using tubers or winter buds is an excellent way to start a culture. Dormant propagules can be collected, held in a dormant state by refrigeration (for up to six weeks), and then planted when desired. Some tubers are buoyant, and should be planted about 4 in deep and covered completely with potting medium. Extra pots (or larger containers) can be prepared to allow some plants to complete their annual life cycle. These plants can be used either to produce tubers, which can be harvested and used for restoration projects, or to produce subsequent crops.

Seed

Most annual aquatic plant species appropriate for restoration projects produce viable seed. However, ease of propagation of most of these by other means and our rather limited knowledge of seed storage and germination requirements limit the usefulness of seed as a starting material for producing plant propagules. We have used seed- or spore-laden sediments (obtained from drained pond cultures) to start plants of several annual species such as southern naiad *Najas guadalupensis*, slender pondweed *Potamogeton pusillus*, horned pondweed *Zannichellia palustris*, and muskgrass *Chara vulgaris*. Seeds are also the propagule of choice for culturing American lotus *Nelumbo lutea*.

2.5 Culture & Maintenance

Planting the Containers

The general procedure for making potted aquatic plants (mature transplants) is as follows:

1. Fill pot to about 4/5 full with fertilizer-amended potting medium.

2. Place pots in growing vessel (e.g., raceway, pool, etc.).

3. Slowly fill the growing vessel to 4 to 6 in above the pot with clean water to saturate the potting medium.

4. Allow filled pots to stabilize for three to four weeks - particularly if using a non-aquatic substrate. Expect an initial nutrient pulse as some nutrients and organics are released into the water. This is evidenced by algal bloom or brown staining of the water by humic materials or by the presence of an organic film on the water surface. Drain the water and refill several times if necessary.

5. Remove individual post from the culture and make an indentation in the center of the potting medium.

6. Plant the propagule and backfill to ensure that the specimen is anchored.

7. Replace the newly potted propagule in the growing vessel and fill to the desired cultivation depth with clean water.

Managing Weeds and Contaminants

As with any culture or crop, unwanted "volunteer" species may cause problems. Pond sediments often contain seeds and spores of aquatic species that might interfere with production of desired species, and certain terrestrial weeds establish readily in shallow cultures used for emergent species production. Hand weeding is the best method to remove unwanted plants.

Inadequate separation of plant species in mixed pond or raceway cultures can also lead to cross-contamination and weed infestations, especially where production of single-species transplants is critical. Growing monocultures in separate tanks will usually reduce cross-contamination. If contamination does occur, rigorous hand weeding will be necessary to correct the problem.

Managing Algae and Epiphytes

Excessive algal growth is always a concern with cultures of submersed aquatic plants. High concentrations of nutrients (especially phosphorus and nitrogen) in the water column will generally support excessive algal growth. Algae, whether growing in the water, on the water surface, or on the plants themselves, may cause problems by reducing growth of desired plants. Algae compete with macrophytes for light, nutrients, and inorganic carbon, and, because they are capable of rapid growth, can quickly become problematic. Once algae become well-established in a culture, they are difficult to control so prevention is prudent. As mentioned earlier, using low-nutrient water and avoiding excess fertilizer will usually prevent algal problems. Reduction of existing algal blooms will require exchanging the water with low-nutrient water and either hand removal of filamentous growths or filtering the water to remove phytoplankton. Shading may also help reduce algal infestations in submersed species cultures. Generally, although frequently present, algae in floating-leaved and emergent species cultures do not cause problems.

Managing Grazing Pests

Herbivore damage may become a problem in some situations. Pond and in-lake plant cultures must be protected from turtles, common carp *Cyprinus carpio*, waterfowl, muskrats *Ondatra zibethicus*, and some invertebrates. Protective exclosures are discussed in the following chapter. Aphids and caterpillars can reach nuisance proportions in raceway and pool cultures, and may require control. Because the use of commercially available, terrestrial pesticides is not permitted in water, we recommend using mosquito fish *Gambusia affinis*, mosquito dunks, or water exchange to control most problematic species.

CHAPTER 3

Establishment

3.1 Site Selection

Founder colony sites should be selected based upon several criteria. Choose well-protected (from winds and wave action), shallow (water less than 6 feet deep) coves -- preferably with gradual slopes (less than 10% grade) -- for establishment of aquatic plants. A fine-textured substrate is most suitable, and generally indicates a favorable environment with minimal wave action. Areas of high sediment re-suspension and thus high turbidity can usually be avoided by selecting such wind- and wave-protected coves. These are generally the clearest shallow waters available. If protected shoreline is not available, wave action may be buffered by using hay bales or geotubes as wave breaks.

Sediment/Substrate

Other than as an indicator of physical conditions, sediment texture does not seem to be critical to successful establishment, and we have had similar results on sandy to muddy substrates. The major consideration is that plant roots must be able to penetrate the sediment to a depth of at least 6 in order to anchor the plant. Hardpan or rocky substrates should be avoided when possible.

Conflicting Uses

Problems with site vandalism can be minimized by avoiding high-use areas such as developed shorelines and areas favored by bank anglers, swimmers, and users of recreational watercraft. However, shorelines adjacent to cooperative property owners may provide opportunities for education as well as site security. Heavily wooded shorelines should be avoided due to excessive shading, which greatly reduces the light available to submersed aquatic plants. Areas with signs of heavy animal activity -- particularly hogs, cattle, or beaver *Castor canadensis* -- should also be avoided.

Planting Depth

The two greatest abiotic influences on aquatic establishment are water-level fluctuations and light attenuation. Because submersed aquatic plants require light to survive, planting at proper depths is critical, particularly if the water is turbid. Water levels of most reservoirs are influenced by both natural (weather or climatic) events and operations (storage or release of floodwaters or water supplies, power generation, etc.), both of which are generally beyond our control. For planning purposes, review historic water-level fluctuations to predict expected levels during early establishment. Based on expected water levels and knowledge of the biology of the plant species, we assign an appropriate depth or depth range for each species. In general, submersed plants will establish best at depths of 20 to 48 in, floating-leaved plants from 10 to 30 in, and emergent plants from 0 to 12 in. Table 2 lists the recommended planting depths for individual species.

3.2 Species Selection

It is advantageous to establish as great a diversity of native plant growth forms and species as possible. This will ensure long-term establishment of at least some species (e.g., drought-tolerant species will survive long drawdowns, while others may not). Diverse communities of native plants also provide the greatest water quality and habitat benefits over the long-term and seldom cause navigational or other problems.

Species should be selected based on specific lake habitats or anticipated environmental conditions. For instance, in a lake known to follow a pattern of water elevation change, concentrating on drought-tolerant species may be best. However, because predicting environmental changes in a reservoir is difficult, we strongly recommend conducting a test planting of as many species as possible to ensure an adequate evaluation. Species that have demonstrated potential for lake restoration are provided in Appendix A, along with information about their culture and planting.

3.3 Season of Establishment

Timing can be as critical as species selection. Planting should occur before or during periods of active growth to ensure establishment. Unlike seeds or less robust propagules, mature transplants can be planted over a wider range of environmental conditions. Depending on location, this may range from mid-spring to late summer (Table 2). In reservoirs that experience spring floods, planting should be delayed until water levels return to their normal summer levels. In general, plants should be planted as early as practicable. Establishment of a viable population from mature transplants is possible in late summer, but late planting reduces the length of growing season remaining and may decrease the likelihood of success. When considering water level fluctuations, it is important to be aware that established plants can tolerate temporary inundation for weeks, but exposure and desiccation only for days or hours.

3.4 Planting Technique

Planting potted aquatic plants is much like planting landscape plants and many of the same principals apply. When installing plants, care must be taken to ensure that root balls are not buried too shallow or that apical tips (especially in rosette-forming species) are not buried too deeply (Figure 4).

Planting densities will vary dependent upon species and exclosure design (next section). Table 3 provides a general planting density guideline for most aquatic plant species. Higher densities will ensure faster establishment of founder colonies and reduce the likelihood of establishment failure (if one dies, others will survive). However, higher densities will increase plant costs so cost/benefit should be considered.

3.5 Establishment Project Phases

Phase 1

Site visits, discussions with reservoir and fisheries managers, and trapping can provide preliminary estimates of the densities of herbivorous species that may be encountered. It is likely that establishment of new colonies of aquatic plants in unvegetated reservoirs will require protection (Smart et al. 1996, Doyle et al. 1997). Once suitable sites are selected, the restoration project should proceed in three phases. Phase 1 involves planting and monitoring (over a full growing season) of test plants of a variety of species within small protective exclosures. We recommend conducting small-scale tests to ascertain the levels of protection needed from grazers in any particular water body. Small exclosures are most suitable for single-species planting: different species planted within small exclosures will invariably compete with one another for resources, and one will likely be dominant, negating the effort of establishing diverse plant communities. One advantage of using small exclosures is that if they are breached it does not threaten the entire founder colony.

PVC-coated galvanized welded-wire is more expensive but much more durable than non-coated wire, and we highly recommend its use in aquatic restoration projects. We do not recommend the use of plastic mesh wire due to its high susceptibilities to damage and degradation. In most cases, 2-in x 4-in mesh (nominal size) is adequate to exclude common grazers such as common carp and turtles. Ring cages (Figure 5) are wire cylinders that serve to protect single or small groups of aquatic plants. Welded-wire is cut into 10- to 30-ft lengths, rolled into cylinders, and ends fastened using c-rings (or hog rings). The resultant cages (3 to 6 ft in diameter) should be anchored using earth staples or tent stakes. For smaller-diameter cages (less than 5 ft), 14-gauge PVC-coated welded-wire is recommended. However, 12-gauge wire is recommended for larger diameter cages (greater than 5 ft). Height of ring cages should not exceed 4 ft to ensure cage strength. If protection from smaller grazers is required (e.g., juvenile turtles and/or crayfish), exclosures can be made from finer mesh material. Alternatively, a sleeve of a finer mesh material can be placed over the wire mesh cylinder. The advantage of this approach is that the sleeve can be removed and reused after initial establishment of the transplant(s).

Tray cages (Figure 6) are designed to protect roots, stem bases, and lower leaves of all aquatic plants, but are most effective when used to protect emergent species and the submersed species wild celery *Vallisneria americana*. Cages are constructed from 2-in x 4-in welded-wire. Shorter trays (6 in tall) are suitable for emergent plants, while taller trays (10 to 20 in tall) are best for submersed species.

Assuming suitable sediments, water quality, and water levels, these plants will establish and expand beyond their protective cages, depending on the level of herbivory. During Phase 1, the level of herbivory and, if possible, the sizes and types of herbivores, should be noted.

Monitoring during Phase 1 is important because the response of the plants will dictate the best course of action to take during subsequent growing seasons.

Phase 2

During the second growing season, those species performing best during Phase 1 should receive additional plantings. However, in many unvegetated reservoirs, expansion of the plantings will require provision of a larger-scale protected environment such as a fenced cove. Phase 2 should result in the successful establishment of founder colonies of several species. Multiple species can be planted in large exclosures without initial concerns of planted species out-competing one another. A major drawback to very large exclosures is that a single breach may put the entire founder colony at risk unless small-scale exclosures are also installed inside them.

Hoop cages (Figure 7) are larger versions of ring cages that allow for planting submersed species at greater depths. Hoop cages are taller (6 ft) and always constructed from 12-gauge, PVC-coated wire. Twenty-five- to 30-ft lengths of wire are cut and formed into cylinders about 7 to 8 ft in diameter. Because of their height, hoop cages tend to be unstable, so hoops of 1 in diameter (nominal size) plastic irrigation tubing are attached to the top and bottom of the cylinder for structural support. The cages are then anchored by weaving PVC piping through the mesh and pressing the pipe into the bottom mud or attaching T-posts externally.

Phase 2 may also involve construction of a fence across the cove mouth, to exclude carp and other rough fish, in combination with additional plantings of selected or preferred species. We have used several large exclosure designs to establish founder colonies in both large and small reservoirs (Figure 8). Exclosures are constructed from T-posts (approximate 8-ft spacing) and 2-in x 4-in PVC-coated welded-wire (12 or 14 gauge) fencing. After T-posts are set (and safety caps installed), fencing is attached using aluminum wire ties. Fencing should extend 10 in or more above normal high water levels that occur during the growing season. The bottom of the fencing should be firm against the substrate at all points to prevent burrowing under by grazers. The interface between the fence and the bottom sediment is critical, and an outward flap at the bottom of the fence helps prevent entry of turtles, carp, and other large grazers. Optionally, a 24–inch-wide fencing flange attached to the bottom of the fence with cable ties (extending away from the protected area) will discourage burrowing.

Cove fences are constructed across the mouths of coves to exclude water-borne grazers, such as common carp and turtles, from planting sites. As designed, fenced coves do not exclude herbivores that can move over land and plants may require a double-layer of herbivore protection (smaller exclosures for individual plants plus the cove fence). Enclosing the cove is generally not practical; however, the potentially large area protected for founder colony development makes the use of cove fences worthwhile in some cases. Avoid coves with inflowing creeks because the fence will trap logs and other debris and may be subject to damage or undercutting during high-flow events. Cove fences are not appropriate where large burrowing mammals, such as beaver are evident, as they are capable of damaging even the stoutest of fences.

Shoreline fences are generally irregular in size, and extend from the shoreline out to a desired depth (generally 3 to 4 ft) and then along that contour parallel to the shoreline. Shoreline fences may be three-sided or include a backing to exclude terrestrial herbivores. Although they do not typically protect as much area as cove fences, in our experience shoreline fences are less likely to be breached. As with cove fences, we recommend a double-layer of herbivore protection (individual plant exclosures plus the shoreline fence) when not using a backing on shoreline fences.

Some sites are suitable for construction of free-standing pens, constructed similarly to cove and shoreline fences. Large, flat areas that are somewhat protected from wind and waves are ideal for using pens; we have established founder colonies in pens ranging from 10-ft x 10-ft to 100-ft x 100-ft. As in other fence types, we recommend adding a bottom flange to reduce the likelihood of breaching by burrowing herbivores.

Phase 3

During Phase 3, colonies expand to fill the area protected by the fenced cove, and begin to spread into unprotected areas by vegetative and/or sexual modes of reproduction. Monitoring should be continued at this stage as large-scale disturbances can have serious consequences on newly established plant communities. Additional species may also be desirable to ensure maximum diversity, stability, and resilience of the aquatic plant community.

3.6 Monitoring and Adaptive Management

Sustaining founder colonies

Typically, planting potted plants in southern reservoirs results in rapid colonization of planted species within protective exclosures. Once plants reach the borders of exclosure protection, however, their rate of spread is greatly reduced or even halted, presumably due to intense levels of grazing occurring outside the fences and cages. Periodically during the growing season, plants seem to get ahead of herbivores, resulting in spread to unprotected areas. This usually occurs in conjunction with falling water levels, and we believe aquatic grazers are less likely to impact plants found in very shallow water depths (6 in and less), thus permitting at least temporary establishment of plants from fragments and other propagules in otherwise unprotected areas. In some cases, when water levels return to normal, herbivores move in and eliminate the unprotected colonies. Once the threshold is exceeded and sufficient spread has occurred (relative to herbivore populations) the unprotected colonies persist. This is the condition that we hope to achieve in all reservoir restoration efforts.

For this to occur, well-established (and continuously protected) founder colonies must be in place at all times during the growing season so that propagules for natural spread are present in sufficient numbers when conditions are favorable. In order to ensure founder colonies are present at all times, the same two obstacles that must be overcome to establish them (water level fluctuations and herbivory) must be dealt with in the longer-term.

Planting at multiple depths

Because many reservoirs serve as flood control and municipal water supplies, water levels are expected to fluctuate, in some cases quite significantly. Founder colonies planted at a single depth relative to conservation pools may well spend much of the year out of water or under too great depths for plant growth, and those times during the year in which water depths are ideal may not seasonally coincide with the growing seasons of particular species. Establishing founder colonies at multiple depths increases the possibility that plants will be actively growing and producing propagules for natural spread throughout the growing season.

To address fluctuating water levels and the need for continuous presence of founder colonies, initially plant submersed species at 2½ to 3-ft depths, floating-leaved species at 2-ft depths, and emergent species at ½ to 1-ft depths (Table 2). When water level in a reservoir increases or decreases by 2 ft relative to elevation at initial planting, construct new exclosures following water level change and plant using the same depths used above. In a typical Texas reservoir, water levels may fall throughout the growing season, and establishing three or more depth tiers of plants is common. Plants exposed to desiccation (or too great depths) generally decline, but may recover when water levels return to suitable depths. Once colonies are in place at multiple depths, water level fluctuations are less likely to impact growth of founder colonies, and continuous production of propagules may be achieved.

Exclosure maintenance

Continued protection of founder colonies from herbivores is critical to their successful establishment and subsequent spread. Materials used in exclosure construction vary in their ability to resist corrosion. For instance, galvanized welded-wire may remain functional only one or two growing seasons before the galvanization dissolves and the wire rusts. Plastic mesh (although cheap and light) is susceptible to UV degradation and damage by beaver, nutria *Myocastor coypus*, or muskrat. PVC-coated welded-wire is stronger and longer-lived than other types, but, along with the others, can be damaged by floating logs, boats, or large animals (such as cattle or feral hogs). In addition to damaging materials, larger herbivores, such as beaver, frequently dig under fences to gain access to plants or to reach the back of coves fenced off from the reservoir. These openings provide access to smaller herbivores such as turtles and common carp.

Because exclosures are subject to breaches of many types, a scheduled maintenance program is desirable in any restoration project. Exclosures should be inspected as frequently as possible, and when damage is noted, repairs should be made immediately.

High water levels may sometimes overtop exclosures. In these cases, wait until water levels have fallen below the tops of the cages, and then make an effort to remove any herbivores that may have been trapped within the exclosure. Both carp and turtles can be removed with seine nets, whereas turtles alone can be trapped with floating fall-in traps.

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Table 1.— Predominant sites of nutrient uptake and photosynthesis in terrestrial and aquatic plants of different growth forms and implications for the culture of aquatic plants.

Growth Form (example)	Photosynthetic medium	Provide inorganic carbon by:	Nutrient uptake	Add nutrients to:
Terrestrial Plants	Air	Atmosphere	Soil	Soil
Submersed (wild celery)	Water	Aeration, mixing, water exchange, bicarbonate addition	Sediment	Sediment, very sparingly to water
Floating-leaved (spatterdock)	Air	Ensure adequate ventilation	Sediment	Sediment, sparingly to water
Emergent (soft rush)	Air	Ensure adequate ventilation	Sediment	Sediment and/or water

Table 2. — Guidelines for planting native aquatic plants.

Plant	Planting Season	Planting Depth (in)	Desiccation Tolerant	Susceptible to Herbivory	Growth Depth Tolerance (ft)
Wild celery*	early spring - early fall	12 - 48	No	High	10
American pondweed	spring - late summer	12 - 48	Yes	High	10
Illinois pondweed	early spring - mid summer	12 - 48	No	High	10
Water stargrass	early spring - late summer	12 - 48	Yes	Moderate	8
White water lily	late spring - mid summer	20 - 36	Yes	Low	6
Spatterdock	late spring - mid summer	20 - 36	Yes	Low	6
Softstem bulrush	early spring - mid summer	0 - 36	Yes	Low	5
Water willow	early spring - mid summer	0 - 36	Yes	Low	4
Flatstem spikerush	spring - mid summer	0 - 12	Yes	Low	2
Squarestem spikerush	spring - mid summer	0 - 24	Yes	Low	2
Pickerelweed	early spring - late summer	0 - 36	Moderate	Moderate	4
Bulltongue	early spring - late summer	0 - 48	Moderate	Moderate	6
Arrowhead	early spring - late summer	0 - 24	No	High	3
Creeping burhead	early spring - late summer	0 - 12	Moderate	Moderate	2
Water hyssop	early spring - late summer	0 - 12	Yes	Low	3

*for southern ecotype; northern ecotype should be planted early to late summer

Table 3. — Recommended planting densities based on growth form and exclosure size.

Growth Form	Small Exclosures	Large Exclosures
Submersed	2 to 8 plants	3-ft to 6-ft centers
Floating-leaved	2 to 4 plants	6-ft to 10-ft centers
Emergent	2 to 6 plants	3-ft to 6-ft centers

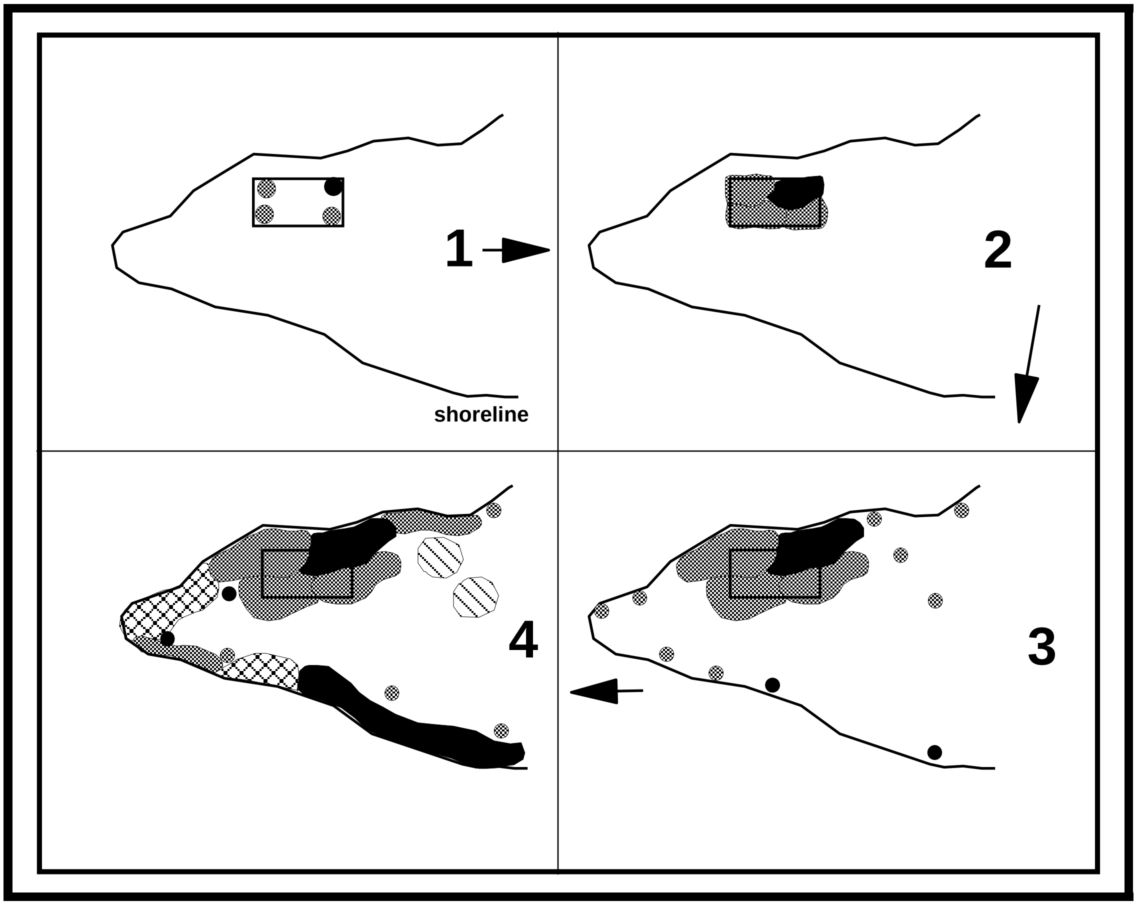
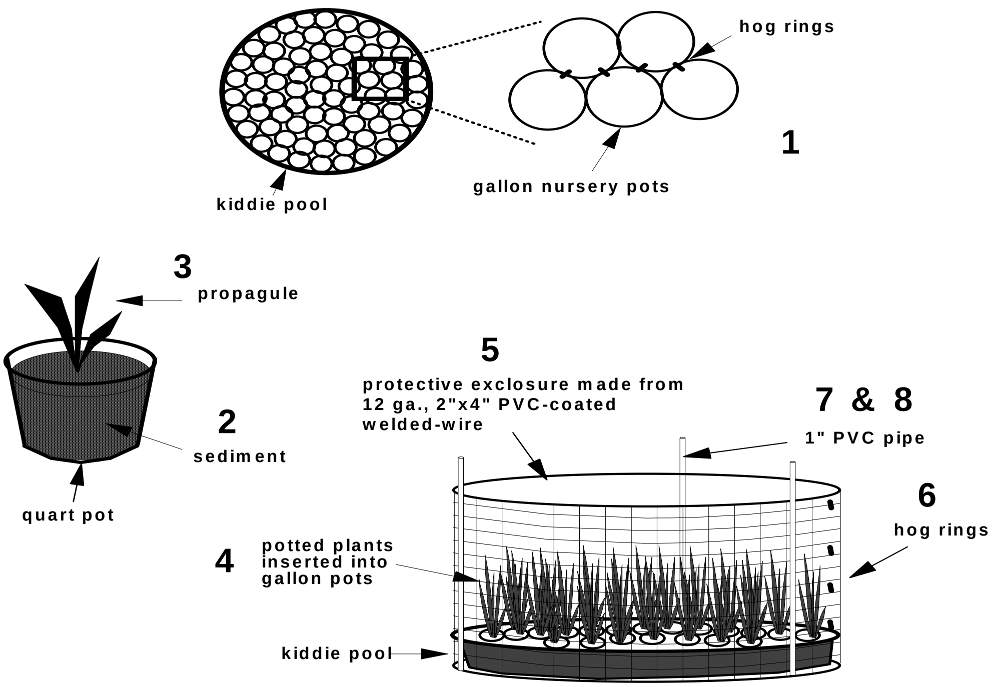


Figure 1. — Progression of establishment in founder colonies: (1) colony is introduced in well-protected area, (2) plants grow to fill the protected area and begin to spread, (3) new colonies expand beyond the protected area, (4) satellite colonies are established outside protective exclosures to provide large-scale fish habitat.

Figure 2. — Example of custom built containers suitable for growing most species of submersed, floating-leaved, and emergent aquatic plants.



1. Attach gallon pots together with hog rings to fill kiddie pool.
2. Fill quart pots with sediment.
3. Plant propagules in quart pots.
4. Insert potted plants into gallon pots.
5. Form a ring cage with protective fencing to fit kiddie pool.
6. Fasten ends of ring cage with hog rings.
7. Weave PVC pipe through ring cage mesh.
8. Push PVC pipe into sediment until firmly anchored.

Figure 3. — Example of in-lake culture system using kiddie pool.

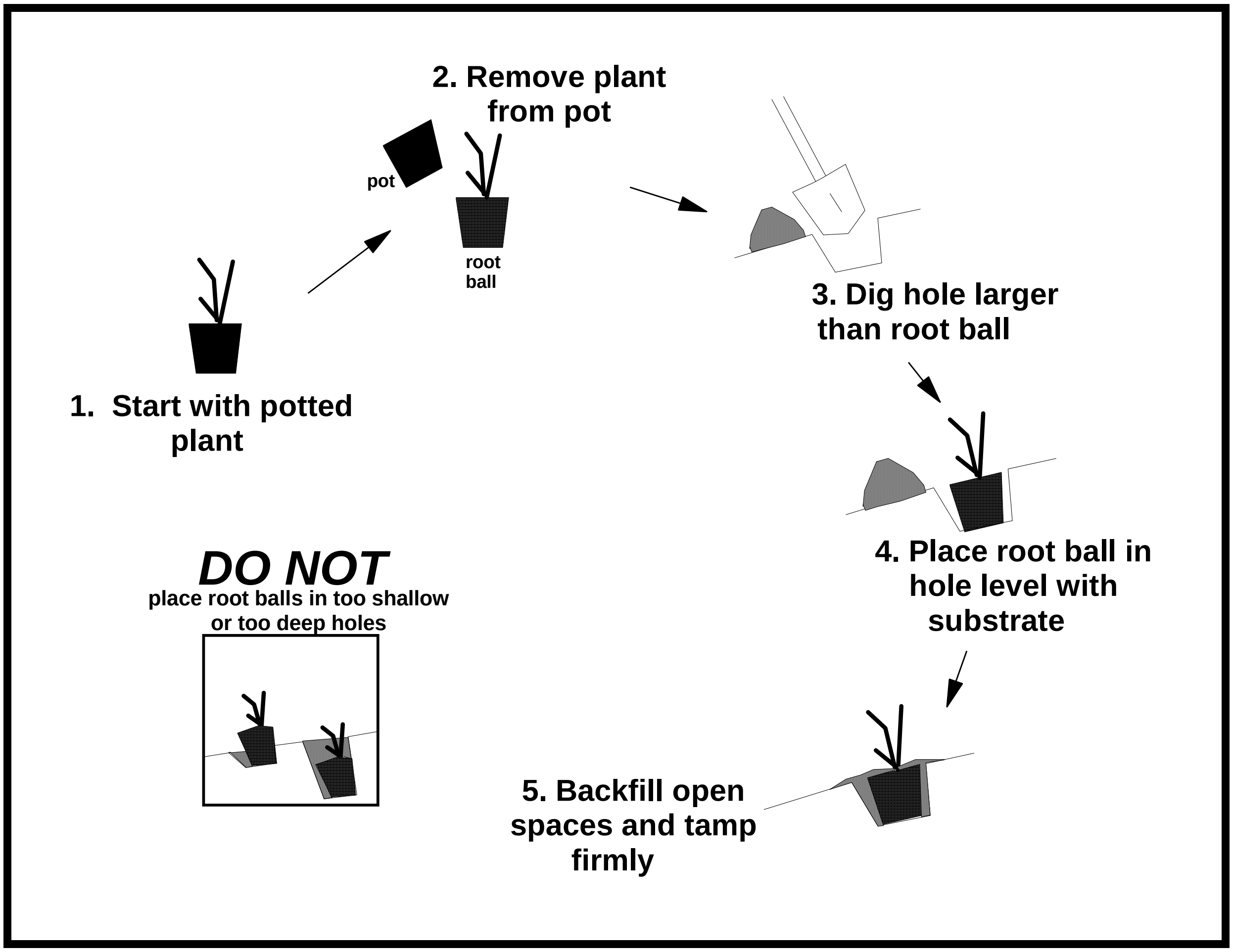


Figure 4. — Recommended planting procedures.

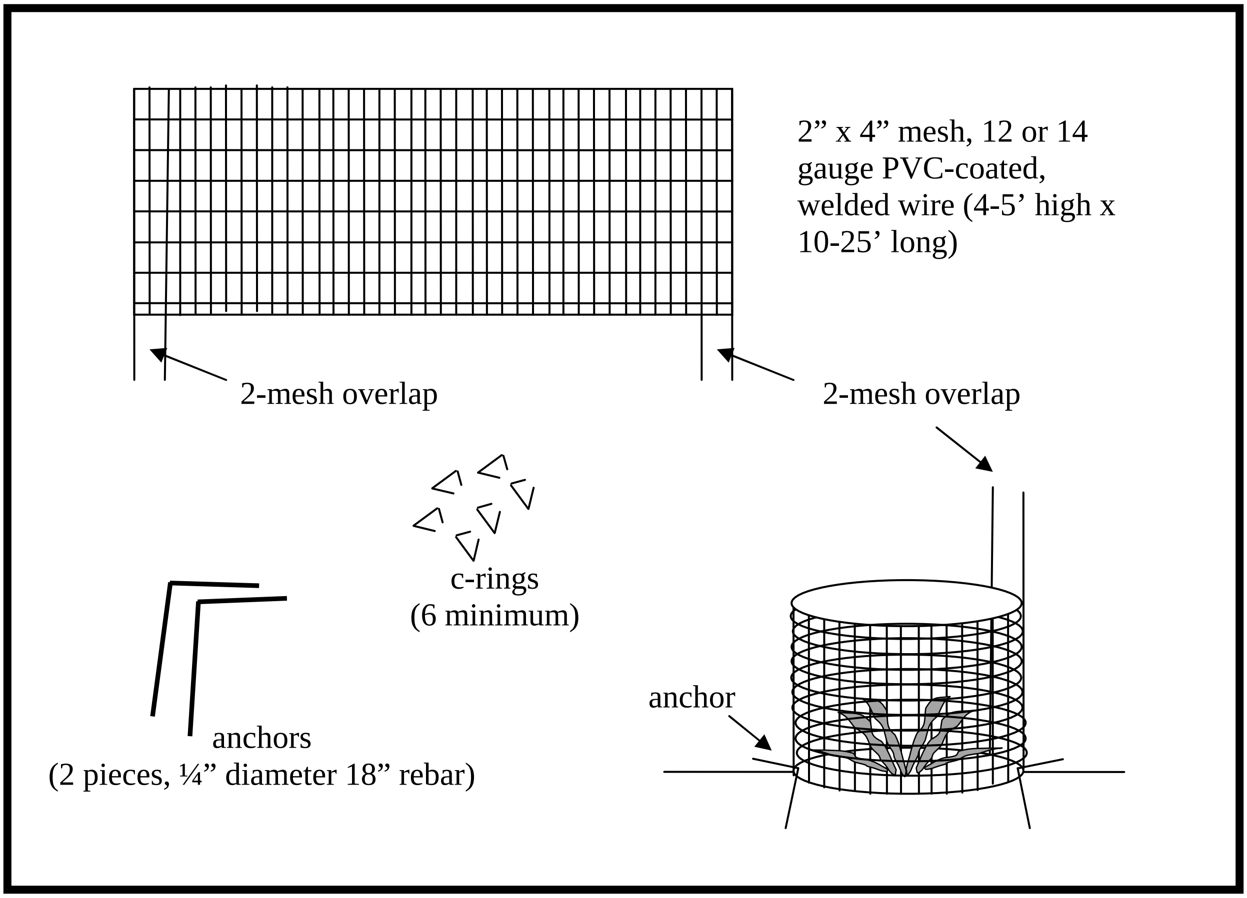


Figure 5. — Example of ring cages used to provide small-scale protection for small founder colonies.

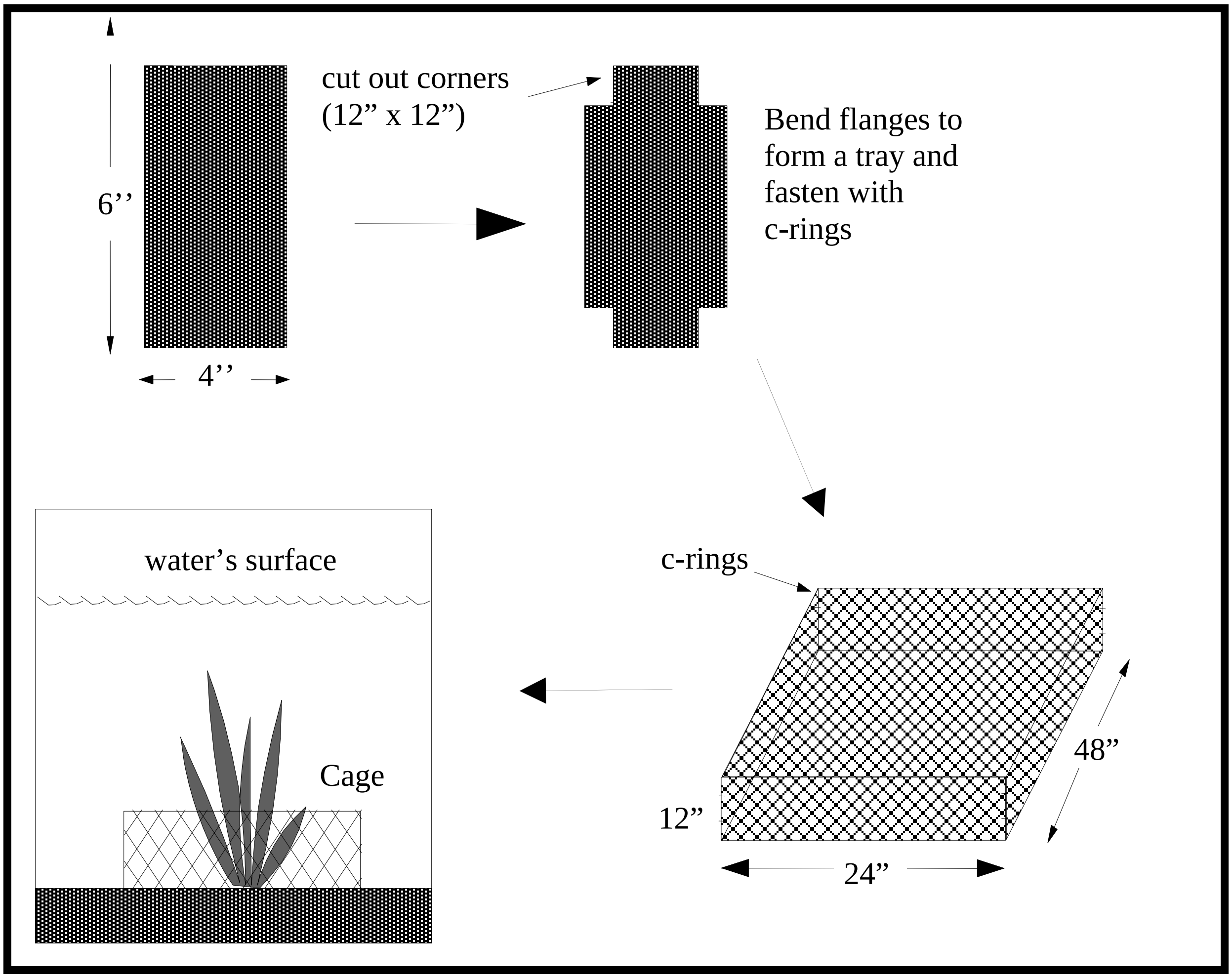


Figure 6. — Example of tray cages for protecting emergent and some submersed aquatic plant species.

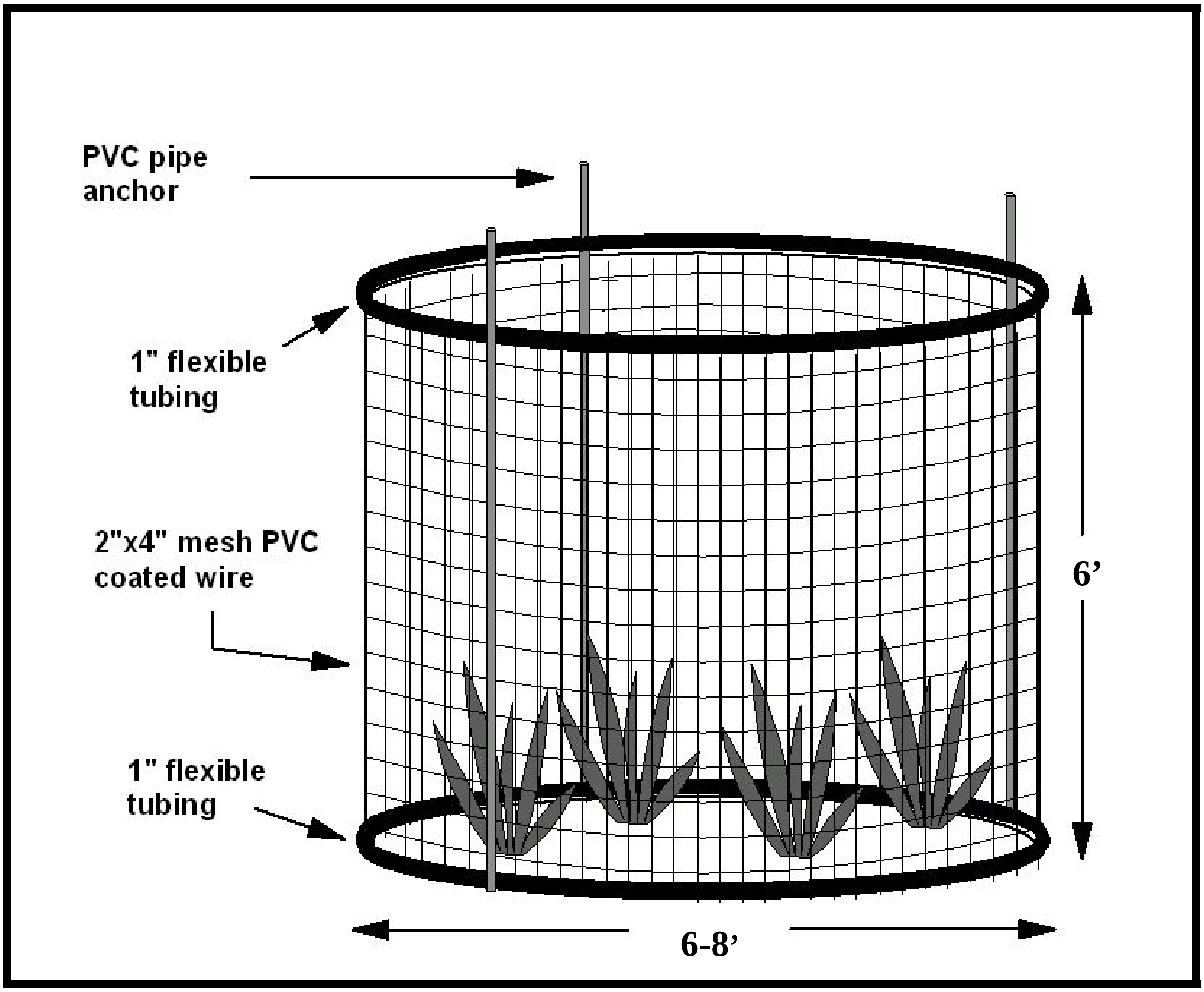


Figure 7. — Example of hoop cages for protecting submersed species in relatively deep water.

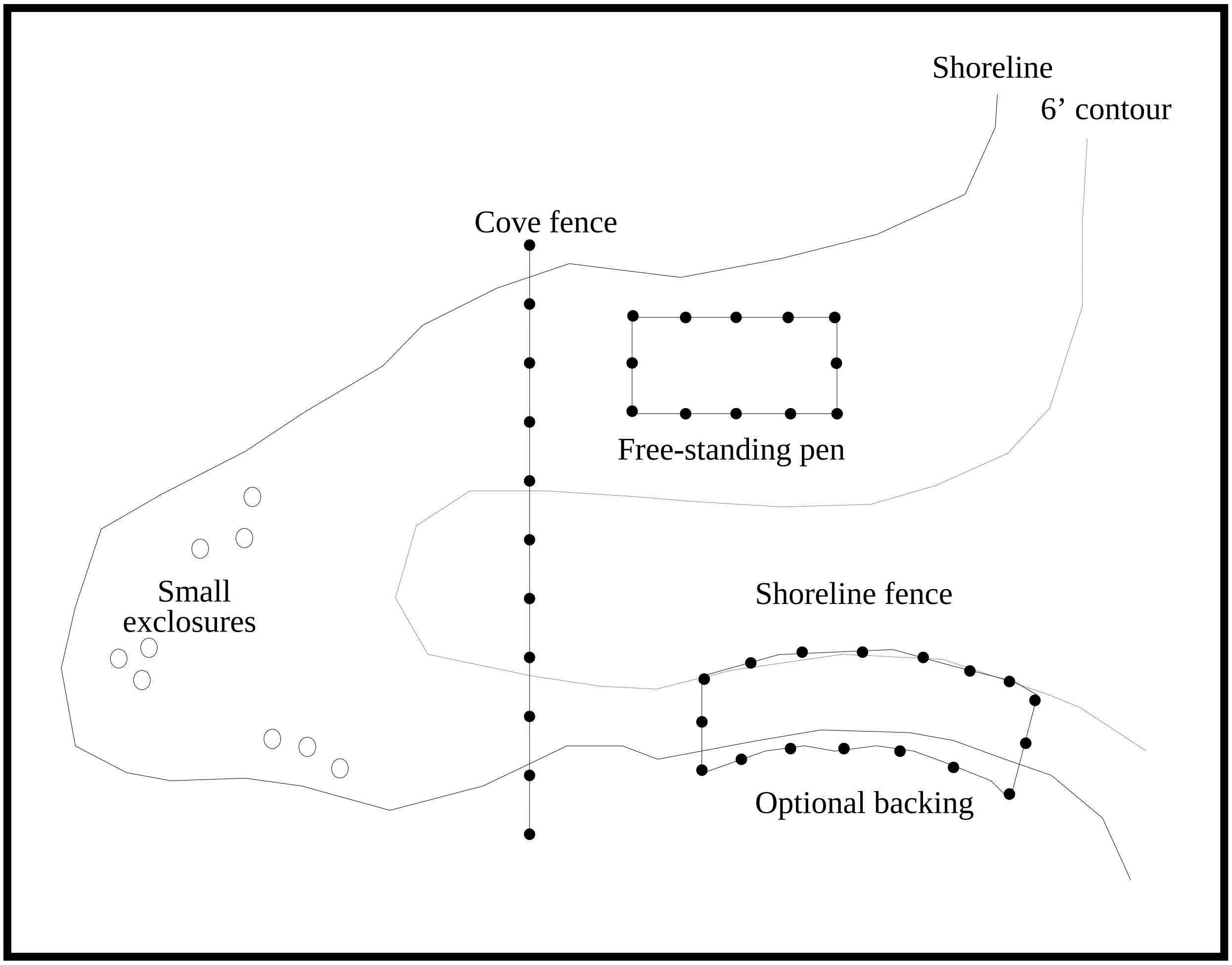
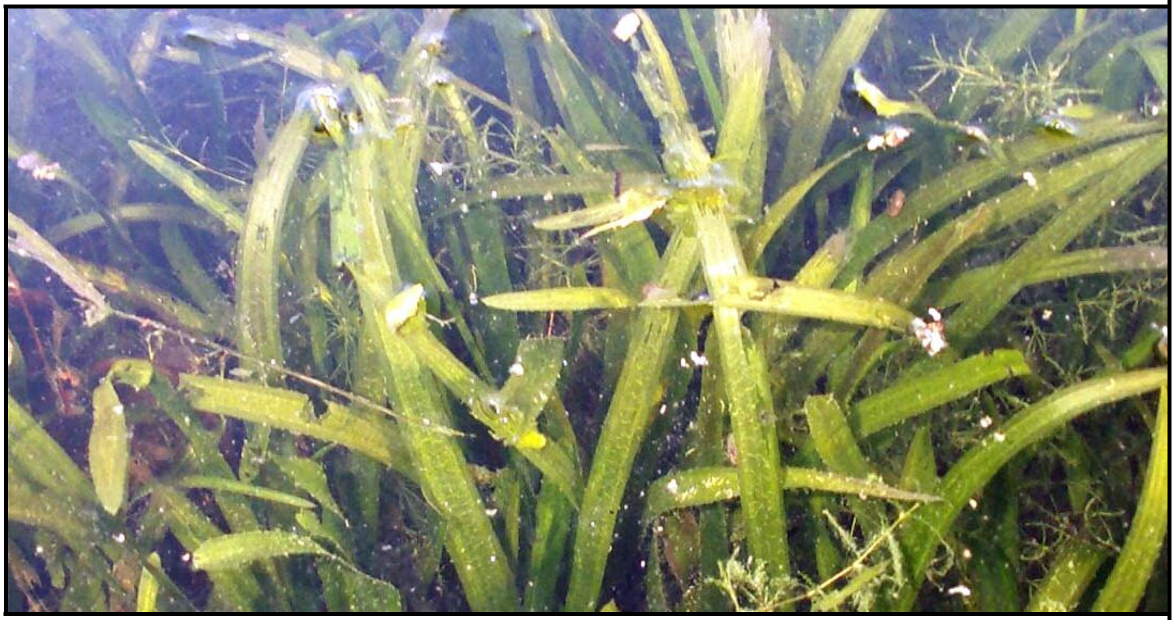


Figure 8. — Examples of various large-scale exclosures used to protect large founder colonies.

APPENDIX A: Aquatic Plant Restoration Candidate Species

This section includes species that we have successfully cultured and established in reservoirs throughout much of the southern U.S. We assume these species, where native, will perform similarly in other parts of the country.

Wild celery



Scientific name	*Vallisneria americana*
Common names	Wild celery, eelgrass, tapegrass, ribbon grass, vallisneria
Growth form	Rooted submersed; rosette form with a basal meristem and ribbon-like leaves.
Reproduction	Produces daughter plants along stolons; sexual reproduction by seed.
Perennation	Evergreen (southern ecotype) or winter bud forming (northern ecotype) perennial.
Range	Throughout the U.S. (absent from parts of the Midwest).
Use	Valuable for fish habitat and waterfowl food. In the south, evergreen habit allows planting over an extended period.
Culture	
Plant	Daughter plants year round (southern ecotype) or winter buds late spring to midsummer (northern ecotype).
Produce	Mature transplants.
Light	75-100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	20-36”.
Comments	Minimum of 12 weeks required for production of mature transplants.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to early fall (southern ecotype); early to late summer (northern ecotype).
Substrate	Sand to muck.
Depth	12-48”.
Comments	Transplants must be planted deep enough to cover the root mass and anchor the plant, but care must be taken not to bury the basal rosettes. Not resistant to desiccation; highly susceptible to herbivory by carp, turtles and waterfowl; will tolerate water up to 10’ deep once established.

American pondweed

Scientific name	*Potamogeton nodosus*
Common name	American pondweed
Growth form	Rooted submersed; produces submersed and floating leaves.
Reproduction	Produces new shoots along stolons; also reproduces by fragmentation and seed.
Perennation	Herbaceous perennial; overwinters as dormant winter buds.
Range	Throughout the U.S.
Use	Valuable for fish habitat and waterfowl food; floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Winter buds in early spring, apical cuttings from spring to midsummer.
Produce	Mature transplants or winter buds.
Light	100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	20-36”
Comments	Field-ready transplants can be produced in 4 to 6 weeks. Rapid growth in small containers may lead to completion of the life cycle in about two or three months. Susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants.
Season	Spring to late summer.
Substrate	Sand to muck.
Depth	12-48”
Comments	Tolerant of desiccation; susceptible to herbivory by carp, turtles and waterfowl; will tolerate depths of 10’once established.

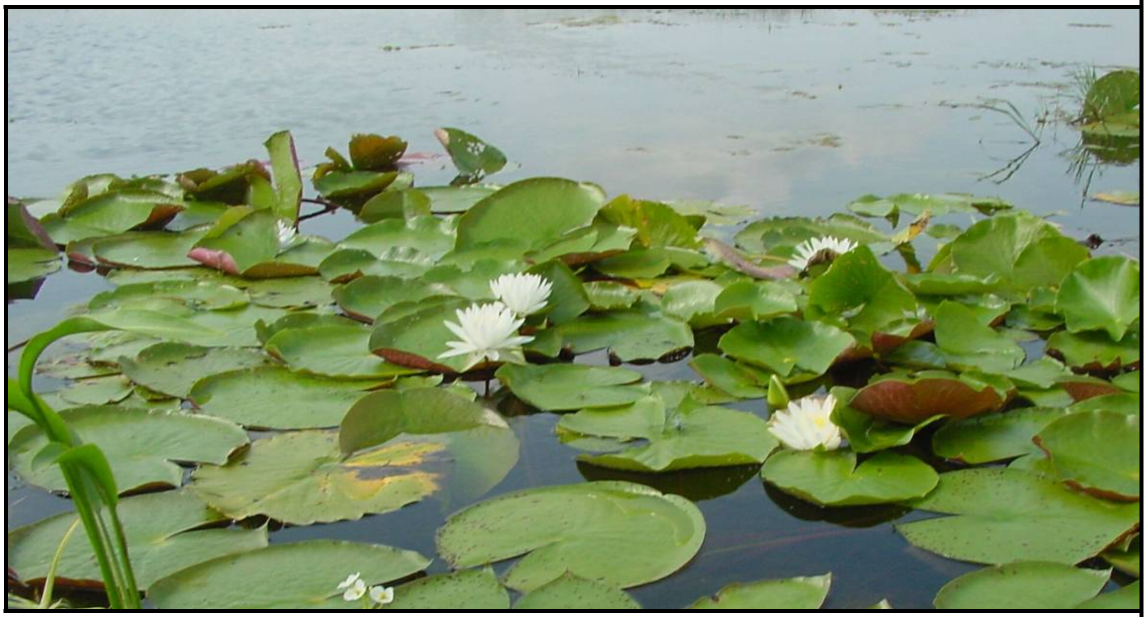
Illinois pondweed

Scientific name	*Potamogeton illinoensis*
Common name	Illinois pondweed
Growth form	Rooted submersed; produces submersed and floating leaves.
Reproduction	Produces new shoots along stolons; also reproduces by fragmentation and seed.
Perennation	Herbaceous perennial; overwinters as dormant stems.
Range	Throughout the U.S.
Use	Valuable for fish habitat and waterfowl food. Floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Apical cuttings from spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	20-36”
Comments	Field-ready transplants can be produced in 4 to 6 weeks. Susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to midsummer.
Substrate	Sand to muck.
Depth	12-48”.
Comments	Not tolerant of desiccation; susceptible to herbivory by carp, turtles and waterfowl; will tolerate depths of 10’ once established.

Water stargrass

Scientific name	*Heteranthera dubia*
Common name	Water stargrass
Growth form	Rooted submersed; produces alternate grass-like leaves along upright stems.
Reproduction	Produces new shoots from short stolons; also reproduces by fragmentation and seed.
Perennation	Herbaceous perennial; overwinters as dormant root crown.
Range	Throughout the U.S.
Use	Valuable for fish habitat and waterfowl food.
Culture	
Plant	Apical cuttings in early spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	20-36"
Comments	Field-ready transplants can be produced in 6 to 8 weeks. Susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplant.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	12-48"
Comments	Tolerant of desiccation; moderately susceptible to herbivory by carp and turtles; will tolerate depths of 8' once established

White water lily



Scientific name	*Nymphaea odorata*
Common names	White water lily, fragrant water lily
Growth form	Rooted floating-leaved; leaves produced at apical tips of branching rhizomes.
Reproduction	Produces new shoots along rhizomes; also reproduces by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes and/or tubers.
Range	Throughout the U.S.
Use	Valuable for fish habitat and waterfowl food. Floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Tubers or rhizome tips in early spring, rhizome tips from spring to midsummer.
Produce	Mature transplants.
Light	100% full sunlight.
Container	6" (1 gallon) nursery pots.
Water depth	20-36".
Comments	Field-ready transplants can be produced in 6 to 8 weeks. Susceptible to aphids and aquatic caterpillar damage.
Field Planting	
Propagule	Mature potted transplants.
Season	Late spring to midsummer.
Substrate	Sand to muck.
Depth	20-36
Comments	Tolerant of desiccation; susceptible to herbivory by beavers and nutria; will tolerate depths of 6' once established.

Spatterdock

Scientific name	*Nuphar advena* [*N. lutea*]
Common names	Spatterdock, yellow pond lily, cow lily
Growth form	Rooted floating-leaved; leaves produced at apical tips of branching rhizomes.
Reproduction	Produces new shoots along rhizomes; also reproduces by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Eastern U.S.
Use	Valuable for fish habitat. Floating leaves are adapted for shallow, turbid waters.
Culture	
Plant	Rhizome tips from early spring to midsummer.
Produce	Mature transplants.
Light	100% full sunlight.
Container	6" (1 gallon) nursery pots.
Water depth	25 to 50 cm.
Comments	Field-ready transplants can be produced in 8 to 10 weeks. Susceptible to aphid infestation.
Field Planting	
Propagule	Mature potted transplants.
Season	Late spring to midsummer.
Substrate	Sand to muck.
Depth	20-36”.
Comments	Tolerant of desiccation once established; susceptible to herbivory by turtles and nutria; will tolerate depths of 6’ once established.

Softstem bulrush

Scientific name	*Schoenoplectus tabernaemontani* [*Scirpus validus*]
Common names	Softstem bulrush, great bulrush
Growth form	Rhizomatous emergent sedge.
Reproduction	Produces new shoots along rhizomes; also reproduces by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes/root crowns.
Range	Throughout the U.S.
Use	Valuable for fish and waterfowl habitat and erosion control.
Culture	
Plant	Divided rhizomes from spring to midsummer.
Produce	Mature transplants.
Light	100% sunlight.
Container	6" (1 gallon) nursery pots.
Water depth	Saturated to 12”.
Comments	Field-ready transplants can be produced in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to midsummer.
Substrate	Sand to muck.
Depth	Moist soil to 36”.
Comments	Highly tolerant of desiccation; susceptible to herbivory by nutria and beavers; will tolerate depths of 5’ once established.

Water willow

Scientific name	*Justicia americana*
Common names	Water willow, American water-willow
Growth form	Rhizomatous emergent forb.
Reproduction	Produces new shoots along rhizomes. Also reproduces by fragmentation and seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Eastern U.S.
Use	Valuable for fish habitat and erosion control.
Culture	
Plant	Apical cuttings from spring to midsummer.
Produce	Mature transplants.
Light	100% full sunlight.
Container	4" (1 quart) or 6" (1 gallon) nursery pots.
Water depth	Saturated to 12"
Comments	Field-ready transplants can be produced in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to midsummer.
Substrate	Sand to muck.
Depth	Moist soil to 36".
Comments	Highly tolerant of drought and herbivory; will tolerate depths of 4'once established.

Flatstem spikerush

Scientific name	*Eleocharis palustris* [*E. macrostachya*]
Common names	Flatstem spikerush, creeping spikerush, common spikerush
Growth form	Rhizomatous emergent sedge.
Reproduction	Produces new shoots along rhizomes; also reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Throughout the U.S. (except Florida and Georgia).
Use	Valuable for fish habitat, waterfowl food, and erosion control.
Culture	
Plant	Divided rhizomes from spring to midsummer.
Produce	Mature transplants.
Light	100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 12”
Comments	Field-ready transplants can be produced in 8 to 10 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Spring to midsummer.
Substrate	Sand to muck.
Depth	Moist soil to 12”
Comments	Tolerant of desiccation; not susceptible to herbivory; will tolerate depths of 2’ once established.

Squarestem spikerush

Scientific name	*Eleocharis quadrangulata*
Common names	Squarestem spikerush
Growth form	Rhizomatous emergent sedge.
Reproduction	Producing new shoots along rhizome; also reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Eastern U.S.
Use	Valuable for fish habitat, waterfowl food, and erosion control.
Culture	
Plant	Divided rhizomes from spring to midsummer.
Produce	Mature transplants.
Light	100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 18”.
Comments	Field-ready transplants can be produced in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Spring to midsummer.
Substrate	Sand to muck.
Depth	Moist soil to 24”
Comments	Moderately tolerant of desiccation; not susceptible to herbivory; will tolerate depths of 2’ once established.

Pickerelweed

Scientific name	*Pontederia cordata*
Common name	Pickerelweed, pickerel plant
Growth form	Rhizomatous emergent forb.
Reproduction	Produces new shoots along rhizomes; also reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes.
Range	Eastern U.S.
Use	Valuable for fish habitat and waterfowl food.
Culture	
Plant	Rhizome tips from spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	6" (1 gallon) nursery pots.
Water depth	Saturated to 24"
Comments	Field-ready transplants can be produced in 4 to 6 weeks. Susceptible to aphid infestations.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	Moist soil to 36"
Comments	Moderately tolerant of desiccation; susceptible to herbivory by waterfowl and nutria; will tolerate depths of 4' once established.

Bulltongue

Scientific name	*Sagittaria platyphylla* [*S. graminea*]
Common name	Bulltongue, delta arrowhead
Growth form	Rhizomatous, tuberiferous emergent forb; exhibits submersed leaves in deeper water.
Reproduction	Produces new shoots along rhizomes; also reproduces sexually by seed.
Perennation	Herbaceous perennial to evergreen; overwinters as dormant rhizomes or in a submersed form; produces tubers.
Range	Southeastern U.S.
Use	Valuable for fish habitat and waterfowl food.
Culture	
Plant	Tubers or divided rhizomes from spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 24”.
Comments	Field-ready transplants can be produced in 4 to 6 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	Moist soil to 48”
Comments	Moderately tolerant of desiccation; susceptible to herbivory by waterfowl, nutria, beavers, and terrestrial mammals; will tolerate depths of 6’ once established.

Arrowhead

Scientific name	*Sagittaria latifolia*
Common name	Arrowhead, duck potato, wapato
Growth form	Rhizomatous, tuberiferous emergent forb.
Reproduction	Produces new shoots along rhizomes; also reproduces sexually by seed.
Perennation	Herbaceous perennial; overwinters as dormant rhizomes; produces tubers.
Range	Throughout the U.S.
Use	Valuable for fish habitat and waterfowl food.
Culture	
Plant	Tubers or divided rhizomes from spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 12”
Comments	Field-ready transplants can be produced in 4 to 6 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	Moist soil to 24”
Comments	Not tolerant of desiccation; susceptible to herbivory by waterfowl, nutria, beavers, and terrestrial mammals; will tolerate depths of 3’ once established.

Creeping burhead

Scientific name	*Echinodorus cordifolius*
Common name	Creeping burhead
Growth form	Emergent forb.
Reproduction	Produces new plants along flowering stems; also reproduces sexually by seed.
Perennation	Herbaceous, short-lived perennial; overwinters as dormant root crowns.
Range	Southeastern U.S.
Use	Valuable for fish habitat and waterfowl food.
Culture	
Plant	Plantlets cut from flowering stems from late spring to late summer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 12”
Comments	Field-ready transplants can be produced in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	Moist soil to 12”
Comments	Moderately tolerant of desiccation; susceptible to herbivory by waterfowl and terrestrial mammals; will tolerate depths of 2’ once established.

Water hyssop

Scientific name	*Bacopa monnieri*
Common name	Water hyssop, coastal water hyssop
Growth form	Emergent, mat-forming forb.
Reproduction	Produces new shoots along stems. Also reproduces by fragmentation and seed.
Perennation	Herbaceous perennial; overwinters as dormant root crowns.
Range	Southern U.S.
Use	Valuable for fish habitat and erosion control.
Culture	
Plant	Apical cuttings in early spring to midsummer.
Produce	Mature transplants.
Light	75 to 100% full sunlight.
Container	4" (1 quart) nursery pots.
Water depth	Saturated to 12”
Comments	Field-ready transplants can be produced in 6 to 8 weeks.
Field Planting	
Propagule	Mature potted transplants.
Season	Early spring to late summer.
Substrate	Sand to muck.
Depth	Moist soil to 12”
Comments	Highly tolerant of desiccation; not susceptible to herbivory; will tolerate depths of 3’ once established.

APPENDIX B: Glossary of Botanical Terms

Apical meristem	The zone of actively dividing tissue at the tip of a shoot or root that produces new tissue, mainly to increase length
Apical tip	Situated at the top or tip of something (see apical meristem)
Basal meristem	Describes a growth form where the plant elongates from the base of the stem (opposite of apical meristem)
Colonization	Formation of new colonies from fragments, seeds, etc., but at a location distant from the source.
Daughter plant	Vegetative reproduction where a new plant of rosette form grows as an extension of a stolon or runner from the parent plant.
Emergent species	A growth from where the shoot extends above the water surface
Exclosure	A physical barrier designed to keep something out.
Expansion	Vegetative spread from the founder colony itself
Floating-leaved species	A growth form where the leaves float on the surface of the water rather than under water (submersed) or above water (emergent).
Flocculate	A process wherein colloids come out of suspension in the form of floc or flakes by the addition of a clarifying agent
Founder colony	A plant-community, establishment strategy where small, protected areas are planted, protected, and allowed to grow.
Macrophyte	An aquatic plant that grows in or near water and is emergent, submergent, or floating but is large enough to see with the naked eye.
Perennate	To survive from season to season for an indefinite number of years
Perennating organs	That part of a biennial plant or herbaceous perennial that allows it to survive the winter; usually a root, tuber, rhizome, bulb, or corm
Propagule	A part of a plant or fungus, e.g. A bud or a spore, that becomes detached from the rest and forms a new organism
Remediation	The process of improving a situation or of correcting a problem
Root crown	Also known as the root collar or root neck, is that part of a root system from which a stem arises

Rosette	A plant growth form where leaves emerge from the apical meristem in a reproducible pattern.
Seed bank	The natural storage of seeds or other propagules, often dormant, within the soil or substrate of a given ecosystem
Stem fragment	A propagule type where live portions of a growing plant are capable of growing vegetatively into a new individual
Stolon	A shoot that bends to the substrate or that grows horizontally above the substrate and produces roots and shoots at the nodes.
Submersed	A plant growth form where the entire plant is capable of long term survival with all plant material beneath the surface of the water
Tubers	A plant structure similar to a root that are enlarged to store nutrients and are used by plants to survive the winter or dry period
Vegetative spread	A form of asexual reproduction in plants where new individuals arise without production of seeds or spores
Winter bud (turion)	A specialized overwintering bud produced by aquatic herbs in response to unfavorable conditions such as decreasing day-length or reducing temperature

APPENDIX C: Commercial Sources of Materials for Native Aquatic Vegetation Restoration Projects

Commercial suppliers of native aquatic plants in Texas:

Joe Snow Aquatic Plants
11141 S. Hunter Hill Ct.
Argyle, TX 76226
(940)-390-7053
jsnow@pwhome.com
http://joesnowaquaticplants.com

J.R. Alphin Jr.
Franklin County Water District, Operations Manager
P.O. Box 559
Mt. Vernon, TX 75457
903-537-4536, 903-860-2544
jr.alphinjr@fcwd.com

Southwest Aquatic Services
P.O. Box 173
Altair, TX 77412
(512) 667-4275, (512) 667-4274
southwestaquatic@gmail.com
http://www.southwestaquatic.com

Commercial suppliers of vinyl coated fencing:

Boatcycle
213 N. Van Buren
Henderson, TX 75652
(903) 657-3791, (903) 657-6873, (800) 333-9154
kghale@boatcycle.com
http://www.boatcycle.com

C. E. Shepherd Company
2221 Canada Dry St. Houston, Texas 77023
(713) 924-4300, (800) 324-6733
http://ceshepherd.com/

Commercial suppliers of raceway liner:

Pondliner.com
7901 N Kickapoo
Shawnee, OK 74804
(866) 766-3548, (405) 275-4600
info@pondliner.com

Texas Parks and Wildlife Department
4200 Smith School Road, Austin, Texas 78744