Technique for rapid establishment of American lotus in remediation efforts

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ABSTRACT

A technique for increasing the establishment rate of American lotus (*Nelumbo lutea* Willd. [Nelumbonaceae]) and simplifying planting was developed as part of a pond remediation project. Lotus propagation techniques typically require scarification of the seeds, germination in heated water, and planting in nursery containers. Then mature (approximately 1 y) nursery-grown stock is transferred to the outplanting site, or scarified seeds are simply broadcast applied to the outplanting site. Mature plants should grow more quickly but can be sensitive to handling, require more time to plant, and cost more. Scarified seeds are easier to plant and are inexpensive but have a lag time in growth, can fail to germinate, and can be difficult to site precisely. We developed an intermediate technique using small burlap bags that makes planting easier, provides greater germination success, and avoids lag time in growth. Data on survival and growth from experiments using mature stock, scarified seeds, and bag lotus demonstrate that bag lotus grow rapidly in a variety of conditions, have a high survival rate, can be processed and planted easily and quickly, and are suitable for a variety of remediation projects.

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KEY WORDS

wetland, pond, restoration, propagation, planting, Nelumbonaceae

NOMENCLATURE

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The American lotus (*Nelumbo lutea* Willd. [Nelumbonaceae]) is a native, flowering, aquatic perennial plant. Its seeds can remain dormant for 200 y (Meyer 1930), and the plants can have a life span in excess of 20 y. American lotus is recognized for its floating and emergent large, round leaves, which can be 60 cm (24 in) in diameter and that bead water when pushed under the surface (Fasset 1957). It has a large, bright yellow flower of up to 25 cm (10 in) in diameter. Leaves and flowers arise directly from rhizomes. Seeds are round, hard, and nutlike and are contained within a light spongy structure. Normally seeds require stratification, scarification, abrasion, or animal digestion for germination. Historically, Native American cultures baked the large roots like sweet potatoes, ate the leaves like spinach, and the seeds were prepared to be eaten like nuts or ground into flour (Borman and others 1997). Seeds and tubers provide food for wildlife such as ducks and muskrat.

The American lotus is found in shallow water in ponds, lakes, sluggish streams, oxbows, and marshes from New York and Ontario south to the Gulf of Mexico, throughout the Mississippi Valley and Great Lakes regions (Godfrey and Wooten 1981). The lotus was known to be widely distributed in reservoirs of the Tennessee Valley Authority as early as 1936 (Hall and Penfound 1944), and currently it remains present in many reservoirs such as Wheeler and Guntersville (TVA 2004).

Growth is related to temperature, with most of the leaf and stem structure disappearing during winter, although tubers survive cold temperatures as long as they are not frozen (Meyer 1930). When growth resumes in the spring, it centers on the sensitive growth tip. If the tip is damaged during this initial growth phase, the plant will often die (Sayre 2004). The ability to spread by way of rhizomes and seeds gives the lotus great capacity to expand and dominate a water body. Lotus may be described as an invasive species, but only Connecticut has formally listed it as a potentially detrimental invasive species (Mehrhoff and others 2003).

The usual approach for starting American lotus in an area is to scarify the seeds and to broadcast them in the target area. If the introduction site is a small area, then occasionally bareroot plants or dormant tubers are used. The first approach has the advantage of allowing large numbers of potential plants to be distributed fairly cheaply and easily, but it may have a high failure rate because of low germination rate or seed placement in unsuitable microhabitats. Also, it may take a few weeks to months for the scarified seeds to germinate, resulting in a delay in plant establishment. The second approach is more costly and time consuming to install but has the advantage of using more mature plants that can be placed more precisely in favorable growing locations. Additionally, these older plants may flower and have seed production during their first growing season. Even this approach may not be successful, however, if other factors, such as wave action or growing-tip damage, cause problems (Dick and Smart 2004; Dick and others 2004). Other studies in southern lakes have recommended that approaches using scarified seeds of lotus be investigated rather than the use of whole plants (Smiley and Dibble 2006). Greater detail about propagation is given in Sayre (2004).

Planting American lotus was recommended as part of a remediation effort in a PCB-contaminated, 9.7-ha (24-ac) pond (P-1 Pond) on the Oak Ridge Reservation (ORR) near Oak Ridge, Tennessee. One of the goals of the remediation was to bind the pond sediments in place, and because lotus can create an extensive rhizome network, it was chosen as one of the treatment plants. Planting conditions varied in the pond. Much of the target area was shallow (<10 cm [4 in] depth), but a considerable area had water deeper than 1 meter (3 ft). Sediments included hard-packed clays, gravel, bedrock slabs, and thick depositional silts. Rapid establishment of treatment plants was desired, so seeds were not chosen as the primary planting form. Most of the treatment plants were purchased in a bareroot form and installed by hand in shallow water sediments. Most of these plants were emergent plants, such as sedges, rushes, or pickerelweed (*Pontederia cordata* L. [Pontederiaceae]). To allow planting in deeper water and to increase the ability to plant lotus in very specific locations, we developed a technique for germinating, growing, and planting lotus using small burlap bags. This approach combined the ease of broadcast seed planting with the improved growth of bareroot planting. To evaluate the technique we conducted cage experiments during the 2010 and 2011 growing season in which we compared seeds, bareroot, and bag lotus. We also tracked establishment of the bagged lotus distributed in the P-1 Pond during the 2009 to 2011 growing seasons.

METHODS

American lotus seeds were collected in February 2009 from a native population in the Hiawassee River approximately 120 km (75 mi) from the ORR. The population occurs in backwaters within a wildlife refuge and has been present for decades. American lotus seeds were also purchased from a commercial seed source. Later, seeds were harvested from a population established in an ORR nursery pond during the 2009 growing season.

Dry seeds were scored using a Dremel® rotary cutting tool to penetrate the dark outer shell, cutting just deep enough (1–2 mm) to reveal the light-colored cotyledon. Although scoring seeds early in the growing season is best, we spaced them out during the first month so we would not be overwhelmed by germinating seeds. Seeds were put in heated (24 to 32 °C [75 to 90 °F]) indoor aquaria under fluorescent lighting on a 12-h daylight cycle. Water changes were made every few days to

Figure 1. Lotus seed in dormant (*left*) and germinated (*right*) stages. Photo by Adam S Riazi

limit bacterial growth and concentrations of dissolved materials. Seeds typically absorbed water, swelling to more than double their original size and often floating to the surface, but viable seeds generally sank again within a few days as the sprout emerged from the seed (Figure 1). Most seeds germinated within 2 wk but some continued to sprout for as long as 12 wk after scoring. No differences in germination were observed among commercially purchased and harvested seeds. The sprouts were allowed to grow in aquaria until the initial stalk was 15 to 30 cm (6 to 12 in) in length.

Once sufficient growth had been attained, seedlings were removed from aquaria for placement in small (8 × 12 cm [3 × 4.8 in]), lightweight (12 g [0.4 oz]) burlap bags (Figure 2). The bags were loose-weave, biodegradable burlap with a drawstring at the opening and were purchased from a commercial craft-supply vendor. Pea gravel was placed in the bottom one-third of the bag to lessen buoyancy. The remainder of the bag was filled with a mixture of nutrient-rich, peat-based potting soil and local topsoil, creating a mean weight of 156 g (5.5 oz) per bag. A seedling was placed just inside each bag and the drawstring was loosely closed around the emerging stem. The entire process could be accomplished in about 3 min at a steady pace. Early in the growing season, bagged lotuses were placed in indoor tanks, with a flow-through water source and controlled light (12-h daylight cycle at 1600–2400 lux) and temperature (20 to 23 °C [68 to 73 °F]) conditions. As outside air temperatures increased, bagged lotuses were transferred to outdoor tanks under natural sunlight. The lotuses were allowed to develop until at least one leaf was present per plant or a set of bags were ready for deployment; holding time varied from 1 to 3 wk.

When enough leaf development was present (Figure 2) or a sufficient number of bags were ready, the lotus bags were taken to the P-1 Pond for outplanting. During the process, the bags were kept wet in a cooler or large tub. At the site, the bags could be placed in desired locations from a small boat or by wading into the shallows. The bags could be dropped or even tossed short distances to the desired locations, with little effort and quite rapidly. The gravel and soil in each bag caused them to sink to the bottom of the pond.

Figure 2. Germinated lotus seed, with sufficient growth for planting, packaged in burlap bag. Photo by W Kelly Roy

Throughout the summers of 2009, 2010, and 2011 seeds were germinated, bagged, and distributed within suitable locations in the P-1 Pond. Surveys were made in 2009 and 2010 of the number of leaves present at different times in the growing season. In 2011, aerial surveys were made of the pond to track the total surface area covered by lotus and other treatment plants during the growing season.

To measure and quantify the effectiveness of our culture and planting methods, we set up 3 test groups of 3 cages in 2 ponds (P-1 and P-3). The P-3 Pond is a smaller, noncontaminated pond, upstream from the P-1 Pond, and is maintained at a fairly constant depth by an outfall weir. Cages were created from 1.2 m (4 ft) tall wire fencing attached to metal posts, and groups of cages were created with similar size areas (<15 m^2 [161.5 ft^2]). The fence material was extended into the soft sediment in an effort to reduce grazing by herbivores that used the pond. Each test group was placed at similar water depths in areas with similar substrates. Test conditions included 1) soft silt sediment in shallow water (10 to 25 cm [4 to 10 in]) in P-3; 2) soft silt sediment in deep water (100 cm [3 ft]) in P-3; and 3) gravel/cobble substrate in shallow water (15 to 30 cm [6 to 12 in]) in P-1. Each test group (Figure 3) included 1) a cage planted with 1- to 2-y-old nursery bareroot plants; 2) a cage planted with lotus cultured using our burlap-bag method; and 3) a cage planted with seeds. The seeds included one test group in which the seeds were scarified (2010 in P-3) and germinated and 2 that were scarified only. The test group in soft sediment and shallow water was started in 2010 (in P-3 Pond) with 25 plants per cage and was monitored for 2 growing seasons; the

Figure 3. Three lotus comparison groups, bagged lotus seed (*left*), scarified lotus seed (*center*), and bareroot nursery stock (*right*). Photo by Michael G Ryon

other groups (another in P-3 and one in P-1 Pond) were started in 2011 with 10 and 15 plants per cage, respectively, and followed for one growing season; fewer plants were used in smaller cages. We monitored the plants biweekly and counted the leaves, as a measure of establishment.

RESULTS

Growth in P-1 Pond

During the 3 y of study, 3338 American lotus seeds were scored and soaked for germination, with the numbers prepared increasing each year (Table 1). The number of seeds that germinated and grew sufficiently to warrant planting in burlap bags ranged from 61% the first year to 91% in the third year. Similarly, the numbers of bagged lotus that continued to sprout leaves in holding tanks and were later planted in P-1 Pond increased from 46% in 2009 to 85% in 2011. As we became more familiar with the process, especially the scarification cuts, the number of successful seed plantings improved. The process allowed us to produce more than 2400 bagged lotus to plant in P-1 Pond over the 3-y remediation effort.

The success of the lotus propagation was also seen in growth of lotus in the P-1 Pond. Initially, surveys by boat could count individual plants, as each plant had few leaves and the plants were generally widely spaced. The number of surviving plants counted at the end of July 2009 was 115, roughly 63% of the bagged lotus put in the pond. At the end of July 2010, 151 plants were observed for a survival rate of 40% for the 2 y of planting to that date. Establishment of lotus was hindered both years by dewatering of the pond in late summer to allow modification or repair of an outlet structure. In 2011, the growth of lotus plants exploded exponentially, making individual counts impossible. Aerial photos taken in June 2011 showed 1170 m^2 (1400 yd^2) of pond surface covered by lotus leaves. By the end of September 2011, the area covered had increased to 2800 m^2 (3350 yd^2) of pond surface. The extensive coverage of the pond was facilitated by a full growing season without a water drawdown.

TABLE 1

Preparation results for bagged lotus planted in the P-1 Pond, 2009–2011.

Year	Seeds scarified	Seeds bagged	Seeds planted
2009	931	565	425
2010	1007	846	794
2011	1400	1277	1189

2010 Experiment

The lotus planted in 2010 in the shallow depth and silt bottom cages all performed similarly during the first growing season (Figure 4). The bag lotus had slightly more leaf growth than the other 2 techniques, but not overwhelmingly. During the second growing season, both bareroot and bag lotus outperformed the seed lotus, with the bareroot being best. By the end of the second year, lotus had fully filled the cage enclosures, had sent out runners far beyond the cage, and all 3 cages had flowering lotus.

2011 Experiments

Similar to the 2-y growing season experiments, the one season of growth in the shallow and gravel conditions was better for the bareroot and bag lotus techniques than for the seed technique (Figure 5). Overall the bareroot approach produced more leaves than the bag lotus. In the experiment with deep water and silt substrates, the bag lotus was clearly superior to the other techniques (Figure 6). In this situation, the bareroot plantings failed to survive.

DISCUSSION AND CONCLUSIONS

Our method of scoring, germination, and burlap bag planting is a highly effective method for planting American lotus. The bag method provides for a high percentage of lotus survival and growth in the cage experiments under all conditions and generates vigorous establishment of lotus colonies when placed in the pond. The burlap bags protect the root structure of the lotus but allow the roots to push through and escape from the

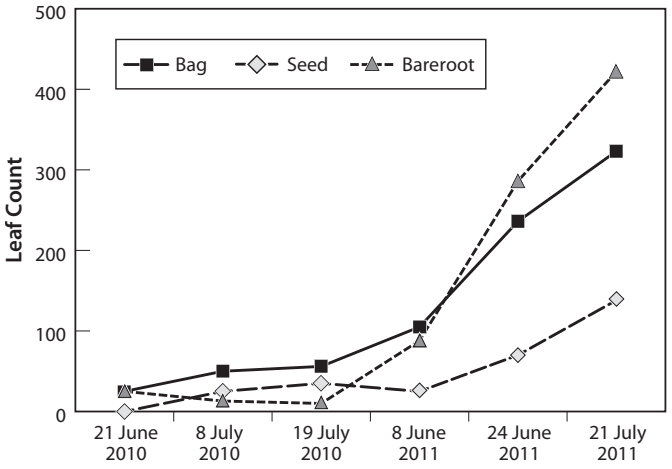

Figure 4. Leaf counts of lotus using 3 outplanting techniques during 2 growing seasons in cages with shallow water depth and soft silt substrate conditions in P-3 Pond.

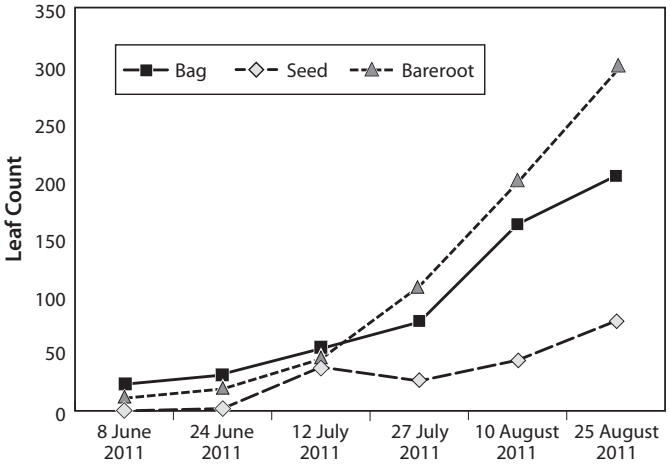

Figure 5. Leaf counts of lotus using 3 outplanting techniques during a single growing season in cages with shallow water depth and gravel-cobble substrate conditions in P-1 Pond.

bag. Also, the soil-filled burlap bags surround the root structure providing them with a nutrient-rich environment in which to grow during establishment in the native soils. The burlap bags deploy easily with minimal plant stress, root damage, or leaf disturbance.

The process of bagging takes only a few minutes per plant, time which is recovered during deployment at the site. The added amount of care reflected by the bag process produces better results than seed application alone and avoids the higher cost of mature plants. Overall this American lotus culture method, utilizing burlap bags, is both a low-cost and minimally labor-intensive method for growth and planting of lotus, providing for a high survival rate and vigorous establishment of lotus plants and lotus colonies after planting.

The bag lotus technique is well suited for remediation projects. Bags can be placed quite precisely, with minimal effort. Sediments do not need to be disturbed and bagged seedlings can be placed in deeper water than can bareroot plants. Compared to seed application, the more developed plants allow for quicker growth and root establishment that can be very important if a rapid stabilization of substrates or plant cover is needed. The bag technique produced the greatest initial growing season leaf counts (Figures 4 to 6) of the 3 techniques tested in soft substrate conditions. This method also proved to be the preferred technique for deeper water (>0.5 m [18 in]) application (see Figure 6). Although the bag technique is not always as effective as bareroot stock, it is cheaper than purchasing nursery plants, thus making it more suitable for many projects. Based on costs, ease of implementation, and survivability in a variety of conditions, the bag lotus technique appears to be a superior method for rapid establishment of American lotus and is suitable for a wide range of projects.

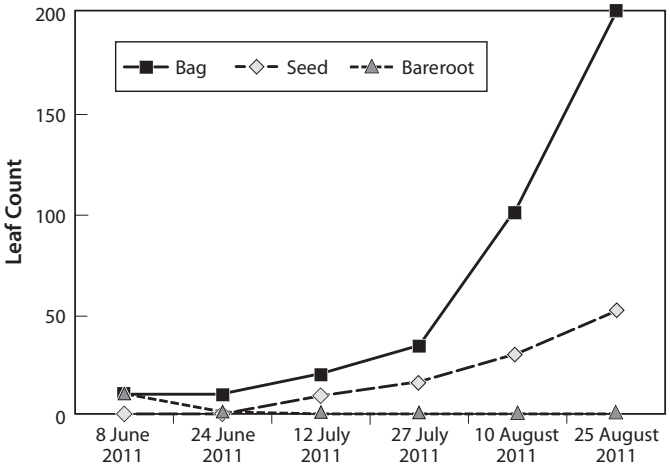

Figure 6. Leaf counts of lotus using 3 outplanting techniques during a single growing season in cages with deep water depth and soft silt substrate conditions in P-3 Pond.

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