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Winter survival of late emerging purple loosestrife (*Lythrum salicaria*) seedlings

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In wetlands, drought or managed late-summer drawdowns create exposed mudflats that provide an excellent substrate for germination of purple loosestrife seeds. If late-emerging purple loosestrife seedlings survive the winter, new or expanding populations of purple loosestrife will result. Spring survival was determined for overwintered purple loosestrife seedlings from seeds planted at weekly intervals in late summer or fall of the previous year. Seedlings of purple loosestrife that emerged from late July to early August had the greatest survival rates and the greatest shoot dry weight, and they were the tallest the following spring. However, 37% of purple loosestrife seedlings that emerged in late August, although stunted, generated a crown that was able to overwinter successfully and regrow the following spring. The number of growing degree days accumulated from planting date to October 6 (the average date of first frost for Minneapolis and St. Paul, MN) was 1,424 for seedlings from seeds planted on July 21 but only 219 for seedlings from seeds planted on September 15. Purple loosestrife seedlings that emerge during late summer through early September in Minnesota may survive the winter to create additional purple loosestrife weed problems in wetland mudflats caused by artificial drawdowns or droughts.

Nomenclature: Purple loosestrife, *Lythrum salicaria* L. LYTSA.

Key words: Crown survival, weed biology, wetlands.

Purple loosestrife is a perennial emergent wetland plant introduced in North America from Europe (Thompson et al. 1987). In North America, this invasive plant forms dense monospecific stands that displace valuable native plant species in disturbed wetland ecosystems (Mal et al. 1992). Seed dispersal is the major source of spread. Purple loosestrife plants are prolific seed producers, averaging 2.7 million seeds per plant (Thompson et al. 1987), thus creating an extensive seedbank (Welling and Becker 1990). Purple loosestrife seeds remain viable in the soil for up to 10 yr (R. L. Becker, unpublished data). Seeds can germinate in a wide range of soil types, soil pH, water levels (Keddy and Ellis 1985), and light levels but have a critical germination temperature between 15 and 20 C (Shamsi and Whitehead 1974a). After emergence, seedlings can survive flooding (Haworth-Brockman and Murkin 1993). When purple loosestrife seeds are present in the seedbank, seedling recruitment is more successful than it is for native species (Welling and Becker 1993).

Drawdowns (artificial cyclic wet and dry periods) are an effective wetland management tool for maintaining productivity in waterfowl marshes (Harris and Marshall 1963; Kadlec 1962). Drawdowns are used to establish annual or perennial emergent vegetation in open water areas to provide cover, nesting material, or seeds for waterfowl (Kadlec 1962; Merendino et al. 1990). Receding water levels caused by late-summer drawdowns or drought expose mudflats and provide an excellent substrate for germinating purple loosestrife seeds (Merendino et al. 1990; Rawinski and Malecki 1984; Smith 1959, 1964). Newly emerged purple loosestrife seedlings have been observed as late as early September in Minnesota (E. J. Katovich, personal communication) and in mid-August in south-central Manitoba (Merendino et al. 1990). Thompson et al. (1987) reported that purple loosestrife seedlings require about 50 d of favorable conditions after emerging to survive the winter. However, definitive characterization of heat unit requirements for winter survival has not been reported. The objective of this experiment was to determine survival of overwintered purple loosestrife seedlings from seeds planted at weekly intervals in late summer. This knowledge will enable wetland managers to predict when purple loosestrife seedlings that are present one season may contribute to stands of purple loosestrife the next season.

Materials and Methods

Purple loosestrife seeds from a single wetland located in Washington County, MN, were collected during the fall of 1996 and 1997. The experiment was conducted on the St. Paul campus of the University of Minnesota (latitude 44°99′N, longitude 93°21′W, 280 m above sea level). Before planting, wetland mesocosms were created outdoors with 1.2-m^2 square boxes, lined with plastic and filled with a standard greenhouse soil (silt loam–sand–manure–peat, 1:1:1:1, v/v/v/v), similar to those used by Welling and Becker (1993). Standard greenhouse soil was used to prevent introduction of purple loosestrife seeds from another seed source. A 1.1-L plastic pot was placed in soil at both ends of each mesocosm. Water was added as required to the pots to maintain soil in a saturated state without disturbing the soil surface. Eight planting date treatments were arranged randomly within a single mesocosm and replicated four times within separate mesocosms in a randomized complete block design. The experiment was conducted during the summer of 1997, 1998, and 1999. At each planting date, approximately 100 purple loosestrife seeds were broadcast onto the soil surface within a 30- by 30-cm frame that was kept in place for the duration of the experiment. Within each frame, seeds were

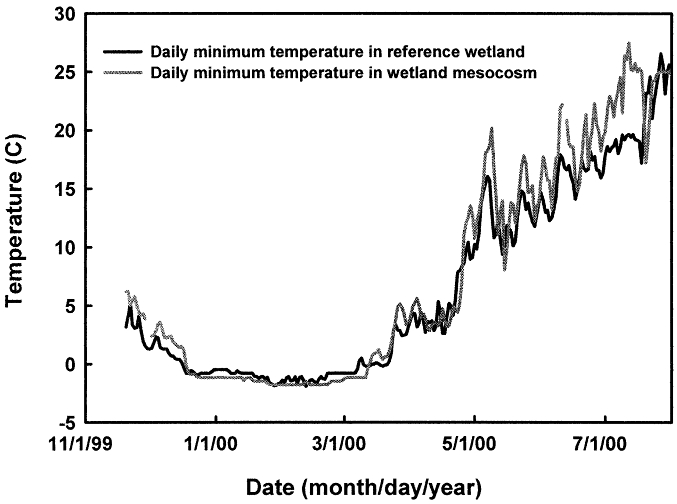

FIGURE 1. Daily minimum soil temperatures in wetland and in wetland mesocosms, 1999–2000.

patted lightly into the soil by hand and watered lightly until emergence. This approach prevented seed movement among planting date treatments. In 1997, seeds were planted on July 7 and 21, August 4, 11, 18, and 25, and September 4 and 8. In 1998, seeds were planted on July 20, August 3, 10, 17, 24, and 31, and September 8 and 14. In 1999, seeds were planted on July 21, August 4, 11, 18, and 25, and September 1, 8, and 15. In 1998 and 1999, a July 7 planting date was not included and a September 15 planting date was added based on preliminary 1997 results that indicated that a later fall emergence date would provide a more comprehensive assessment of winter survival. Although individual planting dates varied by 1 to 2 d among years, they were regarded as the same date for ease of presentation. Seedlings thinned shortly after emergence to 20 per replication per planting date. In late October, the number of surviving plants per planting date was recorded.

Individual soil temperature probes[1] were placed 5 cm deep in two randomly selected mesocosms in late fall and were removed in late summer the following year. In 1998 and 1999, a soil temperature probe also was placed 5 cm deep in the wetland, where seeds for the experiment were collected, to obtain temperatures for comparison with those in the mesocosms. The mesocosms were mulched with straw at the end of October. Mulch was removed in late April the following season. In late May to early June in the year after seeding, the number of surviving purple loosestrife plants from each planting date was determined. The height of the tallest shoot of each plant was measured. Shoots were clipped at soil level, and all shoots for each replication were combined. Shoots were dried at 60 C for 1 wk and weighed.

Growing degree days (GDD_{b10}) were estimated using a base air temperature of 10 C with no maximum temperature (Climatology Working Group 2001). Although a base temperature for purple loosestrife is not described in the literature, base temperatures obtained from other perennial species such as alfalfa (*Medicago sativa* L.) and hemp dogbane (*Apocynum cannabinum* L.) were used as points of reference (Ransom et al. 1998; Sharratt et al. 1989). Growing degree days (GDD_{b10}) were calculated from planting date until October 6 and October 19, the average date of the first 0 and − 2.2 C minimum temperature, respectively, at Minneapolis and St. Paul, MN (Climatology Working Group 2001). The average date of the first 0 C minimum temperature was used to define the length of the frost-free season (Rosenberg et al. 1983). The average date of the first − 2.2 C minimum temperature was included because purple loosestrife shoots were not killed by the first frost (E. J. Katovich, personal observations based on purple loosestrife plants included in the study area and on those growing in wetlands).

Data were analyzed with analysis of variance procedures, and means were separated with a protected LSD test. The year by planting date interaction for each measured parameter was not significant, so data were combined over 3 yr of the study. The relationship between GDD_{b10} and percent survival, shoot height, and shoot dry weight were described by nonlinear regression analyses using Sigma Plot 2000.[2] The goodness-of-fit of the regression models was evaluated with the coefficients of determination (R^2) and F statistics.

Percent survival of purple loosestrife seedlings the spring after planting of seeds as a function of GDD_{b10} accumulated from planting date until the average date of first frost (0 C) was described by Equation 1:

$$y = a/(1 + \exp[-(x - x_0)/b]) \quad [1]$$

where y is the predicted percent seedling survival, a the maximum percent seedling survival, x the accumulated GDD_{b10}, x_0 the GDD_{b10} at 50% amplitude, and b the difference between GDD_{b10} values at 25 and 75% of amplitude. Shoot dry weight the spring after planting of seeds as a function of GDD_{b10} accumulated from planting date until the average date of first frost (0 C) was described by Equation 2:

$$y = y_0 + ax + bx^2 + cx^3 \quad [2]$$

where y is the predicted shoot dry weight per square meter, y_0 the shoot dry weight when GDD_{b10} is 0, a the slope of the line, x the accumulated GDD_{b10}, and b and c the regression coefficients. The relationship between shoot height the spring after planting of seeds and GDD_{b10} accumulated from planting date until the average date of first frost (0 C) was described by Equation 3:

$$y = y_0 + ax + bx^2 \quad [3]$$

where y is the predicted shoot height, y_0 the shoot height when GDD_{b10} is 0, a the slope of the line, x the accumulated GDD_{b10}, and b the regression coefficient.

Results and Discussion

In the summer of 1997, 1998, and 1999, purple loosestrife seedlings emerged within 1 wk after planting of seeds and grew until mid- to late September (data not shown). Seedlings that emerged after the middle- to late-August planting dates were stunted when compared with the earlier planting dates (E. J. Katovich, personal communication). Shamsi and Whitehead (1974b) reported a 13-h critical day-length requirement for shoot elongation and flowering for purple loosestrife. Photoperiods were of 13-h duration during the first week of September in Minneapolis, MN (Climatological Working Group 2001). After the first week of September, a photoperiod of less than 13 h would result in stunting of purple loosestrife stems.

Soil temperatures of the mesocosms and the wetland were similar from November 1999 through July 2000 (Figure 1). Both the mesocosms and the wetland had similar levels of

Table 1. Percent survival, shoot length, and shoot dry weight of purple loosestrife (*Lythrum salicaria*) seedlings the spring after establishment and mean growing degree days (GDD_{b10}) from planting date of seeds to the first 0 or − 2.2 C temperature. Data were pooled over three experiments from 1997 to 2000.

Planting date	GDD_{b10} to stated frost		Survival	Shoot length	Shoot dry weight
	0 C[a]	− 2.2 C[b]	%	cm	g m^{-2}
July 21	1,424	1,507	89	33	544
August 4	1,083	1,167	92	16	167
August 11	937	1,021	81	11	67
August 18	797	881	59	8	33
August 25	657	740	37	6	11
September 4	482	565	9	2	1
September 8	351	434	6	1	0.4
September 15[c]	219	302	0	0	0
LSD (0.05)			14	4	89

[a] Mean GDD_{b10} from planting date to the first 0 C minimum temperature in the fall.
[b] Mean GDD_{b10} from planting date to the first − 2.2 C minimum temperature in the fall.
[c] September 15 planting date was only included in 1998 and 2000.

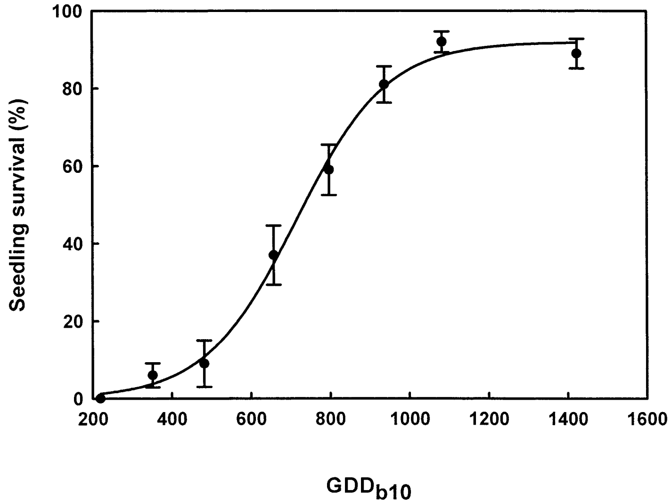

Figure 2. Percent survival of purple loosestrife (*Lythrum salicaria*) seedlings the spring after planting of seeds as a function of GDD_{b10} accumulated from planting date until average date of first frost (0 C). Data were pooled over three experiments from 1998 to 2000. The equation $y = a/(1 + \exp(-(x - x_0)/b))$ represents the line, with $a = 92$, $b = 115$, and $x_0 = 715$ ($R^2 = 0.99$). Error bars represent standard error of the mean.

mulch and snow cover (E. J. Katovich, personal communication), which explains the similarity between soil temperatures at the two locations. Average snowfall for Minneapolis and St. Paul, MN, from 1948 through 1993 (45 yr) was 133 cm (Climatology Working Group 2001). Snowfall in the winters of 1997, 1998, and 1999 was 114, 144, and 89 cm, respectively. Snow depths of 25 cm or more provide enough soil insulation to stabilize soil temperature (Sharratt et al. 1987).

Survival of seedlings the spring after planting differed among planting dates in all 3 yr (Table 1). Based on seedling number in the previous fall, percent survival the following spring did not differ among the July 21, August 4, or August 11 planting dates, with rates of survival being 89, 92, and 81%, respectively. Seedling survival was 59 and 37%, respectively, for the August 18 and August 25 planting dates. Seedling survival on the latest planting dates, September 4 and 8, was only 9 and 6%, respectively. In 1999 and 2000, no seedling after the September 15 planting date survived to the next spring.

Accumulated GDD_{b10} averaged over 3 yr from the date of planting to the average date of first frost (October 6) ranged from 1,424 for seeds planted on July 21 to 219 for seeds planted on September 15 (Table 1). Seeds planted on August 25, with a seedling survival rate of 37% in winter, accumulated 657 GDD_{b10} by the first frost. Average GDD_{b10} until the first frost was 351 for the September 8 and 219 for the September 15 planting dates. The interval between the September 8 and 15 planting dates is a significant break point for survival of purple loosestrife seedlings. A minimum of 351 GDD_{b10} before the average date of first frost was required for winter survival of purple loosestrife seedlings. The relationship between percent survival of purple loosestrife seedlings and GDD_{b10} was best described by a sigmoidal curve (Figure 2).

Average GDD_{b10} accumulated from date of planting to the average date of the first − 2.2 C minimum temperature (October 19) ranged from 1,507 for the July 21 planting to 302 for the September 15 planting (Table 1). The mean number of GDD_{b10} until the first − 2.2 C temperature was 434 for the September 8 and 302 for the September 15 planting dates.

The greatest shoot dry weight the spring after planting was for the July 21 planting date (Table 1). Shoot dry weight for the August 4 planting date was nearly 70% less than that for the July 21 planting date but was greater than that for later plantings. Shoot dry weight was very low (67 g m^{-2} or less) and did not differ among planting dates for August 11 or later. The relationship between shoot dry weight and GDD_{b10} accumulated from planting until the average date of first frost (October 6) was best described by a cubic equation (Figure 3).

The mean shoot height the summer after planting also was greatest for the July 21 planting date, with a mean shoot

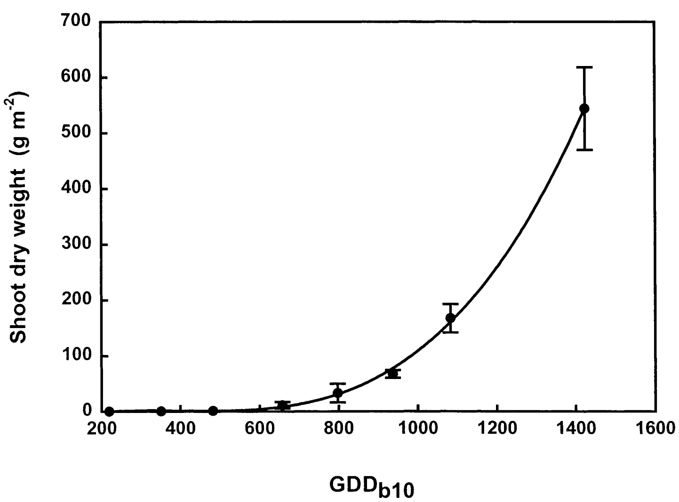

Figure 3. Shoot dry weight of purple loosestrife (*Lythrum salicaria*) plants the spring after planting of seeds as a function of GDD_{b10} accumulated from planting date until average date of first frost (0 C). Data were pooled over three experiments from 1998 to 2000. The equation $y = y_0 + ax + bx^2 + cx^3$ represents the line, with $y_0 = -27.6$, $a = 0.2$, $b = -0.0006$, and $c = 5 \times 10^{-7}$ ($R^2 = 0.99$). Error bars represent standard error of the mean.

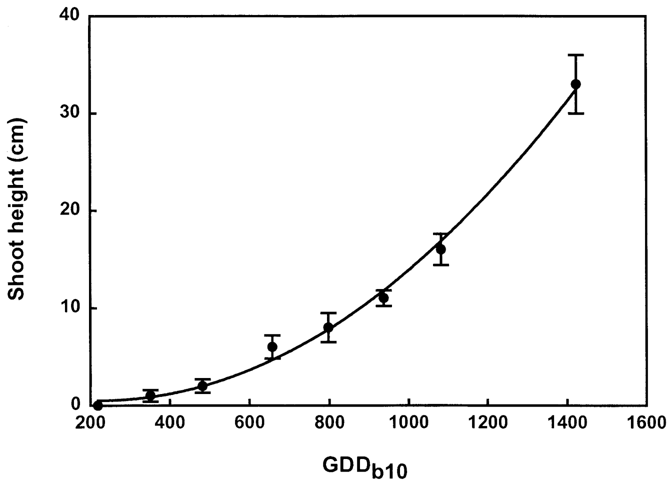

FIGURE 4. Shoot height of purple loosestrife (*Lythrum salicaria*) plants the spring after planting of seeds as a function of GDD_{b10} accumulated from planting date until average date of first frost (0 C). Data were pooled over three experiments from 1998 to 2000. The equation $y = y_0 + ax + bx^2$ represents the line, with $y_0 = 1.6$, $a = -0.01$, and $b = 2 \times 10^{-5}$ ($R^2 = 0.99$). Error bars represent standard error of the mean.

height of 33 cm (Table 1). In comparison, shoot height of plants was 50% less for the August 4 planting date. Shoot height of plants from later planting dates was less than that for those from the August 4 planting date. Although the critical photoperiod of 13 h required for shoot elongation was reached by sampling time in early June, planting dates later than July 21 resulted in stunted shoots the following summer. The relationship between mean shoot height and GDD_{b10} accumulated from planting until the first frost (October 6) was best described by a quadratic equation (Figure 4).

Seedlings of purple loosestrife that emerged from late July to mid-August had the greatest percent survival the following season. However, the results of this study also showed that nearly 40% of the purple loosestrife seedlings that emerged in late August, although stunted, generated a crown that successfully overwintered and regrew the following spring. These results demonstrate that less time is required after emergence and before frost for successful overwintering than the 45 to 60 d described by Thompson et al. (1987). Merendino et al. (1990) reported successful recruitment of purple loosestrife seedlings in an August 15 drawdown at the Delta Marsh in south-central Manitoba, although recruitment was greater after a mid-June or mid-July drawdown.

The results of our study suggest that purple loosestrife seedlings that emerge during late summer and early September in central Minnesota will successfully overwinter and contribute to purple loosestrife weed infestations in wetland mudflats exposed by artificial drawdowns or droughts. A minimum of 351 GDD_{b10} before the first average frost was required for seedling survival in winter, with snow cover in 1997, 1998, and 1999 ranging from below to above normal. Depending on the magnitude of the purple loosestrife seedbank, seedling emergence within 2 to 3 wk of the average first frost date for a given locale may pose an unacceptable risk by creating new or expanding stands of purple loosestrife.

Sources of Materials

[1] Stowaway Tidbit, Onset Computer Corporation, 536 MacArthur Boulevard, Pocasset, MA 02559.

[2] Sigma Plot 2000, SPSS Inc., 444 North Michigan Avenue, Chicago, IL 60611.

Acknowledgments

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