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Decomposition Rates of Purple Loosestrife (*Lythrum salicaria*) and Lyngbyei's Sedge (*Carex lyngbyei*) in the Fraser River Estuary

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ABSTRACT: Using litter bag experiments in the Fraser River estuary in British Columbia, we tested for differences in the relative decomposition rates between leaves of purple loosestrife (*Lythrum salicaria*), an introduced exotic and a native sedge (*Carex lyngbyei*). The difference in the mean decay rate coefficient for the two species was significantly different ($p < 0.01$) and the coefficient for purple loosestrife (0.0110 d^{-1}) was nearly four times higher than for Lyngbyei's sedge (0.0028 d^{-1}). This is the first estimate of the decay rate coefficient for purple loosestrife from an estuary. The rapid decay rate of loosestrife leaves suggests that they supply detritus to the ecosystem in autumn whereas the much slower decay rate of sedge implies that it supplies detritus throughout the winter and early spring. Consumer organisms important in juvenile salmon food webs appear to be adapted to take advantage of the detritus provided in these seasons. The findings have implications for habitat management because purple loosestrife has recently invaded estuaries of the northeast Pacific and may be outcompeting native sedges important in detrital-based food webs.

Introduction

Because of the recent invasion of wetlands in the Fraser River estuary by purple loosestrife, *Lythrum salicaria* (Lythraceae) (Adams 1993), concern has been raised that this plant may be outcompeting endemic plants such as sedges (e.g., Lyngbyei's sedge (*Carex lyngbyei;* Kistritz et al. 1983) that are an important source of detritus for estuarine ecosystems in the northeast Pacific. In this study we tested the hypothesis that the relative rates at which sedge and loosestrife leaves entered the detrital ecosystem of the lower Fraser River and estuary varied. Clearly, the effect of plant species on the form and rates of estuarine detrital trophic processes is of importance. Recent work has shown that dissolved organic carbon from vascular plant decomposition is important for heterotrophic bacteria, which in turn are used by invertebrate fish food organisms (Findlay et al. 1992). The production of particulate detritus is therefore only an estimate of the importance of vascular plant decomposition to the ecosystem, but as described for chum salmon (*Oncorhynchus keta*), detrital flux is an indirect source of nutrition for tertiary consumers in our region (Sibert et al. 1977). The Fraser River is one of the world's largest producers of salmon (*Oncorhynchus* spp.) and the estuary is a vital nursery area for several species of salmonids (Northcote and Larkin 1989). Much of this production is fuelled by detrital pathways. It is important that habitat management agencies such as the Fraser River Estuary Management Program have information on possible changes in these pathways.

Our study on decomposition rates of *L. salicaria* in the Fraser River and estuary gives the first available data for this introduced exotic from an estuarine or large lotic system. We estimated the decomposition rates of leaf material from the two species using a litter bag technique. We also investigated differences in decomposition between locations within the estuary, and conducted a preliminary study of colonization of the detritus by invertebrates. Other than the preliminary work by Moody (1978) and Kistritz and Yesaki (1979), there

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are no estimates of the decomposition rate of sedges in Pacific estuaries. However, decomposition rates of sedges (*Carex* spp.) have been investigated in numerous studies in fresh water (Webster and Benfield 1986). A paper on decomposition rates of *L. salicaria* in Minnesota ponds and lakes has recently become available (Emery and Perry 1996) and provides the first estimates of decomposition rates for this species. The only other published data on the decomposition of plant material from Lythraceae in flowing waters we could locate was for whorled loosestrife (*Decodon verticillatus*) in a small woodland stream in Michigan (Petersen and Cummins 1974).

Materials and Methods

Study Sites

Litter bags were placed at five locations in the Fraser River estuary, including the North and South arms and near Coquitlam on the mainstem (Fig. 1). Tidal range in these reaches of the estuary is between 2.0 m and 3.5 m. Because the marshes drain through tidal creek systems into the mainstem Fraser River, part of the decomposition process may occur on the mainstem shorelines as well as within the marshes proper (Macdonald et al. 1990). To obtain a uniform shoreline substrate and relatively similar immersion times, all bags were placed at approximately mid-tide elevation on riprap revetment substrate (angular stone blocks, approximately 20–50 cm dimensions). This shoreline type accounts for about 30% of the littoral zone in this industrialized estuary. An exception was the Coquitlam site where riprap revetment was not available so litter bags were placed on sand substrate. Because litter floats from marshes to the mainstem river and subsequently drifts upstream and downstream at high tide, litter is as likely to strand on riprap revetment as it is on sand or mud, the other common shoreline types in the Fraser

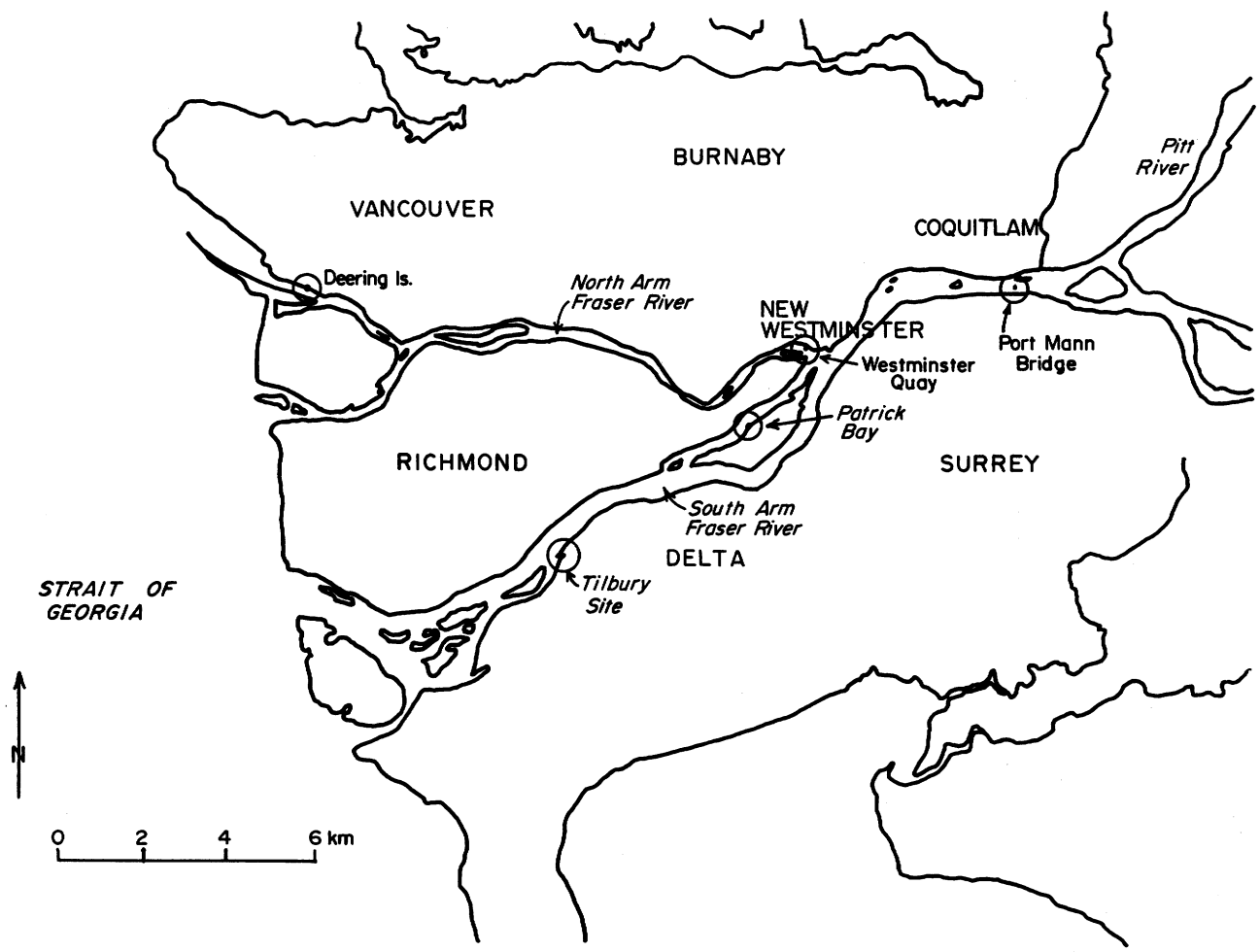

Fig. 1. Map of the Fraser River estuary, British Columbia, showing sites where litter bags were set out for decomposition rate experiments. (Circles)

estuary. Above high water, at all study areas, there was a narrow fringe of riparian vegetation, mostly willow (*Salix* spp), alder (*Alnus* spp.), and blackberry (*Rubus ursinus*)

General descriptions of the sites follow. Two sites were within the portion of the estuary where surface salinity is affected by salt water intruding from the Strait of Georgia; the remainder are only influenced by river water. Surface water and air temperatures typically are 3–8°C and 5–10°C, respectively, between October and February (Brown et al. 1989; Environment Canada climate records).

Deering Island (DI)—This site was located under the north side of the bridge leading to the island at the south foot of Blenheim Street, Vancouver, in the North Arm of the Fraser River. The former channel around Deering Island has been almost completely blocked at the bridge, and water movement is mainly influenced by tidal flow rather than river currents. Predicted average currents in winter in this channel range from 0.2 m s^{-1} to 0.4 m s^{-1} (Stronach 1995). Surface salinities in winter in this reach of the North Arm range from 8‰ to 16‰ (Carey 1990).

Tilbury Slough (TS)—This site was located on the south side of Gravesend Reach, about 200 m downstream of the mouth of Tilbury Slough. Average currents in winter at a nearby site ranged from 0.4 m s^{-1} to 0.7 m s^{-1} (Stronach 1995). Surface salinities in Gravesend Reach vary between 0‰ and 10‰ in winter (Ages 1988).

Patrick Bay (PB)—The location of this site was on the south side of Annacis Channel about 20 m upstream of an abutment on the Highway 91 bridge. Average currents in winter at a nearby site ranged from 0.4 m s^{-1} to 0.7 m s^{-1} (Stronach 1995).

Port Mann Launch (PML)—This site was 40 m upstream from the boat launch area at the Port Mann Bridge, on the north side of the river at Coquitlam. Predicted average currents in winter range from 0.6 m s^{-1} to 0.8 m s^{-1} (Stronach 1995).

Westminster Quay (WQ)—Litter bags at this location were placed on the shoreline at the Renaissance Square development at New Westminster, near the junction of the mainstem Fraser and the North Arm. No estimates of currents are available at this location, but velocities are probably <1.0 m s^{-1}. This was the only site where wave action was relatively severe owing to river traffic.

Litter Bag Techniques

The vegetation was collected in late September 1993. Brown leaves of the sedge *C. lyngbyei* were collected from a compensation marsh (planted in 1989) downstream of Deering Island in the North Arm of the Fraser River. Leaves of *L. salicaria* were collected from Iona Island, also on the North Arm. The vegetation was stored in a cold room at 10°C for 1 wk and subsamples (approximately 50 g wet mass) were then stored in a freezer at −11°C until they were required for placing in the field. All of the samples were placed in the freezer at the same time.

TABLE 1. Schedule for placement and recovery of litter bags containing leaf litter from sedge (*Carex lyngbyei*) and purple loosestrife (*Lythrum salicaria*).

Date in	Date out	Number of bags	
		Carex	*Lythrum*
October 29, 1993	November 29, 1993	3	3
October 29, 1993	March 4, 1994	3	3
November 29, 1993	March 4, 1994	3	3
January 3, 1994	March 4, 1994	3	3
January 31, 1994	March 4, 1994	3[1]	3[2]
February 14, 1994	March 4, 1994	3	3

[1] One additional bag of *Carex lyngbyei* placed at Port Mann Launch and Deering Island.
[2] One additional bag of *Lythrum salicaria* placed at Patrick Bay and Tilbury Slough.

Ten additional samples of *C. lyngbyei* and *L. salicaria* were weighed, dried to constant mass at 105°C for 24 h, and ashed in a muffle furnace at 500°C for 2–3 h to obtain ash-free dry mass data (AFDM), which were then regressed on the wet mass data (WM). Ashed samples were cooled and rewetted to reintroduce the hydration of any clay material. The regressions were then used to convert the measured wet mass of the samples placed in the field to an initial ash-free dry mass.

Plant material was placed in nylon mesh bags (30 cm × 30 cm) with 1-mm mesh size. Each litter bag was filled with a sample of vegetation, closed with a Velcro strip fitted on each bag, and placed at each site according to the schedule shown in Table 1. This schedule ensured that samples of plant tissue at different stages of decomposition were removed at the same time, avoiding potential differences in phenology of invertebrate consumers (Richardson 1992). Three bags were placed in the field at each occasion, except for January 31, 1994, when an additional bag was placed at four locations because of concerns about possible loss of bags due to winter storms. All of the litter bags were attached with nylon ties to a tether line at each site. The bags were attached so that they lay flat on the substrate and did not overlap each other. Two cinder blocks were set apart along the mid-tide level (estimated 2.9 m above chart datum; tide data for Pt. Atkinson, Canadian Tide and Current Tables 1993) at each site on October 29, 1993, so that the tether line strung between them held all of the bags at about the same tidal position. The litter bags were exposed to the air at a frequency

that varied from once to twice daily depending on tidal heights during the time period between placement and recovery of the bags. When the litter bags were removed from the field they were individually enclosed in plastic bags to prevent the loss of invertebrates. Immediately after collection, the litter bags were returned to the lab and frozen.

After the litter bags were recovered from the field and returned to the laboratory, the plant material from the bags was gently washed with tap water onto a series of sieves to separate the vegetation from the invertebrates and finer particles of detritus. A 10-mm sieve was used to collect the large pieces of vegetation washed from the litter bag. A 1-mm sieve retained the remaining vegetation from the mesh bag. Finally, a 90 μm screen was used to collect the invertebrates and accompanying fine particulate detritus. Invertebrates larger than about 1 mm were hand picked out of the vegetation. A white bottomed tray and a magnifying lens were used to sort these larger invertebrates. The large invertebrates and the material on the 90 μm screen were rinsed into a jar and preserved in a 3.7 % formalin solution with rose bengal to stain the animals. Invertebrate samples from the first collection of litter bags, set out from October 29 to November 29, 1993 (Table 1), were examined to determine if there were differences in the numbers and types of invertebrate organisms that had colonized sedge and loosestrife detritus. The vegetation was washed from the 10-mm and 1-mm sieves onto a piece of 1-mm mesh and wrung out or squeezed by hand to remove excess water. Wet, dry, and ash-free masses were then obtained using the methods described earlier.

Data Analysis

The weight loss of *C. lyngbyei* and *L. salicaria* was calculated as the fraction of the initial mass remaining at time (t) and expressed as a percent. The calculations were done using ash-free data because AFDM was considered to be a close approximation of the organic matter content of the leaf litter. The decomposition rate was modelled as a negative (or single) exponential decay function. The model, first proposed by Jenny et al. (1949), has been frequently used to describe decomposition and was discussed in detail by Olsen (1963). The natural-logarithm-transformed data were fitted by least squares regression and the daily loss rates were expressed as exponential coefficients. The mathematical form of the model is the equation of the regression line:

$$\ln M_t = \ln M_o - kt \qquad (1)$$

where M_t is the percent AFDM remaining at time (t), M_o is the initial percent AFDM, and k is the decomposition (decay) rate constant. The value of the slope of the line obtained from the linear regression of ln M_t versus time is the decomposition rate constant. Comparisons between the decomposition rate constants were made using analysis of covariance (ANCOVA). An ANCOVA model with a three-way interaction (time, species, and site) was used. Statistics were calculated using the General Linear Models (GLM) procedure of the Statistical Analysis Systems Institute (SAS 1985).

TABLE 2. Results of regressions of ln percent remaining (AFDM) versus time for *Carex lyngbyei* and *Lythrum salicaria* at each site and decomposition coefficients determined (K, d^{-1}). ns indicates not significant at $p < 0.05$. DI = Deering Island; PB = Patrick Bay; PML = Port Mann Launch; TS = Tilbury Slough; WQ = Westminster Quay.

Site	Species	R^2	K (d^{-1})
All combined	*Carex lyngbyei*	0.20	0.0028
	Lythrum salicaria	0.32	0.0110
DI	*Carex lyngbyei*	0.34	0.0038
	Lythrum salicaria	0.50	0.0032
PB	*Carex lyngbyei*	0.11(ns)	0.0017
	Lythrum salicaria	0.81	0.0052
PML	*Carex lyngbyei*	0.10(ns)	0.0016
	Lythrum salicaria	0.68	0.0110
TS	*Carex lyngbyei*	0.44	0.0046
	Lythrum salicaria	0.72	0.0090
WQ	*Carex lyngbyei*	0.15(ns)	0.0025
	Lythrum salicaria	0.93	0.0290

Results

Litter Decomposition

The k values for *C. lyngbyei* ranged from 0.0016 d^{-1} to 0.0046 d^{-1} (Table 2) and the average over all of the sites combined was 0.0028 d^{-1}. Although the regressions for *C. lyngbyei* at Patrick Bay, Port Mann Launch, and Westminster Quay were not statistically significant ($p > 0.05$), the k values for *C. lyngbyei* at these three sites represent the best fit estimates and therefore were retained for use in further analysis. The overall decay rate coefficient for loosestrife was 0.0110 day $^{-1}$ (Table 2), nearly 4 times higher than for sedge. Loss rates for loosestrife were greater than those of sedge at all sites, excluding Deering Island. After 126 d the leaves of *L. salicaria* were brown, mushy, and indistinguishable from each other, but the leaves of *C. lyngbyei* remained in recognizable form. The decay rate coefficient for *L. salicaria* was much higher at Westminster Quay (WQ) (0.029 d^{-1}) than at any of the other sites. The confidence intervals for regression lines between sample weights and times were higher for *C. lyngbyei* (range 3–5% over all sites) compared to *L. salicaria* (range 10–15%).

Analysis of covariance results for the litter bag experiment are summarized in Table 3. A three-way interaction model ($r^2 = 0.88$) was used to ex-

TABLE 3. Analysis of covariance results. Dependent variable is ln (M), where M is the percent of AFDM remaining. MS is the mean square.

Source of Variation	df	MS	F	P
Species	1	0.002	0.03	0.86
Site	4	0.049	0.95	0.44
Time (days)	1	14.109	271.49	0.0001
Species × Site	4	0.048	0.93	0.45
Time × Species	1	5.150	99.10	0.0001
Time × Site	4	1.495	28.77	0.0001
Time × Species × Site	4	1.645	31.65	0.0001
Error	164			

plain the interactions between species, site, and time. Time, species, and site interactions were important indicators of differences between the decomposition rate constants (i.e., the slopes of the regression lines). The decay rates of the two species were significantly different, as confirmed by the significant interaction of time and species. In addition, the significant interaction of time and site showed that the rate of decomposition also varied with site.

Use by Invertebrates

Gammarid amphipods, harpacticoid copepods, and chironomid larvae were the most abundant invertebrates in the sedge (12 bags examined) and loosestrife (11 bags examined) litter in the samples set out from October to November 1993. These three taxa accounted for >75% of the animals in the litter. All of the taxa were more abundant in loosestrife detritus relative to sedge when the empirical data were scaled (number per g wet mass) by the weight of plant material present (gammarids: 0.09 versus 0.27; harpacticoids: 4.98 versus 11.86; chironomids: 0.38 versus 0.72; for sedge versus loosestrife, respectively). Gammarids were only found in samples from Deering Island and Tilbury Slough, but the other two taxa were observed in samples from all sites.

Discussion

Decomposition Rates

The decay rate coefficient determined for *C. lyngbyei* over all sites (0.0028 d^{-1}) was slightly higher than that summarized for the sedge family (Cyperaceae) from studies conducted mainly in fresh water (Webster and Benfield 1986). The k values for *L. salicaria* were between 0.0032 d^{-1} and 0.029 d^{-1}), with an average of 0.011 d^{-1}. This value was very similar to that determined by Petersen and Cummins (1974) for whorled loosestrife (*Decodon verticillatus*) in a stream (k = 0.010) but higher than that found for *L. salicaria* leaves in 13 Minnesota ponds (mean 0.0028 day $^{-1}$; Emery and Perry 1996). Petersen and Cummins (1974) have suggested that there is a leaf processing continuum where species have either fast (k > 0.010), medium (0.005 < k < 0.010), or slow (k < 0.005) decomposition rates. Based on this scale, *L. salicaria* showed a fast decomposition rate and *C. lyngbyei* had a slow decomposition rate. The high decay rate for *L. salicaria* at WQ may have resulted from the relatively high wave and current energy that characterized this site.

Implications for Food Webs and Habitat Management

The timing of detrital supply to northeastern Pacific estuaries has been recognized as a factor affecting consumer organisms in these ecosystems (Sibert 1982). Our results show that leaves of *L. salicaria* decay rapidly compared to sedge. This suggests that most of the detritus from decomposing loosestrife leaves may have been provided to consumers in the autumn only. In northeast Pacific estuaries, purple loosestrife sheds all of its leaves in the fall, as a single pulsed event, as they are easily lost from the plant during initial autumnal storms or rain events (personal observations). Also, in some freshwater habitats in our region, purple loosestrife loses most of its leaves with the onset of the first frost (personal observations and communication from Martin Genrich, Washington Department of Fish and Wildlife, Moses Lake, Washington). Our litter bag observations suggest loosestrife leaves are reduced to detrital particles within a month. On the other hand, a significant proportion of dead sedge leaves remain attached to the plant during fall and winter and so continually add to the detritus pool during these seasons (Kistritz et al. 1983). The prolonged residence of sedge leaves, together with their relatively slow degradation rate that we have documented, implies that sedges contribute to the detrital pool during fall and winter.

The problem of seasonal variation in detrital supply for consumer organisms in aquatic ecosystems can result in bottlenecks of growth and survival rates, or both (Richardson 1991). Although invertebrate counts showed that consumer organisms may have used the loosestrife as a food supply, the rapid decay of the loosestrife detritus suggests it is probably not available at an optimum time for invertebrate production in the Fraser estuary. Estuarine invertebrates such as gammarid amphipods reproduce at a maximum rate in late winter (Stanhope and Levings 1985), and it is likely that most loosestrife detritus is totally decomposed by then. For example, of 100 g AFDM left to decompose over 6 mo, only about 10 g would be available. On the other hand, sedge detritus would be available in late winter-early spring when gammarids use the

sedge debris for both protection from desiccation as well as food (Pomeroy and Levings 1980). Moody (1978) also showed that 51% of sedge material placed in litter bags on Roberts Bank, Fraser River Estuary, remained after decomposition between October and January, and the remaining material was heavily colonized by juvenile gammarid amphipods.

The recent invasion of loosestrife in estuaries of the northeast Pacific is a serious management concern for fish and wildlife habitat biologists. For example, the problem is being considered by the Fraser River Estuary Management Program in British Columbia (Adams 1993) and by the Washington State Department of Fish and Wildlife in the Skagit River estuary in Washington (Martin Genrich, Washington Department of Fish and Wildlife, Moses Lake, Washington; personal communication). A survey of the Fraser estuary in 1992 showed that purple loosestrife occurred in 18 out of 54 sites examined (Adams 1993) and most of these sites were in the lower estuary where sedge is the dominant native species. If a major shift in the productivity of native plants relative to purple loosestrife does occur in the wetland vegetation community, as has happened elsewhere (e.g., Malecki et al. 1993; Emery and Perry 1996), it is possible that food chain effects could result from the seasonal difference in detritus provenance that our study has shown. Although many data are available on the biomass of Lyngbyei's sedge in the Fraser estuary (e.g., Kistritz et al. 1983), there is no information available for purple loosestrife to determine the relative productivities of the two plants. For example, data are lacking on the biomass of leaves, stems, and belowground roots of purple loosestrife. This information is needed to more completely assess the impact of this invasive species. In spite of this lack of basic information, concern for encroachment of purple loosestrife into sedge marshes in the estuary has already led to some control initiatives (Adams 1993). Pilot-scale biological control experiments have been conducted as a method to reduce the spread of purple loosestrife, but results are not yet available. Other control strategies such as hand-pulling and flooding have also been suggested and implemented in small areas.

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