Habitat Associations of Vancouver Island Water Shrews in Restored and Natural Stream Habitats

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Abstract: The Vancouver Island water shrew (*Sorex palustris brooksi*)[1] is a rare subspecies found only on Vancouver Island, British Columbia. It is a riparian specialist, specially adapted to a semi-aquatic lifestyle and strongly associated with the land/water interface. Human-related activities on Vancouver Island have resulted in the loss or degradation of habitat for *S. p. brooksi*. Mitigation efforts aimed at stream restoration have focused on improving salmon spawning habitat. It is possible that this habitat might also provide suitable habitat for *S. p. brooksi*. To investigate this, we conducted a small mammal live-trapping study in restored stream habitat near Campbell River (Elk Falls) and in unmodified streams at two other sites on eastern Vancouver Island (Casey Creek and Lowry Creek). In addition, we measured stream and upland habitat characteristics and characterized the aquatic and terrestrial invertebrate communities within different habitat types at the three sites. We also measured habitat variables at other sites on eastern Vancouver Island where *S. p. brooksi* had previously been captured. No *S. p. brooksi* were captured during the study, but terrestrial shrews (*Sorex* spp.) and deer mice (*Peromyscus* spp.) were abundant. Based on analyses of habitat and invertebrate community data, three habitat types—Elk Falls vegetated small channels and river, and Casey Creek vegetated small channels—were similar to unmodified habitats where *S. p. brooksi* had been captured. There are many opportunities to improve existing and future fisheries enhancement projects on Vancouver Island to provide habitat for *S. p. brooksi*, including planting riparian vegetation, providing additional in-stream structure, and improving connectivity between important habitats.

Key Words: Vancouver Island water shrew, common water shrew, *brooksi* subspecies, *Sorex palustris brooksi*, habitat associations, prey, restored streams, British Columbia

Introduction

Riparian areas on Vancouver Island, British Columbia (B.C.) are being subjected to an increasing variety of human-related activities. The most significant of these activities are urban development and industrial forestry. In a survey of 14 second-order streams on Vancouver Island, Reid et al. (1998) reported that 93% showed changes in the riparian zone that were attributable to

[1]The BC Species and Ecosystems Explorer (April 2005) lists this subspecies as the common water shrew, *brooksi* subspecies; NatureServe Explorer (version 4.4, April 2005) lists it as the Vancouver Island water shrew.

upstream forestry or urbanization. In addition, construction of dams and diversion channels has resulted in flooding of 4500 ha of primarily lowland coniferous forest, and flooding and altered water flows along 116 km of streams (BCRP 2000).

The Vancouver Island water shrew (*Sorex palustris brooksi*) is a rare subspecies that is restricted to Vancouver Island (Anderson 1934). It is a habitat specialist, living at the land/water interface in riparian habitat. *S. p. brooksi* is a semi-aquatic species that forages both on land and in freshwater streams. Major threats to the subspecies have been identified as urbanization with resultant loss, degradation, and fragmentation of habitat; forest harvesting with concomitant loss and degradation of habitat; and predation from domestic cats, especially near urban areas (Craig, in press).

There have been extensive efforts by agencies to restore fish habitat in watersheds affected by hydroelectric activities. Available data suggest that *S. p. brooksi* might use habitats that resemble coho spawning and rearing habitat (Craig and Wilson 2001; Craig, in press); therefore, habitat restoration and creation projects for salmonids might also create suitable habitat for *S. p. brooksi*. To investigate this possibility, we conducted a small mammal live-trapping study in restored stream habitat near Campbell River (Elk Falls) and in unmodified streams at two other sites on eastern Vancouver Island (Casey Creek and Lowry Creek). In addition, we measured stream and upland habitat characteristics and characterized the aquatic and terrestrial invertebrate communities within different habitat types at the three sites. We also measured habitat variables at other sites on eastern Vancouver Island where *S. p. brooksi* had previously been captured (C. Lee, pers. comm.; C. Morley, pers. comm.). Specific objectives of this project were to

- determine the habitat association characteristics of *S. p. brooksi* in terms of both broad habitat types and specific habitat elements;
- determine whether *S. p. brooksi* use restored salmonid habitats; and
- identify possible modifications to salmonid habitat restoration projects that could accommodate the habitat requirements of *S. p. brooksi*.

Study Areas

The study focused on three sites where we conducted small mammal trapping: restored salmonid habitat at the Elk Falls III coho spawning channel near Campbell River, and unmodified stream habitat at nearby Casey Creek and at Lowry Creek near Port Alberni (Fig. 1). The Elk Falls III coho spawning channel is a large, easily accessible site with a variety of restored stream habitats and a wetland-swamp complex. Records of *S. p. brooksi* exist from the nearby Quinsam River (Craig, in press). We stratified habitats at the Elk Falls study site into the following four categories:

1. Open channel: restored/created wide channel with little riparian or overstorey cover and slow- and fast-moving watercourses with generally rip-rapped banks. Much of the habitat has steep, high banks covered with grass. Other areas have smaller banks with exposed

cobble. Some downed wood is present in the water, but none crosses the water/land interface. The substrate is generally sand or cobble.

2. River: restored/created wide side-channel of the Campbell River with canopy cover, some understorey cover, and fast-moving water. Banks are dominated by loose cobble and boulders. There is little downed wood in the water, but it is present in the surrounding forest. The substrate is primarily cobble and boulder.
3. Swamp: partly restored wetland-swamp complex with dense riparian understorey and overstorey cover. The water is still or very slow-moving. There is abundant downed wood, and the substrate is muddy.
4. Vegetated small channel: restored, narrow channel with overstorey cover (both shrub and tree) and slow-moving water. There is abundant downed wood, and the substrate is muddy or sand and cobble.

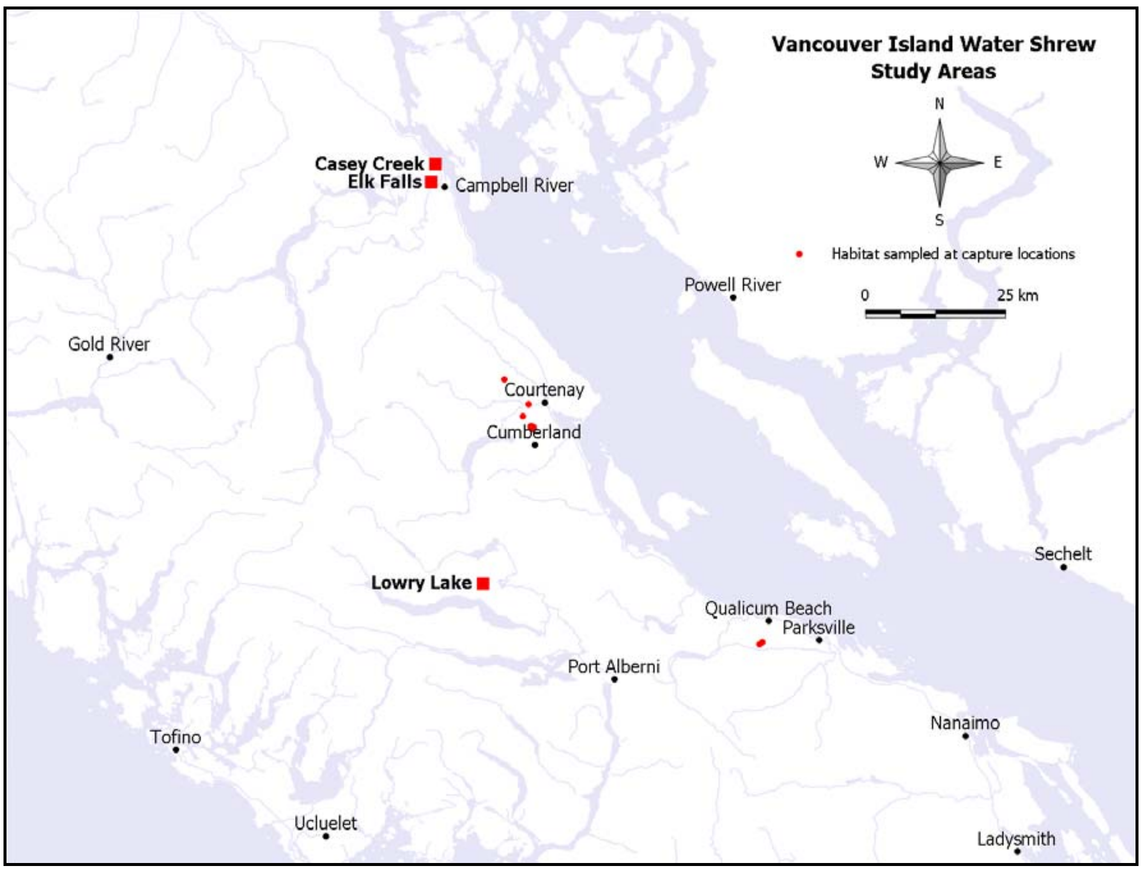

Figure 1. Location of study areas for the Vancouver Island water shrew (*Sorex palustris brooksi*) project. Trapping occurred in restored salmonid habitats at Elk Falls and in unmodified stream habitats in Casey Creek and Lowry Creek. Habitat characteristics were examined at other sites where *S. p. brooksi* had been captured during other studies.

The water levels at Elk Falls are managed for fisheries values with little fluctuation in depth in the main channels. Numerous salmon fry and spawning salmon were present during the study period. In summer, the swamp and one of the smaller channels were dry, due in part to beaver dams. Upland areas are dominated by mature bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), Sitka spruce (*Picea sitchensis*), and western redcedar (*Thuja plicata*). The understorey is dominated by salmonberry (*Rubus spectabilis*), huckleberry (*Vaccinium* spp.), and/or sword fern (*Polystichum munitum*).

The Casey Creek study area, located approximately 4 km northeast of Elk Falls (Fig. 1), is a relatively undisturbed wetland complex with braided streams. Casey Creek flows into the ocean, and the lower reaches are tidal and brackish. Numerous salmon fry were observed in the stream in summer, but no spawning salmon were observed during autumn. We classified the following three habitat types in the Casey Creek study area:

1. Brackish: a well-defined channel with high, steep banks, tidal water fluctuations, and moderate overstorey and understorey cover. The substrate is cobble.
2. Open channel: an open floodplain with forested margins and a meandering and braided (depending on season and water level) watercourse. The watercourse occasionally meanders close to forested habitat. Ground cover consists primarily of grasses and sedges, with some areas of dense salmonberry or skunk cabbage (*Lysichiton americanus*). The substrate is primarily sand and cobble.
3. Vegetated small channel: a well-defined channel with some areas of high, steep banks and moderate understorey and overstorey cover. The substrate is sand or cobble.

Casey Creek water levels are unmanaged, and flows varied considerably between seasons. The location of the watercourse and riparian vegetation changed noticeably each year due to very high water levels during winter and early spring. The upland forest is dominated by bigleaf maple, red alder, and some western hemlock (*Tsuga heterophylla*), and the understorey is fairly dense and dominated by salmonberry.

Lowry Creek, which flows into Lowry Lake in the Ash watershed near Port Alberni (Fig. 1), is an unmodified forested stream where three *S. p. brooksi* were captured in 1996 (Waye 1997). The creek is largely dry in summer, leaving only a few unconnected pools filled with fish fry. The stream is heavily braided in places and is connected during the wet season to many wetland-swampy habitats along its length. The Lowry Creek habitat was classified as ‘vegetated small channel’—narrow channel with overhanging cover, understorey vegetation, and slow-moving water with a cobble and sand substrate. Upland areas are dominated by a mixed forest of red alder, bigleaf maple, and western redcedar. The understorey is dense and dominated by salmonberry with some Douglas maple (*Acer glabrum* var. *douglasii*). Forbs include sword fern, bracken fern (*Pteridium aquilinum* ssp.), and some skunk cabbage.

Methods

Small Mammal Sampling

We established 100 trapping stations spaced 15 m apart at Elk Falls, and 50 trapping stations spaced 15 m apart at Casey Creek. A Longworth-style live trap was placed at the water's edge at each station and was filled with coarse brown cotton and baited with tuna in a small plastic serving cup. Traps were in place and prebaited for one week before trapping commenced to familiarize small mammals with the trap. Trapping began at both study areas during the second week of June 2002. We conducted monthly 3-day trapping sessions at each site until November 2002, resulting in a total of 1800 live trap days at Elk Falls, and 898 at Casey Creek. For the June to October trapping sessions, traps were open for at least 8 daylight hours for 3 consecutive days. During the final trapping session in November, shorter days resulted in traps being open for 7.5 hours. Traps were opened during daylight hours only to reduce the incidental capture of nocturnal species such as deer mice (*Peromyscus* spp.). While open, traps were checked every 4 hours to prevent trap mortalities.

We conducted a 5-day trapping session at Lowry Creek during 19–23 September 2002. The protocol was the same as that used at Elk Falls and Casey Creek, plus we used pitfall traps with drift fences (Hartman 2002). Thirty-three live traps and 10 pitfall traps were installed. We baited traps with tuna, and checked the traps every 4 hours to prevent trap mortalities. Traps were open for 68 hours over 5 days, including two 24-h trapping periods. Several traps (especially pitfalls) were disturbed during the final day of the session, likely by a mink (*Mustela vison*) that we had observed along the stream channel.

We also conducted a final 5-day trapping session at Elk Falls in August 2003 using three different trap types: 68 live traps, 8 pitfall traps, and 27 minnow traps. Traps were open a total of 99 hours (open overnight), resulting in a total of 442 live trap days, 36 pitfall trap days, and 180 minnow trap days. No trapping was conducted in areas without water because there would have been a low likelihood of capturing *S. p. brooksi* in these areas (Hartman 2002).

Hartman (2002) successfully used minnow traps to kill-trap *S. p brooksi*, and minnow traps often kill water shrews accidentally during fisheries research (Craig, in press). We modified our minnow traps to reduce the probability that captured animals would drown. Each trap was equipped with a Styrofoam platform, held in place by two wires such that the platform could move up and down with the water level. The minnow traps were placed in shallow water so that the entrances were underwater but an air space was present at the top of the trap. A plastic cup with tuna was anchored to the platform to provide food for captured animals. Each minnow trap was baited with salmon roe. To provide additional information about potential prey for *S. p. brooksi* in the study area, the contents of each minnow trap were recorded at the final check of the day, after which the trap was emptied.

Habitat Sampling

Data on vegetation, trees, downed wood, and water characteristics were collected at 18 trapping stations at Elk Falls, 9 stations at Casey Creek, and 6 stations at Lowry Creek. Data were also collected at 10 sites on Vancouver Island where water shrews had been previously captured (C. Lee, pers. comm.; C. Morley, pers. comm.).

Data were collected in 5 m x 5 m vegetation plots which had one edge of the plot aligned with the trap location and the rest of the plot extending upslope. The following data were collected at each site: (1) percent canopy cover and dominant species within the canopy, (2) percent cover of mineral soil, (3) percent cover of moss, (4) mean depth of moss (three estimates per quadrat), (5) percent cover of fine litter (three estimates per quadrat), (6) mean depth of the litter layer (three estimates per quadrat), (7) mean cover of herbs (including grasses), (8) mean cover of short shrubs (< 2 m), and (9) mean cover of tall shrubs (> 2 m).

Downed wood was measured along two 20-m transects following Hartman (2002). One transect was placed parallel to the water's edge and extended downstream from the trap site. The other transect was placed perpendicular to the water's edge. Each piece of downed wood ≥ 5 cm diameter that crossed the transect was measured for diameter and was identified to species and decay class following Maser et al. (1979).

The following stream data were recorded at each site: (1) bank full width, (2) wetted width, (3) bank full depth, (4) stream depth measured at five locations across the stream, (5) minimum stream depth, (6) stream flow measured with a flow meter at three locations close to the trap site, (7) stream temperature, (8) substrate size (four samples at each of five locations across the stream), (9) percent cover of short vegetation (< 2 m) at five locations across the stream, (10) percent cover of tall vegetation (> 2 m) at five locations across the stream, and (11) presence/absence of an undercut bank.

Terrestrial and Aquatic Invertebrates

Terrestrial and aquatic invertebrates were sampled at Lowry Creek in late September 2002 and at Elk Falls and Casey Creek in early October 2002. Emphasis was placed on sampling macroinvertebrates that would likely be prey for *S. p. brooksi*.

We sampled terrestrial invertebrates by collecting soil samples and by observing the number of invertebrates visible in a 1 m x 1 m plot at the water's edge. Soil for the samples was dug to approximately a 5-cm depth from at least five randomly chosen points near the trap site. The soil samples also included the litter layer. In the lab, 250 ml of each sample was sorted under a dissecting microscope at 6x magnification. Invertebrates were identified to phylum, class, order, or family, where possible, using up to 50x magnification where necessary. We used Thorp and Covich (2001) for identification keys.

Aquatic invertebrates were sampled at each site using a 1 m x 1 m kick-net with a 2 mm mesh. We disturbed the substratum by hand-rubbing rocks and logs for 2 min, using a garden claw to stir the substrate for 1 min, and then kicking the substrate for 2 min. Where there were no rocks or logs in the plot, the site was disturbed with a garden claw for 3 min followed by 2 min of kicking. Debris captured in the net was stored in 250-ml containers and preserved with 70% ethanol or isopropyl alcohol. In the lab, we subsampled large samples such that a maximum of 250 ml was examined. Samples were sorted under a dissecting microscope at 6x magnification. Invertebrates were identified to order or family, where possible, using up to 50x magnification. During analysis, we adjusted the relative number of individuals for the proportion of the sample examined. Keys used for identification included Macan (1979), Smith (2001), and Thorp and Covich (2001).

Data Analysis

We used multiple logistic regression best subsets analysis (Statistica 1995) to distinguish differences between data from plots where *S. p brooksi* had been captured and where they had not been captured. Percent cover data were arcsine square-root transformed to normalize distributions prior to analysis. We screened variables for multicollinearity and excluded variables that were highly correlated ($r \geq 0.5$). We used Akaike's information criterion adjusted for small sample size (AICc) (Akaike 1985; Burnham and Anderson 1998) to identify models that were best supported by the data. Unlike likelihood ratio testing, AIC allows comparison to be made between non-nested models (Lebreton et al. 1992). Models within 2 ΔAICc of the most parsimonious model were considered to have support (Anderson et al. 1994). Akaike weights were used to identify the relative level of support for the top models (Burnham and Anderson 1998). Overall, model goodness-of-fit was assessed with odds ratios where ratios > 1:1 indicated a result unlikely to occur by chance.

To describe terrestrial and aquatic invertebrate communities by study area and habitat type, we calculated (1) richness (number of families or orders; lower richness suggests poorer water quality), (2) evenness, which reflects how evenly distributed individuals were among the different families/orders, and (3) diversity (a higher diversity index suggests that the community was better balanced) as calculated by the Shannon-Weiner function, which takes into account both community heterogeneity (richness) and evenness (Stirling and Wilsey 2001).

To help characterize the invertebrate community, we calculated an additional three community indices to indicate differences in community structure. The Ephemeroptera (mayflies)/Plecoptera (stoneflies)/Trichoptera (caddisflies) (EPT) complex is considered indicative of relative water quality (Williams and Feltmate 1992). We calculated (1) the number of orders within the EPT complex that were found in each habitat type, (2) the number of families (richness) within the EPT complex that were found in each habitat type (most species in the orders are sensitive to pollution; therefore, lower EPT richness indicates potential environmental stress), and (3) the EPT ratio (number of individuals in EPT complex/EPT complex + number of individuals in Chironomidae), which varies between 0 and 1. Members of EPT are generally considered to be intolerant of poor water quality, while the Family Chironomidae is generally considered to be tolerant of such conditions; therefore, a small EPT ratio might indicate environmental stress.

Results

Small Mammal Sampling

We captured a total of 34 deer mice (*Peromyscus* spp.), terrestrial shrews (*Sorex* spp.), and Townsend's voles (*Microtus townsendii*) at Elk Falls during the six trapping sessions in 2002 (Table 1). At Casey Creek, we captured one terrestrial shrew during the entire trapping period and found another shrew that had built a nest in an open trap (Table 1). We captured 65 deer mice in live traps at Lowry Creek (Table 1). The majority of captures at the Elk Falls study area during the 2003 trapping session were deer mice (89%). One juvenile deer mouse was captured in a minnow trap but was released unharmed. It had eaten some food and had defecated on the Styrofoam platform in the trap, suggesting that our modifications were suitable for small mammals to survive in the traps. We also captured 17 terrestrial shrews, including one in a pitfall trap. No water shrews were captured during any trapping sessions at any of the study sites.

Table 1. Number of small mammal captures by species at Elk Falls, Casey Creek, and Lowry Creek during small mammal trapping in 2002 and 2003. Numbers in parentheses represent the number of individuals captured, where known.

Species	*Number of captures*			
	Elk Falls		*Casey Creek*	*Lowry Creek*
	2002	*2003*	*2002*	*2002*
Deer mouse (*Peromyscus* spp.)	16*	142*	0	65*
Terrestrial shrews (*Sorex* spp.)	17 (14)	17*	2 (2)	0
Townsend's vole (*Microtus townsendii*)	1	1	0	0

* Individuals were not marked; therefore, number of captures represents an unknown number of individuals.

Terrestrial and Aquatic Habitat Characteristics

We omitted the variables percent cover of fine debris, percent canopy cover, percent cover of short shrubs, distance to the closest piece of downed wood, and diameter of the closest piece of downed wood in our analysis of terrestrial habitat data because they were highly correlated with other variables. Based on the best-supported models, *S. p. brooksi* terrestrial capture locations had less ground cover of moss, less grass cover, more and longer pieces of downed wood along the transect, more exposed mineral soil, and greater cover of tall shrubs than locations where *S. p.*

brooksi had not been captured (df = 39, -2LL = 31.8, χ^2 = 24.98, $P < 0.001$; Table 2). The top model identified moss cover, grass cover, and the number of pieces of downed wood crossed by the perpendicular transect as important variables in distinguishing locations where *S. p. brooksi* had been captured from those where they had not been captured. The best supported model correctly classified 80% of capture locations and 84% of noncapture locations (odds ratio 1:24).

Table 2. Results of model selection using logistic regression analysis to distinguish upland habitat at locations where *S. p. brooksi* were captured from locations where they were not captured. Models < 2 ΔAICc of the top model are included. The direction of the relationship with respect to successful trap sites is indicated by a '+' or '-' sign.

Variables	*Model*	*AICc*	*ΔAICc*	*Akaike weight*	*Relative support*
% moss cover (-), % grass cover (-), # pieces DW* (perpendicular) (+)	1	40.43	0	0.20	1
% mineral soil cover (+), % moss cover (-), % grass cover (-), % tall shrub cover (+), DW length (+), # pieces DW (perpendicular) (+)	2	40.72	0.29	0.17	1.16
% mineral soil cover (+), % moss cover (-), % grass cover (-), DW length (+), # pieces DW (perpendicular) (+)	3	40.76	0.33	0.17	1.18
% moss cover (-), % grass cover (-), DW length (+), # pieces DW (perpendicular) (+)	4	41.09	0.66	0.14	1.39
% moss cover (-), % grass cover (-), % tall shrub cover (+), # pieces DW (perpendicular) (+)	5	41.31	0.88	0.13	1.55
% mineral soil cover (+), % moss cover (-), % grass cover (-), % tall shrub cover (+), # pieces DW (perpendicular) (+)	6	41.93	1.50	0.09	2.12

*DW: downed wood

We omitted wetted width and average stream depth from analyses of aquatic habitat characteristics because they were highly correlated with other variables. The top model had more than twice the support of any subsequent model. Based on the top model, water shrew capture locations had shallower minimum stream depths and greater cover of tall shrubs (> 2 m tall) than areas where water shrews had not been captured (df = 32, -2LL = 32.1, χ^2 = 9.75, $P < 0.025$) (Table 3). The next two models that had support (ΔAICc < 2) also identified minimum stream depth and tall shrub cover as important variables. An all-effects model using the two variables identified in the top model correctly classified 75% of successful trap sites and 85% of unsuccessful trap sites with an odds ratio of 1:17.3.

Table 3. Results of model selection using logistic regression analysis to distinguish aquatic habitat at locations where *S. p. brooksi* were captured from locations where they were not captured. Models < 2 ΔAICc of the top model are included. Models within 2 ΔAICc of the top model are included. The direction of the relationship with respect to successful trap sites is indicated by a '+' or '-' sign.

Variables	*Model*	*AICc*	*ΔAICc*	*Akaike weight*	*Relative support*
Minimum stream depth (-), % tall shrub cover (+)	1	38.57	0	0.55	1
Full bank depth (+), minimum stream depth (-), % tall shrub cover (+)	2	40.31	1.74	0.23	2.38
Minimum stream depth (-), average substrate size (-), % tall shrub cover (+)	3	40.40	1.83	0.22	2.50

Terrestrial Invertebrate Community

The most common terrestrial invertebrates were nematodes (Phylum Nematoda), mites (Order Acari), and earthworms (Class Oligochaeta). Snails (Class Gastropoda), sowbugs (Order Isopoda), spiders (Class Arachnida), and slugs (Class Gastropoda) were also common. In general, these groups were commonly found at all of the sampling sites. Individuals of the Orders Heteroptera and Coleoptera were identified only in Elk Falls river habitat. Nematodes were most abundant at Lowry Creek. Mites were most abundant in vegetated small channel habitat at Elk Falls, Casey Creek, and Lowry Creek, and in Casey Creek open channel habitat. Individuals of the Order Symphyla were identified only from Elk Falls open channel and swamp habitat. Terrestrial snails were most abundant in Elk Falls river habitat and Lowry Creek vegetated small channel habitat.

Among habitat types, richness was highest along small channels with high percent cover of vegetation followed by open channel habitat (Table 4). Lowest richness was recorded at the site with brackish water. Diversity did not follow the same pattern; notably, vegetated small channels had the lowest diversity, indicating that the community with the highest richness was dominated by one or more invertebrate orders. The most diverse community was found along the river habitat. Although the number of different orders present in river habitat was only approximately half that found along vegetated small channels, invertebrates were fairly well-distributed among the 14 groups identified, resulting in high diversity.

Table 4. Indices of richness and diversity for terrestrial invertebrates by habitat type among the Elk Falls (EF), Casey Creek (CC), and Lowry Creek (LC) study areas.

	Broad habitat types				
	brackish	*vegetated small channel*	*open channel*	*river*	*swamp*
Richness	5	27	23	14	12
Diversity	1.4	1.3	1.5	2.0	1.7
Maximum diversity	1.6	3.3	3.1	2.6	2.5
Evenness	0.9	0.4	0.5	0.8	0.7
n	1	15	10	3	4

	Habitat types by study area							
	brackish	*vegetated small channel*			*open channel*		*river*	*swamp*
	CC	CC	EF	LC	CC	EF	EF	EF
Richness	5	15	13	21	7	16	14	12
Diversity	1.4	1.5	1.8	1.2	1.0	2.1	2.0	1.7
Maximum diversity	1.6	2.7	2.6	3.0	1.9	2.8	2.6	2.5
Evenness	0.9	0.5	0.7	0.4	0.5	0.7	0.8	0.7
Mean abundance	23.0	26.1	19.4	116.0	31.5	11.5	23.7	14.5
Mean abundance without nematodes	17.0	11.2	14.6	38.2	9.3	8.2	23.3	9.5
n	1	4	5	6	4	6	3	4

The richness and diversity values associated with habitat types were variable among study areas (Table 4). The vegetated small channel habitat at the Lowry Creek site had greater richness but lower diversity than either the Casey Creek or Elk Falls sites, which were similar to each other. Elk Falls open channel habitat had higher richness and diversity than that of Casey Creek. Lowry Creek had more than four times the abundance of insects as the next highest study site-habitat type combination. Lowest invertebrate abundance was recorded at Elk Falls open channel habitat and Elk Falls swamp habitat. Overall, the Elk Falls study area had the three lowest estimates of mean invertebrate abundance. When excluding nematodes from the sample (although a dominant group, they may not be an important prey of *S. palustris* [Whitaker and Schmeltz 1973; Whitaker and French 1984]), mean invertebrate abundance at Lowry Creek was still the highest.

Aquatic Invertebrate Community

Many invertebrate groups such as Order Diptera/Family Chironomidae, Order Trichoptera/Family Lepidostomatidae, Phylum Nematoda, Class Oligochaeta, and Class Gastropoda/Family Planorbidae were identified at numerous sites (i.e., they were not specific to an individual study site). Individuals of Order Amphipoda/Family Gammaridae and Order Isopoda were found only in Casey Creek brackish habitat. Lowry Creek stream habitat was characterized by greater numbers of individuals and greater numbers of samples containing specimens of Phylum Nematomorpha, Order Ephemeroptera/Family Siphlonuridae, Order Diptera/Families Tipulidae and Ceratopogoninae, Order Plecoptera/Family Leuctridae, and Order Trichoptera/Family Leptophlebiidae than other habitat types. Lowry Creek was the only location where Order Trichoptera/Families Limnephilidae and Rhyacophilidae, Order Hirudinea, and Order Diptera/Family Simuliidae were collected. The invertebrate communities in Casey Creek and Elk Falls vegetated small channel habitat, Elk Falls swamp habitat, Elk Falls river habitat, and Casey Creek and Elk Falls open channel habitat were dominated by Order Diptera/Family Chironimidae, Phylum Nematoda, and Class Oligochaeta. At Elk Falls open channel habitat, there were also numerous representatives of Order Trichoptera/Family Hydropsychidae. Order Pelecypoda/Family Sphaeriidae occurred in Casey Creek open channel habitat.

Richness was greater in aquatic invertebrate communities along vegetated small channels (Table 5) than in other habitat types. Diversity was similar in aquatic invertebrate communities in vegetated small channels and open channel habitat. Aquatic invertebrate communities in river habitat were also quite diverse.

Table 5. Indices of richness and diversity for aquatic invertebrates by habitat type among the Elk Falls (EF), Casey Creek (CC), and Lowry Creek (LC) study areas.

	Broad habitat types				
	brackish	*vegetated small channel*	*open channel*	*river*	*swamp*
Richness	7	35	25	11	6
Diversity	1.0	2.4	2.3	2.0	1.6
Maximum diversity	1.9	3.6	3.2	2.4	1.8
Evenness	0.5	0.7	0.7	0.9	0.9
n	1	13	10	3	2

Table 5. Indices of richness and diversity for aquatic invertebrates by habitat type among the Elk Falls (EF), Casey Creek (CC), and Lowry Creek (LC) study areas (cont'd).

	Habitat types by study area							
	brackish	*vegetated small channel*			*open channel*		*river*	*swamp*
	CC	CC	EF	LC	CC	EF	EF	EF
Richness	7	19	16	23	14	20	11	6
Diversity	1.0	1.5	2.1	2.3	1.8	2.1	2.0	1.6
Maximum diversity	1.9	2.9	2.8	3.1	2.6	3.0	2.4	1.8
Evenness	0.5	0.5	0.8	0.7	0.7	0.7	0.9	0.9
EPT* Orders	0	3	3	3	2	2	1	0
EPT richness	0	10	7	9	3	5	5	0
EPT ratio	0	0.12	0.72	0.47	0.12	0.59	0.59	0
Mean abundance	227.5	74.6	34.7	52.3	66.6	58.7	53.3	15.1
n	1	4	3	6	4	6	3	2

*EPT: Ephemeroptera/Plecoptera/Trichoptera complex

There were some differences in richness and diversity within habitat types among study areas (Table 5). The vegetated small channels of Lowry Creek had the greatest aquatic invertebrate richness and diversity. The same habitat at Elk Falls had the lowest richness but a similar diversity index to Lowry Creek. For open channel habitat, Elk Falls had higher richness and diversity of aquatic invertebrate communities than Casey Creek. Casey Creek habitats had the highest mean aquatic invertebrate abundance, which was dominated by *Gammarus* spp. Elk Falls swamp habitat had less than half the mean abundance of the next least abundant site.

When assessing the presence and abundance of the group most sensitive to water quality—the EPT complex—only small vegetated channel habitat had representatives from all three orders. Open channel habitat was missing representatives from Ephemeroptera, and river habitat contained only specimens from Trichoptera. Casey Creek brackish habitat and Elk Falls swamp habitat did not contain any representatives from these three orders. Casey Creek was dominated by Chironomidae (indicated by low EPT ratio) in both vegetated small and open channel habitat; Lowry Creek and Elk Falls had a more favorable ratio.

Other Potential Aquatic Prey

Minnow traps at Elk Falls captured fish fry, amphibian larvae, aquatic snails, and crayfish, all of which are potential prey for *S. p. brooksi* (Conaway 1952; Beneski and Stinson 1987). Crayfish were captured primarily in river and open channel habitat at Elk Falls. Amphibian larvae (northwestern salamanders, [*Ambystoma gracile*]) were typically captured in swamp and vegetated small channel habitat.

Discussion

Small Mammal Sampling

We did not capture *S. p. brooksi* during any of the trapping sessions at Elk Falls or Casey Creek. There are three possible explanations for this: (1) the trapping regime (type of traps or trapping effort) was unsuitable, (2) *S. p. brooksi* were not present at the site during the seasons or years when we were trapping, or (3) *S. p. brooksi* did not occur at the sites. We also did not capture *S. p. brooksi* at Lowry Creek despite using the same trapping protocol that was previously successful at the site (Hartman 2002). There are two possible explanations for this: (1) *S. p. brooksi* were locally extirpated from the creek after Hartman's (2002) study, or (2) the presence of *S. p. brooksi* along Lowry Creek naturally varies among seasons or years, similar to that suggested by Greenwood et al. (2002) for the European water shrew (*Neomys fodiens*).

We used mainly live traps for trapping, which were simpler to install and to maintain than pitfall or minnow traps, and which could be filled with bedding and food to reduce stress on captured animals. Elsewhere, live traps have been reported to be very successful at capturing *S. palustris*. D. Rubbelke (pers. comm.) reported a trapping success rate of 25 trap nights/shrew for live traps used in a study conducted in Minnesota. Hartman (2002) captured 14 *S. p. brooksi* at a variety of sites using pitfall and minnow traps. At least 20 other captures of Vancouver Island water shrews in minnow traps have also been reported (Craig, in press). Hartman (2002) reported a short latency to detection of *S. p. brooksi* in pitfalls of 1–4 days, and a capture success rate of 39 trap nights/shrew. Minnow traps were used at high densities for 1–3 nights, latency to detection was 1–2 days, and the capture success rate was 162 trap nights/shrew. In contrast, Kerridge (1994) did not capture any *S. p. brooksi* at 10 sites using snap traps, pitfall traps, Sherman live traps, and Longworth live traps for a total of 1191 trap nights. Also, Waye (1997) used pitfall, minnow, and snap traps, and captured three *S. p. brooksi* at one site—two *S. p. brooksi* were captured in pitfall traps; the third was possibly killed by a snap trap as it was found floating dead beside a sprung snap trap. The resulting success rate in this study was 1831 trap nights/shrew. Waye's (1997) methodology, which included placing traps 1 m from the land/water interface, was less efficient than that used by Hartman (2002). Based on other studies, our trapping intensity was adequate to capture any *S. p. brooksi* that might have been present. Looking at overall success rates, we were above the trap-night average required to capture 1–2 shrews in pitfall and minnow traps. When looking at the relatively short latency to detection in Hartman's (2002) study, our trapping period was longer than that required in areas where Hartman (2002) had successfully captured *S. p. brooksi*.

Shrews are considered to be crepuscular (i.e., most active at dawn and dusk) (Sorenson 1962). During the trapping season in 2002, traps were open only during daylight hours, although setting often began before sunrise and the final check was often completed after dusk, particularly during autumn. Shrews can starve to death if they go without food for 2–3 hours (Sullivan and

Sullivan 1982; Churchfield 1990), suggesting that they must be active throughout the day and night. In addition, both Conaway (1952) and Sorenson (1962) reported that captive *S. palustris* were active during the day. Craig (In press) documented several sightings of *S. p. brooksi* during the day, and Conaway (1952) recounted several instances where he saw active wild *S. palustris* during daylight hours. Previous studies of terrestrial shrews (Hawes 1975; Craig 1995) have also used daylight trapping sessions. At Lowry Creek in 2002 and Elk Falls in 2003, we also conducted nighttime trapping, and again did not capture any *S. p. brooksi*. This suggests that the daytime trapping protocol was not responsible for the lack of *S. p. brooksi* captures.

Greenwood et al. (2002) suggested that their failure to find sign of European water shrews at previous known localities might be due to natural seasonal/yearly fluctuations. This might be the reason why we failed to capture *S. p brooksi* at Lowry Creek, which was sampled for only one week in early autumn. This explanation is less likely for Elk Falls and Casey Creek, which were sampled during spring, summer, and autumn in 2002. We also sampled Elk Falls during autumn 2003.

Overall, we are confident that the trapping methodology we used, especially when supplemented by overnight trap checks and pitfall and minnow traps, was adequate to determine whether *S. p. brooksi* was present at the Elk Falls and Casey Creek study areas. It is not possible to state definitely that *S. p. brooksi* are not present at Elk Falls and Casey Creek; however, our data suggest that either they are not present or are transient to the areas, or that they occur in extremely low densities.

Upland Habitat Characteristics

The data analysis identified successful trap sites as having lower percent cover of grass and herbs and greater percent cover of tall shrubs than unsuccessful trap sites. French et al. (2001) reported that European water shrews, which have similar life-history characteristics to *S. p. brooksi*, also avoid grassy habitat. Clark (1973) reported that *S. palustris* is most common in habitats with at least 75% vegetation ground cover. Our habitat data set from unsuccessful trap sites was heavily influenced by Elk Falls and Casey Creek open channel habitat, which were grassy and had little or no canopy cover and low shrub cover. The identification of grass as an important component of unsuccessful trap sites likely reflects the preference of *S. p. brooksi* for forested habitat.

Canopy cover was excluded from the analysis because it had a high negative correlation with grass cover; however, examination of means indicated that successful trap sites tended to have greater canopy cover than unsuccessful trap sites (> 1.5 SE difference between means). A similar result was reported for the European water shrew; no sign of shrews was discovered in areas without trees (Greenwood et al. 2002). Our model also identified unsuccessful trap sites as having greater moss cover than successful trap sites. This occurred even though moss cover was negatively correlated with grass cover and was positively correlated with shrub cover and canopy cover (weakly). This reflected the relatively high moss cover (7–9%) in Elk Falls river and swamp habitat, and Casey Creek vegetated small channel habitat.

The analysis identified a positive association between successful trap sites and higher volumes of downed wood. This likely reflects the generally greater amount of downed wood associated with successful trap sites in forested habitat. Terrestrial shrews travel beside downed wood (Craig 1995) and inside tunnels in the wood that are created by larger species of small mammals (Terry 1981). Shrews, like other small mammals, are potential prey for a variety of predators (Henttonen 1985; Churchfield 1990); consequently, they rely on cover to protect them while traveling (McLeod 1966; Craig 1995). Downed wood provides protected travel corridors (Hayes and Cross 1987). Decayed logs also serve as nesting and foraging habitat for shrews (*S. palustris*) (Thomas 1979); as logs decay, they provide habitat for different communities of invertebrates (Maser and Trappe 1984; Harmon et al. 1986). Shrews also forage in the open and then use logs to cache or consume prey in safety (McLeod 1966; Yoshino and Abe 1984). Downed wood in water provides habitat for aquatic invertebrates (Harmon et al. 1986; Sedell et al. 1988; Scherer 2004). For water shrews, downed wood provides a physical connection between aquatic and upland habitats. Especially in areas with steep banks, sudden drop-offs, or deep water, downed wood may be very important to *S. p. brooksi's* ability to move in and out of water.

Our analysis of habitat characteristics agrees with that of Waye (1997) and Hartman (2002), who both reported on the only other study of *S. p. brooksi* in which habitat data were collected. Hartman (2002) found that *S. p. brooksi* were captured in young and old forests at elevations from sea level to 320 m. Craig (In press) summarized available data from various sources, including descriptions of other capture locations, and concluded that *S. p. brooksi* were captured in a variety of forested conditions except for clearcuts. *S. p. brooksi* have also been captured in nonforested marsh-type habitat where sedges were the dominant vegetation and little or no grass was present (C. Lee, pers. comm.; C. Morley, pers. comm.).

Stream Habitat Characteristics

The habitat characteristic most strongly associated with successful trap sites was the percent stream cover by tall shrubs (> 2 m). The presence of shrub cover overhanging streams would be most influential on small waterways and could provide high levels of organic input (leaves) that would support aquatic invertebrate foraging (Minshall 1967). In addition, the presence of overhanging vegetation is important for regulating water temperature (Noel et al. 1986).

Successful trap sites were also more likely to be in areas with shallower water. Although *S. palustris* has been reported to sustain (forced) dives for up to 47 s (Calder 1969), it is unknown how deep the shrews will dive. European water shrews can dive to a depth of 2 m (Greenwood et al. 2002).

All of the stream channels that we visited where *S. p. brooksi* were previously captured were dry or dominated by small standing pools of water in mid-summer; therefore, it appears that a permanent watercourse is not a required habitat element for this subspecies. Kinsella (1967) also reported that *S. palustris* uses seasonal streams; however, it is unknown how far water shrews can move from permanent watercourses.

Hartman (2002) reported that *S. p. brooksi* were captured in stream habitats that represented a wide range of stream widths, flow rates, depths, and substrates. Based on previous work, Craig (In press) concluded that high quality habitat for *S. p. brooksi* includes intact riparian systems with cobble or gravel streambeds, abundant in-stream downed wood, and dense riparian vegetation.

Areas at Elk Falls (primarily swamp and vegetated small channel habitat and, to a lesser extent, river habitat), and some areas at Casey Creek (vegetated small channel habitat) appeared to be suitable for *S. p. brooksi* based on upland and stream habitat characteristics. These areas are apparently rich growing sites with abundant shrub cover, canopy cover, and downed wood. Similarly, the watercourses appeared suitable in that they had mainly slow-moving water (except for river habitat) and overhanging vegetation, and a substrate that generally consisted of sand/gravel or small cobble.

Terrestrial Invertebrate Community

Smaller shrew species (< 8 g), such as *S. vagrans* and *S. monticolus*, have smaller, less powerful jaws than larger shrew species and are not strong diggers (Terry 1981). As a result, these species are primarily surface foragers (Churchfield and Sheftel 1994). Their diet is composed mainly of surface-dwelling invertebrates, (84–86%), with soil-dwelling invertebrates comprising much lower proportions (8–12%) (Churchfield and Sheftel 1994). Most prey taken are 3–10 mm long (Churchfield 1990). Larger shrews, such as *S. p. brooksi*, would be expected to have a broader diet but likely forage more on surface-dwelling invertebrates than on soil-dwelling species. The terrestrial diet of *S. palustris* consists of insect larvae, spiders, slugs, snails, and flies (Whitaker and French 1984). In one study, as much as 50% of the diet was made up of slugs and earthworms (Whitaker and Schmeltz 1973). Another study reported that 19% of the diet was composed of slugs and snails (Whitaker and French 1984).

In general, we found the dominant groups of terrestrial invertebrates to be fairly similar among all habitat types. Earthworms, slugs, and snails, which are important as potential food for *S. p. brooksi*, were found in similar abundance among all habitat types. Other potential prey were found primarily in Elk Falls river habitat, which had bug and beetle larvae and abundant terrestrial snails. Additionally, Lowry Creek had abundant terrestrial snails, and Elk Falls open channel and swamp habitat had individuals from the Order Symphyla (garden centipede).

The Lowry Creek study area had higher overall abundance of terrestrial invertebrates/sample and a higher richness value than any other study area. The lower diversity value of the Lowry Creek community reflected the dominance of nematodes in the community (an average of 79/sample); however, even when nematodes were removed from the count, mean invertebrate abundance was still > 1.5 times the mean abundance in the next most populous sample (Elk Falls river habitat with nematodes excluded).

Terrestrial invertebrates typically are abundant and fill a variety of ecological roles. Land uses such as forestry (Fuchs et al. 2003) and livestock grazing (Abbott et al. 1979), and habitat fragmentation (Bromham et al. 1999) can influence the abundance and richness of terrestrial invertebrates. The diversity of the invertebrate community is influenced by the amount and characteristics of the vegetation and litter layers (Ehrlich and Murphy 1987). Insects may be more numerous on moist, nutrient-rich sites (Shvarts and Demin 1994). A site with more vegetation and vegetation layers likely has more niches available for insects. Conversely, disturbance of the vegetation or litter layer may result in a less diverse and less abundant invertebrate assemblage (Bromham et al. 1999). Mean overall abundance (excluding nematodes) was lowest in habitat with little vegetation cover (Elk Falls and Casey Creek open channel habitat), and in habitat that had a silt/mud substrate (Elk Falls swamp habitat). Overall, these results suggest that the upland habitat at Lowry Creek area had better potential foraging habitat for *S. p. brooksi* than habitat at either Elk Falls or Casey Creek. The terrestrial invertebrate communities in the Elk Falls and Casey Creek vegetated small channel habitat and the Casey Creek open channel habitat were most similar to that at Lowry Creek.

Aquatic Invertebrate Community

Our results regarding aquatic invertebrate communities must be interpreted cautiously because we collected only one sample at each plot location (although multiple samples were collected per habitat type) in one season of one year. Because of this we were unable to address sample variation (Clarke et al. 2002).

Aquatic insects and other aquatic organisms are an important component of the diet of *S. palustris*. Previous work reported that 49% of *S. palustris* stomachs examined contained aquatic invertebrates (Conaway 1952). Common insects in the diet include members of the Orders Plecoptera, Ephemeroptera, and Trichoptera, as well as tipulid larvae and other Dipterans (Beneski and Stinson 1987). Other aquatic organisms found in the diet of *S. palustris* include leeches, fish, salamander larvae, and fish eggs (van Zyll de Jong 1983; Beneski and Stinson 1987).

Aquatic invertebrate communities are affected by both water quality and substrate quality (Courtney and Clements 2002). Benthic invertebrate communities can be influenced by substratum (particle size, roughness, texture, interstitial spaces) (Crosa and Buffagni 2002); therefore, sampling aquatic invertebrates provides information on both site condition and potential habitat quality for *S. p. brooksi*.

No studies have been conducted on the relationship between water quality and *S. p. brooksi* presence, but we assumed that this subspecies is less likely to be present in areas of poor water quality. The relationship between water quality and species presence has been described for the European water shrew (Greenwood et al. 2002).

All habitats except for Elk Falls swamp habitat had a similar abundance of aquatic macroinvertebrate potential prey. The very low richness, mean abundance, and EPT ratio for swamp habitat indicate that the site would likely not provide suitable habitat for *S. p. brooksi*. Caution must be used, however, in interpreting the EPT ratio because it can, in some cases, be a misleading indicator of water quality. The ratio uses an average tolerance assumption for families, but there may be different tolerances at the genus level (Lenat 1993). In particular, some species of Order Ephemeroptera show greater tolerance to environmental degradation than others—a distinction that may be masked at the family level (Davis et al. 2003). In this case, the complete lack of representatives from any of the groups is a clear indication of compromised water quality.

Although Casey Creek brackish habitat had high abundance of sampled aquatic invertebrates, it was dominated by *Gammarus* spp., which has been reported as a prey group for the European water shrew (Greenwood et al. 2002), but is not known as being prey for *S. palustris* (Beneski and Stinson 1987). Not surprisingly, no members of the EPT complex were present in brackish habitat. It is unknown whether *S. p. brooksi* will use brackish habitat, but based on previous diet and habitat use studies, it is unlikely.

In general, the vegetated small channel habitats, especially at Lowry Creek and Elk Falls, tended to have high richness and diversity of aquatic invertebrates. In addition, these were the habitats that had representatives from each of the sensitive Ephemeroptera/Plecoptera/Trichoptera Orders. There was some indication that Casey Creek vegetated small channel habitat was slightly compromised in that it had a relatively lower diversity index and lower EPT ratio than the other study areas; however, the relatively high mean abundance of invertebrates and the presence of all three orders of the EPT complex suggest that Casey Creek vegetated small channel habitat would still provide suitable aquatic habitat for *S. p. brooksi*.

Overall, Lowry Creek provided the best potential aquatic foraging habitat for *S. p. brooksi*. The high richness and diversity indices, the presence of representatives of all three orders in the EPT complex, the moderate EPT ratio, and the overall invertebrate abundance suggested that the aquatic invertebrate community was intact and diverse; however, the creek partially dries in the summer and so might be expected to have lower dissolved oxygen conditions, which would negatively affect aquatic organisms (Smock and Gilinsky 1992). The potential environmental stress in this system is suggested by its slightly lower EPT ratio (more Chironomidae). Other habitats appeared to follow a continuum of potential aquatic suitability.

Conclusions

Overall, the restored Elk Falls study area was comprised of four distinct habitat types, but only two are likely to provide suitable habitat for *S. p. brooksi*: vegetated small channel habitat and river habitat. Both of these habitats had suitable vegetation cover and stream characteristics and suitable terrestrial and aquatic invertebrate communities. At the unmodified Casey Creek study area, the vegetated small channel habitat might also provide suitable habitat for *S. p. brooksi*, but it is unlikely that open channel or brackish habitat would do so.

At both the Elk Falls and Casey Creek study areas, suitable habitat was generally found along short stream segments. The home ranges of water shrews are likely comprised of long linear bands that follow the water's edge (Beneski and Stinson 1987), similar to those reported for the European water shrew (Churchfield 1990). Buckner and Ray (1968) estimated the home range of *S. palustris* in a bog in Manitoba to be 0.2–0.3 ha. Based on this estimate, and if home range width is assumed to be 10–25 m, then home range length would be 100–300 m. Thomas (1979) suggested that a viable population of *S. palustris* would require a minimum of 1600 m of linear stream habitat. The absence of *S. p. brooksi* (or their presence at the site in very low densities) might be the result of insufficient habitat quantity rather than quality.

Management Recommendations

The most practical way to enhance habitat for *S. p. brooksi* on Vancouver Island is to consider this species in the design of fisheries enhancement projects. The focus of these projects is on improving in-stream conditions to provide suitable habitat for fish. Creation or enhancement of habitat for *S. p. brooksi* can be incorporated into these projects by expanding the scope of the project to include some of the adjacent riparian area. Overall, an intact healthy riparian system is the best habitat for *S. p. brooksi*. Specific enhancements that can be made include the following:

- Plant riparian vegetation and place downed wood such that connections are made to suitable nearby habitats (wetlands, seepages, small tributaries, braided channel).
- Place downed wood across the land/water boundary to provide travel routes.
- Use downed wood and rocks to create small pools < 1 m deep that can provide foraging habitat.
- Use gravel or cobble substrate. This is typically placed in spawning areas but could be used elsewhere.
- Connect wet depressions adjacent to the channel, and plant riparian vegetation throughout.
- Focus efforts within 30–50 m of the channel, and plant advanced stock native vegetation where necessary to encourage dense undergrowth.

- Avoid using grass seed mixture to stabilize slopes; plant riparian vegetation instead. Where grass seed must be used, combine it with riparian vegetation plantings to avoid creating grassy slope conditions where riparian vegetation is slow to develop.
- Avoid the use of rip-rap, which creates an artificial substrate that might not be suitable for *S. p. brooksi*. In most cases, enhancement projects will not occur in habitats where rip-rap is necessary; however, where it is being considered, investigate the possibility of creating a more natural stream condition by using alternate methods (Gillilan 1996).
- Emphasize connectivity of the created/restored habitat with existing suitable habitat. This can be accomplished by planting vegetation or placing downed wood to create movement corridors.
- Rehabilitate/enhance any degraded habitat along waterways that are connected to the enhancement project. Try to ensure that at least 2 km of contiguous suitable habitat is present.
- Note the location and condition of potential barriers to small mammal movement (e.g., culverts, roads [Yanes et al. 1995; Trombulak and Frissell 2000; Clevenger et al. 2001]). Where new crossings are being planned, consider using bridges with a widely-spaced footprint to limit the amount of rip-rap required to prevent scouring, large open-bottomed pipe arch culverts, or large box culverts. Wherever possible, use natural substrate through the crossing, and plant vegetation on either side of bridges or culverts to increase the likelihood that water shrews will use them.
- Some barriers to fish passage (e.g., beaver dams, downed wood) are not barriers to water shrews. These structures might create suitable water shrew habitat by flooding areas and creating shallow pools. When removing these structures from streams to enhance fish habitat, be aware that this might degrade habitat for *S. p. brooksi*. Where possible, compensate for this loss of habitat by retaining some structures, connecting the habitat with alternate suitable habitat, or creating alternate habitat such as a side-channel.

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