Improving Livetrapping Methods for Shrews (Sorex spp.)

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Abstract

Known for their high metabolism, shrews possess an incessant need to eat high quality foods. This drives much of the biology of shrews and has caused great difficulties when attempting to study shrews using mark-recapture methods. I reviewed the literature and identified potential causes of varied trappability in small mammals. Weather related factors were important in determining activity levels and thus trappability. Social relationships (both inter- and intraspecific) were found to contribute to trappability, in some cases with dominant individuals completely excluding subordinates from traps. Trap type was the easiest factor for a researcher to vary, and thus received most of the attention in the published literature. Sherman, pitfall, and Longworth traps were commonly used, and although pitfall traps are commonly used as removal traps, there is the potential for their use as live traps. The pitfall and Longworth traps seemed the most appropriate for capture of particularly small mammals, especially shrews; however comparisons between these three trap types were confounded by differing methods used for each trap type, and small sample sizes. I tested the relative efficiencies of pitfall and Longworth traps for livetrapping vagrant shrews (Sorex vagrans), and found the Longworth trap to be much more efficient, capturing up to five times as many individual shrews as pitfall traps. I also tested the utility of addition of mealworms as food for shrews, and the effect of increased trap check frequency on the trap mortality rates of vagrant shrews. The addition of mealworms significantly reduced mortality rates, and the addition of one midday trap check, so that traps were not left open for more than 8 h, reduced overall trap mortality rates in mealworm baited traps from nearly 60% (in nonmealworm baited traps, checked at 12 h intervals) to less than 10%. Finally, I tested the

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effect of drift-fences on capture rates of shrews in pitfall and Longworth live traps on riparian and upland traplines. I found no significant differences between the trap types, or between traps equipped with drift-fences, and those without. However, any effect would have been masked by overall low trap success during this experiment.

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Chapter 1 General Introduction and Species Biology

Shrew Taxonomy and Distribution

Shrews, in general, are very small mammals. Including the minute Etruscan shrew (Suncus etruscus), which has a total length of 35 mm and an adult body weight of 2 g (Churchfield 1990), shrews are among the smallest species within the Class Mammalia. Shrews are included in the Order Insectivora, which also includes hedgehogs, moles, solenodons, and tenerecs. Although some species groups are commonly called shrews (e.g. tree shrews, elephant shrews), the true shrews all fall within the Family Soricidae. Within the Soricidae, there are two Subfamilies, the Crocidurinae (white toothed shrews), and the Soricinae (red toothed shrews). The Crocidurinae are entirely old world in their distribution, and although some species are palaearctic, the majority are tropical species (Churchfield 1990). Although the classification of shrews will certainly change as new genetic information becomes available, there are currently four extant tribes recognized within the Soricinae: the Soricini, Blarini, Neomyini, and Notiosorcini (Ohdachi et al. 2006). The Subfamily Soricinae occurs in North and Central America, Europe, and Asia (except the Middle East) (Churchfield 1990). The genus Sorex is of holarctic distribution, is the second largest genus within the Soricidae following Crocidura, and is one of the more well studied genera (a particularly well studied shrew is the common shrew, S. araneus). In North America, there are 33 species of shrews (Churchfield 1990), of which 27 are in the genus Sorex. There are approximately 20 species of shrews in Canada, including Blarina brevicauda, Cryptotis parva, and 18 species of Sorex, of which 12 are found in British Columbia. The 12 species of Sorex that occur in British Columbia

include three that are found nowhere else in Canada; the Pacific water shrew (*S. bendirii*), Preble's shrew (*S. preblei*), and Merriam's shrew (*S. merriami*).

Shrews and Rodents

Several families of rodents (e.g. Heteromyidae, Dipodidae, Muridae) contain species with body sizes similar to those of shrews. Given that body size is a determinant in many life history traits, it is no surprise that there are similarities between the two groups. In fact, many ecological studies include both shrews and small rodents in studies of "small-mammal" communities. There are, however, some key differences between the life histories of rodents and shrews. The life history traits of shrews have been well reviewed (e.g. Innes 1994, Taylor 1998, Churchfield 2002, Gliwicz and Taylor 2002); here I briefly discuss some of the major differences between shrews and small rodents as they relate to the differing energetic strategies of these taxa.

The primary driving factors in the differences between shrews and small rodents is the very high metabolic rates of shrews. Although an increased metabolic rate is expected with decreasing size and increasing surface area to volume ratio, shrews take this to an extreme; the smallest shrews approach the minimum size for maintenance of endothermy (Churchfield 2002, Ochoińska and Taylor 2005). In addition, soricine shrews have metabolic rates several times higher than comparably sized rodents (Chew 1951, Taylor 1998, Gliwicz and Taylor 2002), and exceed the metabolic rate predicted for comparably sized mammals by 258% (Ochoińska and Taylor 2005) to 366% (Taylor 1998). This difference is especially evident in reproductively active individuals; a lactating female shrew weighing only 10 g, may have similar peak energy consumption to a lactating female vole weighing 25 g.

Several competing hypotheses have been proposed to explain the high metabolic rate in soricine shrews. Vogel (1976) suggested that the origins of the different metabolic strategies in soricine and crocidurine shrews lie in their different evolutionary environments. The crocidurine shrews arose predominately in the afrotropical region, with tropical climates, developed relatively lower metabolic rates, and incorporated a daily torpor period. The soricine shrews arose primarily in the palearctic region, developed relatively high metabolic rates, and are strict homeotherms (Taylor 1998). Other authors (e.g. Genoud and Vogel 1990, Stephenson and Racey 1995) have proposed that the difference in metabolic rate in crocidurine and soricine shrews is a result of differing life histories, especially the relatively larger litter sizes in soricine shrews (average 5-7 young per litter – maximum of up to 15 in Neomys fodiens – in soricine, versus average 3-4 young per litter in crocidurine shrews, Churchfield 1990). In either case, the heightened metabolic rate in soricine shrews may reflect the energetic requirements for thermoregulation in especially cool temperate or arctic regions (Sparti and Genoud 1989)

This high metabolic rate drives the incessant need for shrews to eat, and to eat high quality foods. Gliwicz and Taylor (2002) discuss the relative proportion of high quality food in the diets of several groups of rodents, and soricine shrews. Gliwicz and Taylor (2002) define high quality foods as seeds or invertebrates (approximately equivalent in terms of energy) and suggest that, as insectivores, shrews consume high quality foods 100% of the time, while the most insectivorous rodent mentioned (the birch mouse, *Sicista betulina*) consumes high quality foods 90-95% of the time. Voles in the

genus *Microtus* are primarily folivorous, and consume high quality foods only 5% of the time (Gliwicz and Taylor 2002).

The high metabolic rate, and the food requirements necessitated by it, may also represent one of the root causes of the small size of shrews. Bergmann's rule suggests that, due to decreasing surface area to volume ratio, the size of a particular taxon should increase with latitude, as a strategy to reduce metabolic costs of thermoregulations as minimum temperatures decrease. Although 76% of shrew species are found in tropical or subtropical regions (Churchfield 2002) there are, between 50 and 60 species of shrews, including 75% of the genus *Sorex*, that live at latitudes above 50°N (Churchfield 2002). The three smallest species of *Sorex* (*S. minutissimus*, *S. minutus*, and *S. hoyi*) all have ranges extending beyond 60°N (Churchfield 2002). Some researchers (e.g. Mezhzherin 1964, Ochoińska and Taylor 2003) have reported that some shrews display the inverse of Bergmann's rule, with body size negatively correlated with latitude, and positively correlated with temperature. The question raised by several researchers is "Why, given that compliance with Bergmann's rule should provide a fitness advantage when living at high latitudes, are shrews so small (Churchfield 2002)?"

The answer, according to Hanski (1994), Churchfield (2002), and Gliwicz and Taylor (2002), and the mechanism by which the high metabolic rate of shrews drives their small size, lies in the food requirements of small individuals. Although smaller individuals have higher mass-specific metabolic rates than larger individuals in the same taxon, their per-capita (or absolute) food requirements are lower than those of larger individuals. This provides a potential advantage for shrews living at higher latitudes, where arthropod abundance may decline significantly during winter. It has been

estimated that *Sorex* spp. must consume their body weight in food each day, with pregnant and lactating females consuming up to 300% of their body weight daily (Churchfield 1990). Fat storage in shrews is typically confined to the interscapular and subscapular regions, and regions with high vascularity, and nearly all fat storage by shrews is in the form of brown adipose tissue. Although the storage of brown adipose tissue in shrews may provide an insulatory function, it is probably more important as rapidly metabolized energy source, and site of nonshivering thermogenesis (Merritt 1995). Because shrews are not able to store large quantities of insulating fat, they take advantage of the reduced absolute food requirements of small size, and may in fact reduce their body mass as winter approaches (Mezhzherin 1964); this has been termed the Dehnel effect (after Dehnel 1949, cited in Taylor 1999).

Although small size is advantageous for shrews in terms of absolute food requirements, larger size may enable shrews to access different food resources (Churchfield 2002). Shrews can be subdivided into small (<5 g), medium (5-10 g), and large (>10 g) species, with communities of shrews commonly assembling in a manner that reduces size class overlap, perhaps to aid in food resource partitioning (McCay *et al.* 2004). In North America four species of shrew (Pacific water shrew *Sorex bendirii*, common water shrew *Sorex palustris*, northern short-tailed shrew *Blarina brevicauda*, and Elliott's short-tailed shrew *Blarina hylophaga*) have average body sizes greater than 10 g. The water shrews are semi-aquatic, foraging on terrestrial as well as aquatic invertebrates, while the short-tailed shrews are adapted for fossorial life. The small and medium sized shrews are mostly epigeal, and subdivide food resources based on body size. Although small shrews are capable of taking lepidopteran, orthopteran, and dipteran

larvae, their main food sources are usually arthropods shorter than 10 mm (Churchfield and Sheftel 1994, Churchfield *et al.* 1999). These small shrews are strictly epigeal, feeding on small arthropods (Churchfield and Sheftel 1994, Churchfield 2002), while medium sized shrews include a hypogeal component to their foraging strategy, burrowing through leaf litter and upper soil horizons, and feed on larger invertebrates such as earthworms. Because medium sized shrews are able to use a third dimension (depth) while foraging, the horizontal size of their territories are correspondingly smaller than those of the two dimensional (strictly epigeal) foraging small shrews, in turn leading to potentially higher densities of medium sized shrews. Large shrews, specializing in fossorial or especially semi-aquatic foraging strategies, and having higher absolute food requirements, may have lower densities than medium sized shrews (or even small shrews) depending on the availability of their required resources.

Because of the reduced availability of invertebrates, winter is a critical period for *Sorex* shrews. As an adaptation to this period, all species of *Sorex* are essentially "biennial" (Hanski 1994), that is, individuals do not mature until their second year, may have one or multiple litters in their second year (depending on the length of the breeding season) and die before reaching their third year. This is in stark contrast to small rodents. Many small rodent species adopt what Gliwicz and Taylor (2002) have termed a Type I life history strategy, which closely resembles the life history of other r-selected species. Small rodents, although born altricial, develop quickly and are able to reproduce within a few weeks of being born. This may be beneficial for the lifetime fitness of an individual rodent which can access multiple food sources (seeds, invertebrates, vegetation) through winter. However, in the case of shrews, the primary limiting resource (invertebrates)

becomes severely limited during winter. This limited food supply, coupled with the cost of maintaining endothermy at the high surface area to volume ration of such small mammals, makes winter a critical time for shrews. Shrews must therefore adopt what Gliwicz and Taylor (2002) term a Type II life history strategy where shrews sacrifice reproduction in their first year in order to find and defend a territory, which will supply food and cover through the winter period (Gliwicz and Taylor 2002). Shrews which attempt to breed in their first season are selected against in two ways (Gliwicz and Taylor 2002). First, the energetic requirements of pregnancy and lactation must be traded off against growth, and the little storage of adipose tissue that shrews are capable of, leading to reduced overwintering success. Second, shrews are not able to develop as rapidly as rodents, leading to first year litters being born exceptionally late in the season, leaving little time for the young to prepare for winter, again reducing the probability of overwinter survival. This life history strategy of devoting the first year to growth and territory defense, leaving only the second season for reproduction reduces the intrinsic population growth rate of shrews. Because of this, although shrews may be numerically dominant in some communities (Dickman 1980, Chapter 3), they lack the capability to recover from disturbance that many rodent species possess. This consideration may be especially important when species of special concern, such as those occurring naturally at low densities (e.g. the water shrews) are considered.

The Pacific Water Shrew

The Pacific water shrew is B.C.'s largest shrew species (Nagorsen 1996), and is the largest species of *Sorex* in North America (Maser 1998). It is alternatively known as the marsh shrew (Pattie 1969) and Bendire's shrew (Cowan and Guiguet 1965). Nagorsen

(1996) reported that the Pacific water shrew is dark brown. slightly paler on the ventral side than the dorsal, and has a unicoloured tail. Total length averages 154 mm (70 mm tail), and weight averages 13.2 g. A row of stiff hairs fringe the hind feet, and serve to assist in propulsion while foraging in the water. The thick coat retains air, insulating the shrew while underwater, and air bubbles give the submerged shrew a silvery appearance (Pattie 1969). The common water shrew occurs much more extensively in North America than the Pacific water shrew, and where the species co-occur they are generally separated by elevation, with the common water shrew occupying higher elevations (above 600-800 m, Nagorsen 1996).

All shrews are insectivores, and the Pacific water shrew may be the most specialized feeder. Whitaker and Maser (1976) reported that up to 25% of the Pacific water shrew's diet may be composed of aquatic invertebrates. This species appears to be a habitat specialist, rarely being captured more than 50 m from water (Gomez and Anthony 1998), and thus is termed a riparian obligate. When foraging in streams, Pacific water shrews are able to run across the surface for 3-5 sec, scull on the surface, and quickly dive (Pattie 1973); the longest swimming period observed was 3.5 min (Pattie 1969).



Figure 1.1: Omitted due to copyright restrictions. The figure contained a map of the distribution of the Pacific water shrew (*Sorex bendirii*) and can be found in Pattie, D.L. 1973. *Sorex bendirii*.

Mammalian Species 27: 1 – 2.

The Pacific water shrew has a restricted distribution in B.C., being limited to the extreme south-west corner. In B.C., the Pacific water shrew is found as far east as the Chilliwack valley, and north to the Seymour River (Figure 1.1) (Nagorsen 1996). In addition, Nagorsen (1996) reports that in B.C., the Pacific water shrew is generally found below 600 m, but capture records indicate that the species can occur up to 850 m. This region of B.C. is highly fragmented, with much of the natural habitat converted to agriculture, and an increasing amount of urban area. Due to decreasing available habitat, and rarity throughout its range, the Pacific water shrew is currently classified as endangered by COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) (COSEWIC 2006). As the population in Canada is at the northern extent of the

Pacific water shrew's range, it constitutes what can be termed a peripheral population. Bunnell et al. (2004) have argued that peripheral populations should be priorities for conservation only if they are disjunct from core populations, and thus are potentially genetically distinct. However, Channell and Lomolino (2000a, b) and Lomolino and Channell (1995, 1998) have documented that for a variety of taxa, when population declines, followed by a consequent range collapse, are triggered by human activities, species persist in areas at the periphery of their range rather than at the core. That is, human caused declines generally have a direction associated with them. This has major implications for conservation (Lomolino and Channell 1998), and requires that peripheral populations of species of concern be awarded at least as much, if not more, priority than core populations. Such peripheral populations are likely to become important sources for future recolonization of core habitats where the species has been extirpated.

Organization of the Thesis

The primary purpose of this thesis is to identify a trapping methodology that will be appropriate for the study of Pacific water shrews. I accomplished this in two ways. In Chapter 2, I review various factors that contribute to the trappability of small mammals with particular reference to shrews. In Chapter 3, I present data collected over two field seasons where I compared the effect of two types of traps (the Longworth live trap, and the pitfall trap) on the trappability of *Sorex* spp. in grassland and riparian forest habitats in southwestern B.C. In Chapter 4, I present general conclusions from my work, and present my recommendations for future research, especially on methods used to study Pacific water shrews.

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Chapter 2 : A review of factors affecting the trappability of small mammals¹

Introduction

In studies of small mammal communities an important assumption is that all individuals on a given area are equally trappable (i.e. have an equal probability of capture). This is especially important when indices of abundance are used (Anderson 2001), and when studies trade off a relatively low sampling effort at each site sampled in order to sample a higher number of sites and thereby improve statistical power (e.g. Hanser and Huntly 2006, Stapp 2007). An accurate assessment of trappability is also required when using enumeration methods such as the minimum number known to be alive (MNA) index to estimate population size rather than mark-recapture models such as the Jolly-Seber population estimate (Krebs and Boonstra 1984). An accurate assessment of trappability also depends on (in the same manner as an accurate estimate of population size) the assumption that all individuals on a given area are equally trappable. To the degree that activity levels affect the probability of capture, factors affecting activity levels will also affect trappability of the target species (Sarrazin and Bider 1973). However, there are a variety of factors that can influence the activity patterns of small mammals. These include the time of day, the phase of the lunar cycle, weather, habitat type, community interactions among species, and dominance interactions among individuals within a species. Any researcher planning to study small mammals needs to

¹ A version of this chapter will be submitted for publication

Stromgren, Eric J. A review of factors affecting the trappability of small mammals, with emphasis on shrews (*Sorex* spp.)

understand how these factors may interact with each other, and with the type of trap used to contribute to the results obtained. Here I review the role that each of these factors plays in affecting trappability, and how they may interact to affect the trappability of small mammals, particularly shrews.

Weather Factors

A major factor affecting the daily and seasonal distribution and activity of small mammals is the weather. Activity patterns, in turn, affect trappability of the target animals. Vickery and Bider (1981) reported that deer mice (Peromyscus maniculatus), red-backed voles (*Clethrionomys gapperi*), and jumping mice (*Napaeozapus insignis*) were more active on warm rainy nights. This pattern was also noted by Doucet and Bider (1974) and Vickery and Bider (1978) for the masked shrew (Sorex cinereus). Marten (1973) reported that activity of deer mice, red-backed voles and prairie voles (Microtus *pensylvanicus*) in Ontario were tightly correlated with weather, particularly the temperature at sundown and cloud cover, while the nocturnal activity of two species of Peromyscus (P. truei and P. californicus) in California was most strongly correlated with sundown temperature. For rodent species, the generally accepted hypothesis for increased activity under cloudy skies and light rain is that these conditions contribute to predator avoidance. Further support for the predator avoidance hypothesis is offered by Stokes et al. (2001) who noted that daytime activity in cotton rats (Sigmodon hispidus) decreased when predator pressure was high (warm sunny days), although they did note physiological trade-offs such as increased daytime activity following stressful (e.g. cold, wet) nights, and decreased nocturnal activities in prairie voles on cold winter nights. Cloudy skies reduce predation pressure by decreasing visibility, while rain provides both

auditory and olfactory cover (Vickery and Bider 1981). Differing responses to weather may also provide for niche separation between similar species, as reported for deer mice, and white-footed mice (*Peromyscus leucopus*) in New England (Drickamer and Capone 1977), where white-footed mice were more active on cloudy and rainy nights, and deer mice were more active on cloudless dry nights. Without taking into account species specific responses to weather patterns in this case, the trappability of one species may be under or over represented relative to the other.

In shrews, weather-driven activity patterns are likely related to their foraging ecology, rather than to niche separation or predator avoidance (McCay 1996). Pankakoski (1979) noted that the activity of the common shrew (Sorex araneus) had a significant positive correlation with humidity and seemed to respond (although not significantly) positively to increased temperature. Getz (1961) noted that masked and short-tailed (Blarina brevicauda) shrews preferred mesic to wet sites over dry sites, and hypothesized that because shrews have difficulty avoiding evaporative water losses (likely due to their high surface area to volume ratios) they were able to occupy only environments with higher humidity. The need to maintain water balance would help account for the higher activity levels documented for shrews. McCay (1996) compared masked shrew activity levels in irrigated and non-irrigated forest, and found that activity increased following rain on nonirrigated but not on irrigated plots. Doucet and Bider (1974) found that rainfall had the greatest effect on shrew activity when the onset of rainfall was between 18:00 and 24:00 h, that is, when rainfall began early in the main activity period. Because shrews have very high metabolic rates they must forage in bouts every few hours throughout the day to meet their energy requirements. Thus, even in situations with high

predation risk shrews must spend a substantial amount of time foraging. However, if conditions are suitable (i.e. moist enough to maintain water balance without retreating to burrows) shrews may extend foraging bouts, leading to heightened trappability, and the higher densities detected by McCay (1996) in irrigated forests. The increased activity with rainfall observed in shrews may also be related to increased prey abundance. Rainfall may increase the surface activity of larger, somewhat fossorial, invertebrates (e.g. earthworms), providing a food source not normally available to small and medium sized shrews (e.g. masked shrews). In fact, McCay and Storm (1997) found increased abundances of invertebrate prey in irrigated forests, and suggested this as a mechanism for increased activity (and densities) of masked shrews.

A second factor, which affects small mammal activity in a similar manner, is the lunar cycle, specifically as it relates to the amount of moonlight. With increased moonlight at full moon, predation risk increases for small mammals. Price *et al.* (1984) noted that desert-dwelling heteromyid rodents tended to select habitats with higher cover values (i.e. "brush" rather than "open" habitats) during nights with more moonlight. Brown *et al.* (1988) attempted to confirm this hypothesis experimentally by manipulating predation risk in outdoor enclosures. Brown *et al.* (1988) reported that desert heteromyid rodents altered their behaviour, by reducing foraging activity, in response to increased predation pressure, measured as either owl presence or increased illumination. Jensen and Honess (1995) reported that under conditions with high cover value (i.e. increased vegetation height) increased moonlight had a negligible effect on rodent activity levels. Stokes *et al.* (2001) also reported that moonlight had little effect on rodent activity levels, presumably because adequate cover was present on their study sites. The strongest effects

of moonlight on activity and trappability have been observed in heteromyid rodents, which may be due to the habitats generally occupied by heteromyid (deserts), compared to murid (forests, grasslands, etc.) rodents. The desert habitats occupied by heteromyid rodents tend to have a patchy vegetation distribution, with large open spaces, providing distinct areas with and without cover. Forest and grassland habitats may have a much more gradual transition between high and low cover values of particular patches, which would mask differences in activity levels caused by, as individuals shifted activity to nearby areas with higher cover values.

Temperature may also have an effect on activity of small mammals, particularly on the timing of activity. In studies of prairie voles and cotton rats in Kansas, Stokes et al. (2001) noted varying responses to temperature between species and in different seasons. Both cotton rats and prairie voles avoided hot summer and fall afternoons by adopting a nocturnal or crepuscular activity pattern, as animals opted for foraging in less physiologically stressful conditions. In winter and spring, however both cotton rats and prairie voles became more active diurnally, probably in response to physiologically challenging cold nights. An important point made by Stokes et al. (2001) was that the evolutionary history of cotton rats and prairie voles influenced their differing responses to weather, even though they occurred sympatrically. Prairie voles, having evolved in cool temperate climates were particularly sensitive to high temperatures, whereas cotton rats, having adapted to hot, desert environments, were more strongly affected by cold temperatures. I was unable to find any published reports on the effects of either moonlight or temperature on activity patterns of shrews. Shrews, with their typically high metabolic rates, require food every few hours, and thus have activity periods spread over

a 24-h day. Typical shrew activity patterns are discussed by Rust (1978), in regard to two species, Trowbridge's shrew (*Sorex trowbridgii*) and the ornate shrew (*Sorex sinuosus*). Shrews generally have periods of activity separated by periods of quiescence with a periodicity around one hour, regularly spaced over every 24-h period, with increasing activity levels during nocturnal hours, and with between 20 % and 40 % of the 24-h period spent active.

Biological factors

A major factor affecting the trappability of small mammals is the presence of dominance interactions among species, and among individuals of the same species. Under conditions with limiting resources, many small mammals adopt territorial behaviour, to varying degrees (Ostfeld 1990). In response to territoriality and competition, small mammals have evolved a variety of mechanisms to avoid conflicts. Most important among these mechanisms affecting trappability may be "avoidance competition" (Righetti et al. 2000), where subordinate individuals actively avoid areas (e.g. traps) frequented by dominant individuals. This effect may be especially important in shrew communities (Dickman 1991, Rychlik and Zwolak 2005) which commonly assemble and partition food resources according to the size of individuals, with larger individuals excluding smaller individuals from certain resources (McCay et al. 2004). Experimenting with Townsend's voles (*Microtus townsendii*), Boonstra and Krebs (1978) and Beacham and Krebs (1980) determined that adult Townsend's voles excluded juveniles from Longworth live-traps. When pitfall traps were used, juvenile Townsend's voles were caught, demonstrating that due to the dominance interaction between adult and juvenile voles, each trap type was effectively sampling only a portion of the

population present. However, even within a single genus this effect may not be consistent. Boonstra and Rodd (1984) tested whether Longworth and pitfall traps sampled different portions of prairie vole populations, and found that, although juveniles tended to enter pitfall traps at a younger age than Longworth traps, both juvenile and adult subsets of the population were adequately sampled by Longworth traps. Further, Singleton (1987) failed to detect an effect of dominance on captures of house mice (Mus musculus) in Australia in pitfall and Longworth live-traps, as evidenced by an even capture rate across age and sex classes. Despite differing results in this aspect, the presence of an effect of conspecific scents on captures of small mammals is relatively well documented (e.g. Rowe 1970, Boonstra and Krebs 1976, Mazder et al. 1976, Daly et al. 1980). Wuensch (1982) documented both sex-specific and social rank (dominant/subordinate) level responses to trap odour in deer mice and house mice, however, he also described an inter-species effect where house mouse-scented traps served to 'attract' male deer mice. Wuensch (1982) hypothesized that this effect was due to a dominance relationship where male deer mice are intolerant of intruding house mice, and thus actively search for and pursue the intruder when its scent is detected. Daly and Behrends (1984) also documented an interspecific effect where scented traps were more likely to capture rodents of any species than clean traps, and noted that when traps were moved, they were more likely to recapture the same individual than expected by chance. Finally, Sullivan et al. (2003) reported that when animals were removed from trapping grids (to simulate killtrapping), the number of individuals captured from formerly uncommon species increased, as numbers of individuals of formerly common species decreased. Sullivan et al. (2003) suggest three possible explanations for this result. First, their trapping grids

may have been saturated with individuals, although approximately 40% of traps remained open on any one night. Second, species that were rare before removal trapping may have been socially subordinate, and may have avoided, or been excluded from traps by resident, dominant individuals. Third, species rare before removal trapping may have immigrated into a relatively empty trapping grid, suggesting large-scale habitat partitioning, and competitive exclusion. In either of the second or third cases, a dominance relationship exists between the species captured and the species that is not, and this relationship is thus affecting the trappability of the less commonly captured species.

Trap Type

Of all the factors affecting trappability of small mammals, the type of trap used may have the greatest effect. Also, as trap type is the easiest factor for researchers to vary when examining trappability, it has received the most attention. The most commonly used trap types include snap (kill), Sherman (live), pitfall (kill or live), and Longworth (live) traps. Multi-capture traps such as the Ugglan (live) trap that require animals to climb a ramp, where they are tipped into a holding area, have been successfully used in a variety of circumstances, and there are a variety of trap types constructed by researchers for use in their own particular studies. In situations where the researcher needs to follow the fate of individuals through time, for example, to determine survival, weight gain/loss, or reproductive success when evaluating habitat quality (Van Horne 1983), or when species of special concern (i.e. threatened species) are present in the study area, kill-traps are inappropriate, and live traps are required. There may be reasons for kill-trapping to be used in ecological studies, for instance when ecological studies are coupled with studies

of zoonoses. However, in general, ethical considerations should prevent the use of killtraps in most ecological studies. Further, ethical considerations aside, Sullivan *et al.* (2003) have shown dramatic shifts in small mammal communities following removals, indicating that potentially spurious results may be obtained if removal (i.e. kill) trapping methods are used to sample small mammal communities. Thus, whether the requirements of the study, ethical considerations, or a desire to avoid spurious results lead the researcher to use live-traps, the fact remains that the most effective live-trap needs to be determined. The relative efficiencies of kill traps have been well documented, both among types of kill-traps (e.g. Mengak and Guynn 1987, McComb *et al.* 1991, Kalko and Handley 1993), and between kill and live-traps (e.g. Williams and Braun 1983, MacCraken *et al.* 1985, Galindo-Leal 1990) here I review studies comparing the effectiveness of common types of live traps, including pitfall traps, which are often used as removal traps, but when operated dry, and checked at a suitable interval, may be used quite successfully as live-traps.

Sherman versus pitfall traps

Five studies have directly compared Sherman and pitfall traps. Sealander and James (1958) used $7.5 \times 7.5 \times 25$ cm Sherman traps compared with Victor 4-way snap traps, Museum Special snap traps, Havahart live traps, three live trap ("Young," "Evans," and "Wisconsin") types which are no longer in use, and pitfall traps made from No. 10 cans, $\frac{2}{3}$ filled with water. Sealander and James (1958) found Sherman traps captured nearly four times the number of individuals per 1000 trap nights as pitfall traps, and concluded that Sherman traps were the most generally effective of the trap types studied. Umetsu *et al.* (2006) used 60 L pitfalls, $37.5 \times 10 \times 12$ cm, and $23 \times 7.5 \times 8.5$ cm

Sherman traps, and found pitfalls to be more effective than Sherman traps, capturing 16 species which were not captured by Sherman traps. Sherman traps, in turn, captured only one species that was not captured in pitfall traps. In addition, Umetsu et al. (2006) found that Sherman traps usually captured adults, while pitfalls captured the whole age range, or in some cases predominantly juveniles. Anthony et al. (2005) compared small (13.8 \times 6.4×8.4 cm) and large ($17.0 \times 5.4 \times 6.5$ cm) Sherman traps and Longworth traps to pitfall traps (two No. 10 cans taped together). Anthony et al. (2005) used 25 of each type of live trap, and only 5 pitfall traps per grid; however, when the ratio of live traps to pitfalls was accounted for, pitfall traps captured more individual Sorex than live traps in the first year of the study, but not in the second, and failed to capture many rodent species. Williams and Braun (1983) conducted perhaps the most extensive comparison of Sherman and pitfall traps. Using large $(7.6 \times 8.9 \times 30.5 \text{ cm})$ Sherman traps, 7.6 L pitfall traps, and Museum Special snap traps, Williams and Braun (1983) found that pitfalls captured 60% more individuals than Sherman and snap traps combined (90 individuals in pitfalls, 46 in snap, and 8 in Sherman traps), far more shrews (65 compared to 1 in snap, and zero in Sherman traps), and six small-mammal species compared to four caught in Sherman and snap traps. MacCraken et al. (1985) compared Sherman and pitfall traps for capturing shrews in southeastern Montana. Three species of shrew (masked shrews, dwarf shrews Sorex nanus, and Merriam's shrews Sorex merriami) were captured, and all shrews captured were caught in pitfall traps. To correct for the different portions of the small mammal community sampled by pitfall and Sherman traps, and particularly to increase efficiency of shrew captures, several authors (e.g. Cole et al. 1998, Silva 2001) have used a mixture of both trap types on their trapping grids.

Overall, it appears that for complete small mammal community assessment, pitfall traps may be more efficient that Sherman traps. The specific advantage of using pitfall traps over Sherman traps in temperate climates appears to be their ability to census the soricid community (Williams and Braun 1983, MacCraken *et al.* 1985). The ability to sample not only the rodent community but also the soricid community increases both the number of species detected by pitfall traps, and the total number of individuals captured.

Sherman versus Longworth traps

Two studies have compared Longworth and Sherman traps. Morris (1968) carried out two trials. In the first trial, Sherman and Longworth traps were set concurrently, with one of each trap type at each trap station. With this arrangement, similar to a cafeteria trial, the animals chose the trap type that they preferred to enter. When the choice was offered, most animals preferred Sherman traps, with significant differences in total number of individuals captured, and in number of deer mice captured. In the second trial, Morris (1968) operated both traps together as in the first, followed by trapping with Longworth traps only, followed by trapping with Sherman traps only. In this situation, operation of Sherman and Longworth traps together caught significantly more *Microtus* than Longworth or Sherman traps operated alone. This difference was not significant for *Peromyscus* or *Clethrionomys*. Also, Morris (1968) did not detect significant differences in the number of *Microtus, Peromyscus*, or *Clethrionomys* captured between Sherman and Longworth traps operated alone.

Anthony *et al.* (2005) compared large and small Sherman traps with Longworth traps over two years, and used a two way contingency table analysis to test for differences in the proportion of animals caught in each trap type and year. They found

differing results in each of the two years. In their first year, Anthony *et al.* (2005) captured a higher proportion of the *Sorex* population in Longworth traps while Sherman traps captured a significantly proportion of the *Peromyscus* population. Both small and large Sherman traps caught a significantly smaller proportion of the *Sorex* population, while large Sherman traps caught a significantly smaller proportion of the *Peromyscus* population. The proportion of the *Peromyscus* population captured in Longworth traps did not differ significantly from what was expected. In the second year, however, small Sherman traps caught a significantly smaller proportion, Longworth traps did not capture a significantly different proportion than expected. Small Sherman traps also caught a significantly higher proportion of the western harvest mouse (*Reithriodontomys megalotis*) population. In the second year, large Sherman traps caught a significantly higher proportion of the western harvest mouse (*Reithriodontomys megalotis*) population. In the second year, large Sherman traps caught a significantly higher proportion of the western harvest mouse (*Reithriodontomys megalotis*) population. In the second year, large Sherman traps caught a significantly higher proportion of the western harvest mouse (*Reithriodontomys megalotis*) population. In the second year, large Sherman traps caught a significantly higher proportion of the western harvest mouse (*Reithriodontomys megalotis*) population. In the second year, large Sherman traps caught a significantly higher proportion of the *Peromyscus*, prairie vole, and meadow jumping mouse (*Zapus hudsonius*) population, while Longworth traps caught a significantly smaller proportion.

Although the study by Morris (1968) was somewhat limited in time (four 4-night trapping sessions), it did provide insight into the efficiencies of the two trap types. Morris' (1968) study indicated that, although it would be desirable to use both Sherman and Longworth traps, using either should provide a sufficient measure of the small mammal community. Anthony *et al.*'s (2005) study was complicated somewhat by differing results in different years. They suggested that one cause may have been their use of new Sherman traps in the second year. Although perhaps unlikely that the age of the trap plays a great role in the capture efficiency of these two traps, one possible hypothesis is that the treadle mechanism on Sherman traps is subject to more wear and

tear than is the treadle mechanism on Longworth traps. Perhaps in the first year or two of use, Sherman traps are more able to capture lighter species (e.g. *Sorex* spp., and the western harvest mouse), and this ability becomes similar to that of the Longworth traps after a few years, with eventual deterioration to the point that the Longworth trap becomes superior. Given the abuse suffered by all field equipment, this suggests that from a practical point of view, the Longworth trap would be more useful for small mammal research.

Longworth versus pitfall traps

Six studies have compared the effectiveness of Longworth and pitfall traps for capturing rodents. Boonstra and Krebs (1978) and Beacham and Krebs (1980) conducted similar studies comparing the trappability of Townsend's voles in Longworth and pitfall traps. They found that adult (dominant) Townsend's voles excluded a subordinate portion of the population from accessing the Longworth traps. In both studies, pitfall traps captured a large portion of the juvenile population that was not recorded in Longworth traps until they matured, and also captured a portion of the population that was never recorded in Longworth traps, and these animals presumably remained as subordinate individuals. Because a large portion of the population was captured in only one or the other trap type, it may be necessary to use both trap types to adequately sample Townsend's voles. Carrying out a similar study on prairie voles, Boonstra and Rodd (1984) also noted that pitfall traps tended to capture more juvenile voles first, had a slightly lighter average weight at first capture, and sampled a small portion of the population (18%) that was never recorded in Longworth traps. Voles captured in Longworth traps first had a 2-7 week delay before entering pitfall traps, while voles

entering pitfall traps first had a 4-6 week delay before entering Longworth traps. Boonstra and Rodd (1984) found that Longworth traps performed much better at sampling dispersing voles than pitfalls (contrary to Boonstra and Krebs 1978, Beacham and Krebs 1980). Boonstra and Rodd (1984) also noted that a slight majority (53,7%) of first captures were in Longworth traps, and concluded that, in general, Longworth traps performed better than pitfall traps, and were sufficient to sample prairie vole populations. Singleton (1987) used Longworth traps and a variety of pitfall trap-drift fence combinations to sample house mice in Australia. He found that although mice were slightly more susceptible to repeated captures in pitfall traps than Longworth traps, both trap types adequately sampled all portions of the population. Because several rodent species (e.g. house mice, jumping mice Zapus spp., deer mice) are capable of escaping from most commonly used pitfall trap types when operated dry, a concern with trap type comparisons is that pitfall traps would be more effective if a way could be found to contain captured animals. Walters (1989) used 25 L metal drums with a 3.5 cm hole drilled in the centre of a closed lid so that captured deer mice would be unable to jump free. He found that pitfall traps performed as well as or better than Longworth traps for capturing deer mice. Walters (1989) noted that the efficiency of pitfall traps exceeded that of Longworth traps, particularly in capturing juveniles. There may have been a dominance hierarchy operating to exclude juveniles from Longworth traps as reported by Boonstra and Krebs (1978) and Beacham and Krebs (1980) in Townsend's voles, and as evidenced by equal trappability of juveniles in Longworth and pitfall traps on grids where the adult population was removed. Innes and Bendell (1988) compared pitfall, Longworth, and Victor snap traps for sampling a complete small mammal community in

northern Ontario. They found that pitfall traps were the least efficient, capturing the fewest species, with fewer individuals per 100 trap nights. Longworth traps were intermediate in number of individuals per 100 trap nights, but sampled 10 of the 11 species present, more species than either pitfalls or snap traps, although pitfalls were the only trap to sample the 11th species, the North American pygmy shrew (*Sorex hovi*). Prince (1949) also noted that pitfall traps were particularly effective for capturing North American pygmy shrews, which are difficult to sample with other trap types. Snap traps captured the highest number of individuals per 100 trap nights and 9 of the 11 species, but failed to capture the least chipmunk (Eutamias minimus). Because Innes and Bendell (1988) used different methods for all three trap types, the accuracy of the comparison between trap types is confounded with the differences in methods. The limitations of Innes and Bendell's (1988) comparison are discussed, particularly with respect to shrew captures in Chapter 3, along with two further studies (Craig 1995, Shore et al. 1998) which examined the efficiency of Longworth and pitfall traps for capturing shrews, in particular.

Conclusion

Many factors affect the trappability of small mammals. These factors can be related to weather, such as temperature, rainfall, and moonlight, or they can be biological, such as the interaction between dominant and subordinate individuals in a community. Biological and weather factors may also interact to varying degrees. For example: low quality habitat may be unable to support dominant, breeding individuals, and so a population in this habitat may be entirely supported by immigration from high quality habitats (Van Horne 1983), in which case, dominance interactions may be negated
because all individuals are of the same social rank. Also, the effect of predation risk (a biological factor) will modify behaviour patterns of individuals, but a lack of moonlight due to a new moon, or cloudy night will mitigate this factor, perhaps to a significant degree in areas with many predators. Conversely, an increase in moonlight may serve to decrease activity, especially in open areas (Brown 1988). Rainfall may serve to increase the activity of rodents by providing auditory and olfactory cover from predators (Vickery and Bider 1981), but may only increase the activity of shrews in areas where there is a subsequent increase in the availability of invertebrate prey (McCay 1996). The factor affecting trappability that is most directly under the control of the researcher is the type of trap used. Although many comparisons of live traps have been made, there were few that have been done in an extensive sense (e.g. Boonstra and Krebs 1978, Beacham and Krebs 1980, Innes and Bendell 1988, Anthony et al. 2005), and of these, there was much variability arising from unequal numbers of traps, and differing results by year (Anthony et al. 2005), use of different methods with different trap types (Innes and Bendell 1988), and extensive study of single species (Boonstra and Krebs 1978, Beacham and Krebs 1980), that may not transfer to other species within a single genera (Boonstra and Rodd 1984) let alone species in other genera (Singleton 1987). Further extensive, balanced, pairwise, comparisons between Sherman, Longworth, and pitfall traps are necessary to accurately assess which trap type is most effective for each portion of multi-species small mammal communities, or if, in fact, one trap type can accurately assess complete communities.

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Chapter 3 : Pitfall versus Longworth Livetrapping of Shrews (Sorex spp.)²

Introduction

In all studies of small mammal communities a source of bias is introduced by the type of trap used (e.g. Boonstra and Krebs 1978, Williams and Braun 1983, Kalko and Handley 1993, Anthony et al. 2005). This bias can influence estimates of species richness (Innes and Bendell 1988), and population structure (Boonstra and Krebs 1978, Beacham and Krebs 1980, Boonstra and Rodd 1984). Shrews (Soricidae) have proven difficult to sample using conventional traps, leading to the development of pitfall trapping techniques (Brown 1967, Williams and Braun 1983, Bury and Corn 1987, Kalko and Handley 1993, Kirkland and Sheppard 1994). On comparison with conventional snap and Sherman traps, several authors (e.g. Pankakoski 1979, Williams and Braun 1983, Umetsu et al. 2006,) have suggested that pitfall traps capture more species of small mammals, as well as more individuals, particularly shrews. Pitfall traps have predominantly been used as removal traps (e.g. Kalko and Handley 1993, Kirkland and Sheppard 1994, Greenberg and Miller 2004) as their ease of maintenance, once installed, can provide for large sample sizes, with minimal effort on the part of the investigator (Williams and Braun 1983). Ethical concerns aside, Pucek (1969) documented difficulties using standard regression approaches for removal trapping when applied to shrews. Cawthorn (1994) suggested that removal trapping may provide data of limited use because little information regarding behaviour of individuals is obtained. In addition, Sullivan et al.

² A version of this chapter will be submitted for publication.

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(2003) have reported that results from removal trapping small mammal communities may lead to spurious conclusions, when compared with livetrapping. Despite these shortcomings, removal trapping has been the predominant method for study of shrews in North America (but see Hawes 1977, Cawthorn 1994, Craig 1995, Boonstra and Bowman 2003). In Great Britain, however, livetrapping estimates of shrew populations have been included in several small mammal studies (e.g. Dickman 1980, Churchfield 1980, Dickman and Doncaster 1987, 1989, Churchfield et al. 1997, Churchfield et al. 2000). Effective livetrapping studies that have included shrews used several trap types, including dry pitfalls (Cawthorn 1994, Craig 1995), Longworth traps (e.g. Chitty and Kempson 1949, Dickman and Doncaster 1989, Craig 1995, Churchfield et al. 2000), Ugglan traps (Malmquist 1985, 1986, Lambin and MacKinnon 1997) a Russian designed live-trap (Whitaker and Feldhammer 2000, 2005), and a modified Sherman live-trap (Hays 1998). In addition, pitfall traps are sometimes used in combination with drift fences, and the size and type of pitfall trap and drift fence may vary with the objectives of the study (Handley and Kalko 1993). Debate remains as to which trap type is most suitable for livetrapping of shrews.

Three commonly used commercial live-traps are the Longworth (Chitty and Kempson 1949), and Sherman box-traps, and pitfall traps. The Sherman trap has a slightly less sensitive treadle mechanism than the Longworth trap, and due to the design of the mechanism, is susceptible to more wear and tear. Anthony *et al.* (2005) compared Longworth and Sherman traps, and found that when older Sherman traps were used (the first year of their study) the relative efficiencies of the three trap types were different than when new Sherman traps were used (the second year of their study). This effect was

especially pronounced in the lighter species trapped (e.g., shrews and the western harvest mouse *Reithriodontomys megalotis*). Because of the susceptibility of the treadle mechanism in Sherman traps to wear and tear, and the lowered ability of older Sherman traps to capture smaller species, the Longworth trap probably represents a better live trap for capturing small species, such as shrews. Little research has been done investigating the relative efficiencies of Longworth and pitfall traps for capturing shrews, and those studies that have been done have been faced with problems such as small sample sizes and inconsistent methodology. A comprehensive comparison of these two trap types is warranted.

Livetrapping studies of small mammal communities have often been faced with high trap mortality of shrews (e.g. Sullivan and Sullivan 1982, Sullivan *et al.* 1998). Livetrapping studies specifically targeting shrews have avoided this problem by providing a suitable food source such as ground meat, or blowfly (*Calliophora* spp.) pupae, and checking traps frequently (every 1.5 - 4 hrs) (Hawes 1977, Little and Gurnell 1989, Craig 1995).

My objectives were to determine if, with minor alterations to standard livetrapping protocols, shrews could be readily included in small mammal community studies; and then to evaluate a revised method for capturing riparian small mammals, particularly the Pacific water shrew (*Sorex bendirii*). Here, through Experiments 1 and 2 I test four hypotheses:

1. pitfalls will be more effective than Longworth traps for capturing shrews,

 drift fences will significantly improve capture rates of shrews in Longworth and pitfall traps,

addition of appropriate bait significantly decreases trap mortality of shrews, and
shorter intervals between trap checks significantly reduces trap mortality of shrews.

Experiment 1 was designed to test Hypotheses 1 and 3, and was carried out in my first field season (May – September 2006). Although not specifically designed to test Hypothesis 4, data from Experiment 1 was used retrospectively to examine the relationship between the length of the interval between trap checks, and trap mortality rates. Two questions were raised in Experiment 1 (did the drift fences used increase the efficiency of Longworth traps to a greater extent than pitfall traps; and, do the results obtained in Experiment 1 apply in multi-species communities in forested habitats). Experiment 2 was designed to answer these questions, and was carried out in my second field season (May – September 2007).

Methods

Experiment 1

Study Area

All three study sites (grids A, B, and C) were located in agricultural set-aside fields in western Delta, south coastal B.C., Canada, approximately 20 km south of Vancouver. This region is typified by large areas of active farmland on flat topography at or near sea level. Crops currently harvested in this area include vegetables, root crops, maize, blueberries, and cranberries. A portion of this region is also used for perennial forage production for livestock. The climate is mild, with cool wet winters and warm dry summers. Average daily temperatures were 10.1°C with maximum mean daily temperature occurring in August (17.6°C) and minimum mean daily temperature in

January (3.3°C) (Environment Canada 2004). Mean annual precipitation was approximately 1200 mm, with the majority (860 mm) falling between October and March (Environment Canada 2004). Sites A and B were 3-year-old set-asides, while site C was a 4-year-old set aside. These set asides were established through the Delta Farmland and Wildlife Trust, and consisted of farm fields removed from production, initially seeded with a mixture of forage grass species and clover, and left for a period of up to four years, with the goal of restoring soil quality, and providing wildlife habitat in an agricultural matrix.

Trapping

At each site one 1-ha trapping grid was set up with 100 (10 x 10) trap stations spaced 10 m apart. Although grass cover within fields was heterogeneous, with some areas having little cover (areas flooded for much of the fall, winter and spring), and some areas with dense growth of reed canary grass (*Phalaris arundinacea*), I was able to locate all three grids within relatively homogeneous areas of the study sites. In this manner I attempted to control for the effect of differing cover on predation risk to small mammals, and in turn, the potential differing effects on trappability that this could have caused. Each station was equipped with one 3-m long, 30-cm high drift-fence constructed from PVC vapour barrier stapled to wooden stakes. The bottom edge of each drift-fence was buried approximately 5 cm into the ground to prevent animals from passing under them. At each site, I randomly assigned to 50 trap stations one dry pitfall trap, while the other 50 received two Longworth traps. Pitfall traps consisted of two #10 cans duct-taped together (total dimensions 15.7 cm diameter, 35.6 cm deep) and buried so that the rim was flush with the ground (Bury and Corn 1987). Pitfall traps were placed centrally along

the drift-fence, such that animals passing on either side would be captured. Longworth traps were placed at either end of the drift-fence so that the opening was aligned along one side of the fence. In this manner, I attempted to equalize the chance that an animal encountering a drift-fence also encountered a trap, although pitfall traps were still capable of multiple captures while a station with Longworth traps was only capable of a maximum of two captures per interval between checks. Longworth traps were pre-baited for a period of two weeks prior to the initial trapping session. I attempted to allow animals to become accustomed to pitfalls by placing a small amount of bait on and around the lid of the closed trap. During trapping sessions, I baited all traps with whole oats and a slice of carrot, and provided coarse brown cotton for bedding. In addition, I randomly selected 25 stations of each trap type to receive approximately 6 g of mealworms as sustenance for insectivores (hereafter traps baited with mealworms are referred to as "baited", while those baited only with oats and carrot are "non-baited"). The resulting treatments; Longworth (baited or non-baited), and pitfall (baited or nonbaited), were kept at their assigned trap station for the duration of the project. Trapping was conducted for two nights every month from May through September 2006, for a total of five trapping sessions. Traps were set the evening of day one, checked morning and evening of day two, the morning of day three, and then locked open (Longworths) or closed (pitfalls) between sessions. Due to high trap mortality rates through the first two sessions, a midday check was added so that traps were not left open without a check for more than 8-9 h. If daily maximum temperatures were projected to exceed 25°C, traps were checked approximately every 3 h. All captured individuals were identified to species, weighed and marked, rodents with serially numbered ear tags (Monel no. 1,

National Band and Tag Co.), and shrews with unique combinations of spots of blond or black hair dye (Craig 1995). Rodents were assessed for sex and reproductive condition (males scrotal or not, females lactating or not). All individuals were released at point of capture after measurements were taken.

<u>Analysis</u>

This experiment followed a split-plot, randomized, complete block design with two fixed factors: trap type, and bait treatment, and one random factor: block. The three replicate trapping grids acted as blocks, and the trapping period (time) was included as the split plot, to test for an interaction between trapping sessions and treatments. Because some treatments (i.e., non-baited traps) were expected to have high mortality rates, only the first capture of any individual was included in the analysis. I calculated the number of new captures per trap session, and trap mortality rate (expressed as a percentage). I evaluated the effect of bait and trap type on number of captures using PROC GLM (Table 1, model 1) in SAS v. 9.13 (SAS institute 2003). I also used PROC GLM to evaluate the effect of bait and trap check interval on trap mortality. Due to a small sample in pitfalls, analysis of trap mortality rate was limited to shrews captured in Longworth traps. Intervals were either long (12-14 h), medium (6-10 h) or short (3-4 h). Because interval lengths were confounded within trapping periods, the model used to analyze the effect of bait treatment and interval on mortality rate included interval rather than period (Table 1, model 2). Assumptions of normality were tested using the Kolmogorov-Smirnov test, while homogeneity of variance was tested using Bartlett's test. I performed a natural logarithm transformation (ln c + 1), so that this variable met assumptions of normality and homeoskedasticity (Zar 1999) Where multiple comparisons within treatments were

necessary, I used pairwise T-tests, with a Bonferroni adjustment to guard against type 1 error (Kutner *et al.* 2005). For ease of interpretation, all data are hereafter expressed as untransformed least squares-means (\pm standard error). In one case (baited Longworth traps, checked at short intervals) the least squares-mean gave a meaningless result (i.e., negative morality rate), and so this point has been set to zero. *P* < 0.05 was considered statistically significant for all tests.

Table 3.1: Models analyzed using PROC GLM. Model 1: y is the number of animals captured, T is the treatment effect, B is the block effect, TB the treatment by block interaction, P is the session (split-plot) effect and TP the treatment by session interaction. Model 2: y is the mortality rate, T is the treatment effect, B is the block effect, TB the block by treatment interaction, I is the interval effect, TI the treatment by interval interaction. Model 3: refers to Experiment 2 where y is the number of individuals captured, T is the treatment effect, and B is the block effect.

Test	Model
Catch by Trap Type – Bait Treatment combination, and Trapping Session (Model	$y_{ijk} = \mu + T_i + B_j + TB_{ij} + P_k + TP_{ik} + \varepsilon_{(i)jk}$
1)	
Mortality rate by Bait Treatment and	$\mathcal{V} = \mu + T_{i} + B_{i} + TB_{ii} + I_{i} + TI_{ii} + \varepsilon_{(i),i}$
Interval (Model 2)	\mathcal{F}_{ijk} I I J ij k ik $(I) jk$
Catch by Trap Type and Drift Fence	$y_{ii} = \mu + T_i + B_i + \varepsilon_{ii}$
Treatment (Model 3)	

Experiment 2

Study Area

I selected three study sites with the criteria that they were of high habitat quality (Craig 2005), in close proximity to recent (<20 yrs) captures, and spatially dispersed over the Canadian range of Pacific water shrews. Thus, the three sites selected were: Sumas Mountain Regional Park (Abbotsford), Tynehead Park (Surrey), and The University of British Columbia's Malcolm Knapp Research Forest (MKRF) (Maple Ridge). All three sites lie within the Coastal Western Hemlock Dry Maritime (CWH_{dm}) Biogeoclimatic Ecosystem Classification (BEC) subzone (Green and Klinka 1994). The CWH_{dm} is characterized by mature stands containing western hemlock (*Tsuga heterophylla*). On drier sites Douglas-fir (*Pseudotsuga menziesii*) may form dominant canopies, and western red cedar (*Thuja plicata*) may form dominant canopies on wetter sites (Meidinger and Pojar 1991).

The three study sites selected were second growth forests with abundant Douglasfir and western hemlock. Western red cedar was present at all three sites. The Sumas site was approximately 600-700 m in elevation, nearing the upper limit of the elevation range for Pacific water shrews, and was located at the headwaters of Wades Creek. Being higher in elevation, amabilis fir (Abies amabilis) was present as a minor stand component. Western red cedar and western hemlock were the dominant species regenerating on disturbed sites. Riparian areas were dominated by red (Alnus rubra) and slide (Alnus crispa) alder, and bigleaf maple (Acer macrophyllum). The understory was dominated by salmonberry (*Rubus spectablis*), black gooseberry (*Ribes lacustre*), and devil's club (Oplopanax horridus), and contained components of huckleberry (Vaccinium spp.), red flowering currant (Ribes sanguineum), and vine maple (Acer circinatum). The Tynehead site had riparian areas dominated by red alder, with an understory of salmonberry, and a small component of vine maple. Sitka spruce (Picea sitchensis) was a minor component at Tynehead, as was western red cedar. Dominant riparian forests at the MKRF site were Douglas-fir and western hemlock, with a sparse shrub understory (although dense in patches) of salmonberry and huckleberry.

Trapping

At each site, I laid out eight traplines. Four traplines followed the course of a small stream, with traps set as close as possible to the stream edge (hereafter riparian traplines). Parallel to each of the four riparian traplines, and located 30 m away from the stream, was another set of four traplines (hereafter upland traplines). Each riparian and upland trapline was separated from the next trapline (up and downstream) by at least 100 m following the stream channel, or, where several tributaries were trapped, each with two traplines, by at least 150 m overland.). I randomly assigned one of four treatments to each trapline, resulting in two replicates (one riparian, and one upland) of each treatment at each site. The four treatments were: 1) a pitfall trap set within 2 m of the trap station (hereafter, separate pitfall), along natural runways (logs, rocks, stumps, etc.), 2) a pitfall trap at the centre of a drift fence, at the trap station (hereafter, pitfall with drift fence), 3) two Longworth traps set within 2 m of the trap station (hereafter, separate Longworth), along natural runways (logs, rocks, stumps, etc.), and 4) two Longworth traps, one at either end of a drift fence, at the trap station (hereafter, Longworth with drift fence). Drift fences were constructed of PVC vapour barrier 3 m long by 30 cm high, and were buried 5-10 cm into the ground to prevent animals from moving under the fence. In one case (MKRF streamside pitfall with fence), the substrate did not permit the installation of pitfall traps, and so the assigned treatment was substituted with the separate Longworth treatment. Trapping occurred for two nights every four weeks from May to September 2007, for a total of five sessions. All traps were baited with whole oats and carrot, and either mealworms or wet cat food to sustain shrews, and supplied with coarse brown cotton for bedding. During trapping sessions, traps were checked at least every 8 h, and if

daily maximum temperatures were expected to exceed 25 °C, traps were locked open during the day. All captured animals were identified, weighed, and uniquely marked, rodents with a serially numbered ear tag (Monel no. 1, National Band and Tag Co), shrews with hair dye applied in a unique pattern. All rodents were sexed and assessed for reproductive condition (males scrotal or not, females lactating or not). Shrews were not sexed, as only very pregnant or lactating females, and very scrotal males are discernable. All individuals were released at point of capture after measurements were taken. Between trapping sessions, Longworth traps were left containing bait and locked open (i.e., prebaited). I attempted to pre-bait pitfall traps by providing sticks so that any animals entering the trap would be able to climb out. However, due to mortality of shrew-moles (*Neurotrichus gibbsii*) in flooded pitfall traps, the pitfall traps were closed between sessions, following session two, removing any effect that prebaiting may have had.

<u>Analysis</u>

Experiment two was designed as a split-plot randomized complete block with three fixed factors; trap type, drift fence, and distance from the stream. The three regional replicates acted as blocks and were included in the model as a random factor. Time (trapping period) was included as the split, to test for a period by treatment interaction. Due to low numbers of captured shrews, I pooled all five trapping sessions, as well as the streamside and 30 m upland traplines with identical treatments, and analyzed the pooled data using PROC GLM in SAS v. 9.13 (SAS Institute 2003) as a randomized complete block design with one fixed (treatment) and one random (block) factor (Table 1, model 3). Residual error terms met the assumptions of normality and homogeneity of variance, and no transformations were performed. Multiple comparisons were made using pairwise

T-tests with Bonferroni's correction to alpha, to guard against type 1 error (Kutner *et al.* 2005). All data are presented as least squares mean (\pm standard error). *P*<0.05 was regarded as statistically significant for all tests.

Results

Experiment 1

Over the course of five trapping periods, 436 individual shrews were captured, and were the numerically dominant small mammal. The second most frequently captured small mammal in Experiment 1 was the Townsend's vole (144 individuals). In Experiment 1, I also captured 7 deer mice and 1 house mouse. The treatment had a significant influence on number of captures ($F_{3,6}$ = 34.54, P < 0.01) (Fig. 3.1). The bait treatment had no significant effect (Longworth baited vs. non-baited, t_6 = 0.31, P = 0.77; Pitfall baited vs. non-baited, t_6 = 1.85, P = 0.11, Corrected alpha = 0.004) on average number of shrews caught. Both Longworth treatments captured significantly more shrews than either pitfall treatment ($t_6 < -5.99$, P < 0.001, Corrected alpha = 0.004). Longworth traps captured an average of 11.00 (± 1.66) individuals/session (non-baited), and 11.53 (±1.66) individuals/session (baited). Pitfalls captured an average of 2.07 (± 1.66) individuals/session (non-baited), and 1.13 (± 1.66) individuals/session (baited). The block effect was significant ($F_{2.59}$ = 6.72, P < 0.01), however, there was no significant interaction between the blocks and treatments ($F_{6.59}$ = 1.40, P = 0.25).

Table 3.2: Pairwise t - test results for baited (i.e., additional mealworms to sustain shrews) vs. nonbaited (i.e., grain baits only) checked at short (3-4 h), medium (8-9 h) and long (~12 h) intervals, Bonferroni corrected alpha = 0.003

	Comparison	$t_{20} =$	<i>P</i> =
Baited Traps	Short vs. Medium Interval	-1.33	0.1986
	Short vs. Long Interval	-3.14	0.0051
	Medium vs. Long Interval	-2.72	0.0132
Non-Baited Traps	Short vs. Medium Interval	-0.93	0.3644
	Short vs. Long Interval	-1.83	0.0820
	Medium vs. Long Interval	-1.35	0.1907
Short Interval	Baited vs. Non-Baited	0.96	0.3465
Medium Interval	Baited vs. Non-Baited	2.47	0.0225
Long Interval	Baited vs. Non-Baited	3.64	0.0016





Figure 3.1 Least square mean (± S.E.) number of new shrews captured in each of four trap type-bait treatment combinations. The bait treatment had no significant effect, but for both bait treatments the Longworth trap caught more individuals than the pitfall trap

The bait ($F_{1,2} = 34.48$, P = 0.0278) and interval ($F_{2,20} = 7.83$, P = 0.0031)

treatments were both statistically significant in determining a difference in mortality rate. A statistically significant interaction between bait treatment and trap check interval was not detected ($F_{2,20} = 0.67$, P = 0.52). Shrews captured in baited traps experienced average mortality rates of 8.05% (± 2.84) while those in non-baited traps experienced 31.60% (± 2.84) mortality (Fig. 3.2). When combined with the interval treatment, shrews captured in non baited traps, checked at long intervals, experienced the highest mean trap mortality rates (53.68 ± 6.51 %) while those in baited traps checked at short intervals experienced no trap mortality (Fig. 3.3). I did not detect a significant difference ($t_{20} = -0.93$, P = 0.36, corrected alpha = 0.003) in trap mortality rates between baited traps checked at medium and short intervals. Statistical results for all meaningful pairwise t – tests are located in Table 3.2.





traps received only grain baits.



Figure 3.3: Effect of additional mealworm bait, and trap check interval on mean(±S.E.) mortality rate of vagrant shrews. Short intervals were 3-4 h between checks, medium were 6-10 h, and long were 12-14 h.

Experiment 2

In Experiment 2 deer mice were numerically dominant (180 individuals), with shrews (50) second, Oregon voles (*Microtus oregoni*) third (34), shrew moles (*Neurotrichus* gibbsii) (3), short-tailed weasels (*Mustela ermanea*) (2), jumping mice (*Zapus trionatus*) (1), and Townsend's chipmunks (*Tamias townsendii*) (1) making up minor components. In experiment two I was unable to detect significant differences between treatments ($F_{3,6} = 0.06$, P = 0.97). An average of 3.67 (± 2.38) to 5.00 (± 2.38) shrews were captured in each of the four treatments (Fig. 3.4). The Longworth with drift fence treatment had the highest mean capture rate, the separate Longworth and pitfall with fence treatments had equal mean capture rates (4.00 ± 2.38 shrews), and the separate pitfall treatment captured the fewest. No Pacific water shrews were captured over the course of the study.





Discussion

Experiment 1

In Experiment 1, I tested the influences of trap type (Longworth or pitfall) and additional mealworm bait (baited or non-baited) on capture rates and trap mortality of vagrant shrews. A third treatment, trap check interval was introduced in response to high trap mortality during the first two trapping sessions. Contrary to my hypothesis (1), that pitfall traps would be more effective than Longworth traps for capturing shrews, Longworth traps captured significantly more (up to 5 times more) vagrant shrews than pitfall traps. In Experiment 2, Longworth and pitfall traps captured an equivalent number of shrews, and, contrary to my hypothesis (2), the effect of drift fences was not significant. However, due to a small sample size, differences were difficult to detect. In fact, the minimum detectable mean difference between any two treatments was 12.48 captures, while the maximum mean difference observed was 1.34.

Three other studies have compared Longworth and pitfall traps. Innes and Bendell (1988) compared capture rates of small mammals in Longworth and Victor mouse (snap) traps, and plastic pitfalls (16 cm diameter, 12 cm depth) containing a preservative. Due to high trap mortality in Longworth traps (>95%), all three trap types acted as removal traps for *Sorex* species. They reported that snap traps captured the greatest number of shorttailed shrews (Blarina brevicauda), masked shrews (Sorex cinereus), and smoky shrews (Sorex fumeus). Pitfalls captured the second highest number of masked and smoky shrews, and were the only trap to capture American pygmy shrews (Sorex hoyii). Longworth traps captured the second highest number of individual short-tailed shrews (Innes and Bendell 1988). Part of the reason for their relative success in capturing large numbers of shrews in snap traps, in contrast to other reports (e.g. Mengak and Guynn 1987, McComb et al. 1991), may be due to snap trap transects being relocated every four to five days. Also, pitfall grids were operated continuously while Longworth traps were set for only one night out of 5 - 10 (mean of 8). Pygmy shrews are considered rare (Long 1974); however Prince (1941) reportedly captured many in water traps. Due to their small size (2.2 - 6 g), Longworth traps not set to their lightest tripping weight may fail to capture pygmy shrews. Also, Shore et al. (1995) expressed concern that the Eurasian pygmy shrew (Sorex minutus), which is similar in size to the American pygmy shrew, would be able to walk under the treadle bar in Longworth traps, and thus not be captured. Craig (1995) compared Longworth traps to the same type of dry pitfalls that I used and operated both singly (i.e., without drift fences). Using one pitfall and one Longworth trap at each trap station, Craig (1995) was able to capture vagrant, masked, and dusky (Sorex monticolus) shrews. Craig (1995) reported that most resident (71.6% of individuals

captured > 1 time) shrews were captured in both types of trap, while significantly more transient (64.4% of individuals captured only one time) were captured in pitfalls than Longworths. Also, of the resident shrews captured in only one type of trap, significantly more (69.5%) were captured in pitfalls. Thus, pitfalls had a significantly higher number of shrew captures than Longworths. Similar to my Experiment 2 Craig (1995) captured few (126 over nine trapping grids) shrews in 60-80 year-old coniferous forest, and combined species for analysis, masking any species-specific response.

Shore *et al.* (1995) used Longworth traps equipped with a treadle ramp and smaller (9.5 cm diameter, 15 cm deep) dry pitfalls on an upland blanket bog, to live-trap common (*Sorex araneus*) and Eurasian pygmy shrews. They reported that 89% of shrews were caught in Longworth traps. Also of note, no shrews captured in pitfalls were recaptured in them, although shrews were recaptured in Longworths. Because Shore *et al.* (1995) limited their study to one trapping grid, and a single week of trapping, their sample size was small (18 Eurasian pygmy, 17 common shrews). Thus, extrapolation of these results to other systems is difficult.

As expected, with respect to hypothesis (3), that addition of appropriate bait would decrease trap mortality of vagrant shrews, addition of mealworm bait to traps significantly reduced trap mortality. Shrews have very high metabolic rates (Pearson 1947, Churchfield 1990, Gliwicz and Taylor 2002), and are commonly thought to require 80 – 100% of their body weight in food each day. During pregnancy, females may consume up to 300% of their body weight each day (Churchfield 1990). Shrews are primarily insectivorous, and thus grain baits used for rodents are probably not a suitable food source. Crowcroft (1951b) suggested that additional food was not necessary;

however, traps must be checked, at a minimum, every 2 h to decrease trap mortality. Otherwise, Pearson (1950) suggested that a mixture of meat, liver, and cereal grains provided a suitable food. Crowcroft (1951a) maintained shrews in the laboratory on a diet of earthworms and oats, supplemented with vole and mouse corpses, and occasional fish. Younger *et al.* (1992) were able to decrease trap mortality of masked shrews using pieces of whitefish, while Craig (1995) used raw beef or pork. My results agree with Churchfield (1990) and suggested that invertebrate baits such as blowfly pupae or mealworms provided a suitable food source.

This is the first study to include a test of my hypothesis (4), that a reduction in the interval between trap checks would significantly reduce trap mortality rates of vagrant shrews. Previous studies have successfully live-trapped shrews using trap check intervals ranging from 1.5 h (Hawes 1977) to once daily (Hays 1998). Hays (1998) used modified Sherman traps that provided a large nesting area, and contained a large quantity of appropriate food (mealworms). The significant influence of trap check interval on trap mortality may be due to shrews consuming large quantities of food upon entering the traps, and starving later in the day (Crowcroft 1951a). An additional concern is that stress resulting from confinement may increase trap mortality rates post-release for animals confined for longer periods (Craig 1995). In Experiment 1 the trap check interval treatment was not included in the design from the outset, thus, there is a need for further refinement of my results through an experiment specifically designed to test this hypothesis.

In the literature, pitfall traps have been used in a variety of ways, with variations in the size and arrangement of traps, and the use of drift fences. A common arrangement

of pitfall traps follows Bury and Corn (1987) and uses several pitfalls arranged around an array of three drift fences each at least 3 m long. This arrangement is commonly used with one array per site, and because it may take up to a month to capture all the species occurring on a site (Bury and Corn 1987), these pitfall arrays are usually operated as continuous removal traps. My drift fence arrangement resembled one of these arms operated independently; however, my arrangement could not be expected to capture all the shrews encountering it, as could be expected of large arrays. Because of this, and because I used several short (2 night) trapping sessions rather than a single continuous sampling period, my results were not directly comparable with those of authors using pitfall arrays to capture shrews. In a literature review of pitfall trapping for shrews, Handly and Kalko (1993) discussed differential effectiveness of different sizes of pitfall traps, and their operation with drift fences, and made recommendations for different combinations depending on the goal of the study. Also, because of the small sample size in Experiment 2 I was unable to evaluate the relative effect of drift fences on Longworth and pitfall traps; nor was I able to evaluate a potential species-specific response.

Conclusions

Longworth live-traps captured a significantly greater abundance of vagrant shrews than pitfall traps on agricultural set asides in Delta, B.C. The use of mealworms as a supplemental food in traps significantly reduced trap mortality rates, as did reduced intervals between trap checks. My sampling protocol involved provision of mealworms in a quantity approximately equal to the body weight of the largest shrew species expected to be captured, and a maximum interval between trap checks of 8 h. This protocol provided for inclusion of live-capture results for shrews into small mammal field studies,

by reducing trap mortality rates from 54% using standard rodent trapping protocol, to 8% using my protocol. Further work is required to evaluate the hypotheses tested in my Experiment 2, which was limited due to small sample size. In particular, an important improvement would be to increase the sample size in each treatment, either by lengthening the traplines used, by increasing the number of replicates used, or both. Specifically, the evaluation of species-specific responses and the relative effect of drift fences on pitfall and Longworth traps is warranted. Finally, because no Pacific water shrews were captured the efficiency of these two trap types for capturing this elusive species remains to be assessed.

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Chapter 4 : General Conclusions

Introduction

Shrews are among the smallest organisms in the Class Mammalia. Much of the biology of shrews, including their diet, body size characteristics (i.e., in some cases opposing Bergmann's Rule), food resource partitioning, and 'biennial' life history owes to their exceptionally high metabolic rates. The high metabolic rate of shrews has also been at the root of historic difficulties in livetrapping. Removal (i.e. kill) trapping of small mammals should be restricted by ethical concerns, and by the desire to preserve the quality of the data obtained (e.g. Sullivan *et al.* 2003). In situations where species of special concern (e.g. the Pacific water shrew, *Sorex bendirii*, in south western British Columbia) may be present, removal trapping methods are inappropriate. However, the dominant method of study for shrews in North America has been removal trapping using charged (i.e., half filled with water or a preservative) pitfall traps. More efficient (for the researcher) and effective (at capturing shrews) methods are required if the study of complete small mammal communities (including shrews) is to continue using mark-recapture type experiments.

The ultimate goal of my research has been to inform the methods of study for the Pacific water shrew, an endangered shrew species occurring in south western B.C. To meet my ultimate goal I conducted a comprehensive literature review of the factors that potentially influence differing susceptibility to capture (trappability) in small mammals, in particular, shrews (Chapter 2). I carried Experiment 1 (May-September 2006) (Chapter 3) to evaluate the effect of additional insect baits (i.e. mealworms) and the frequency of

trap checks on trap mortality rates in vagrant shrews (*Sorex vagrans*), as a proxy for *Sorex* spp. in general. Experiment 1, along with Experiment 2 (May-September 2007) (Chapter 3), also sought to identify the most suitable trap type for capturing shrews by comparing two trap types (Longworth and pitfall), that have previously been effectively used to sample shrew communities, and to determine the effectiveness of drift fences for increasing the capture rates of shrews in livetraps. Together, the literature review, Experiment 1, and Experiment 2 can be used to inform the methods used to livetrap *Sorex* spp. in general and the Pacific water shrew in particular.

Factors affecting trappability

In studies of small mammal communities using mark-recapture methods, a key assumption is that all individuals on a given area are equally trappable. This assumption must be met for valid inferences to be made whether population estimation approaches, such as the Jolly-Seber population estimate, or enumeration methods, such as the minimum number known to be alive (MNA) index, are used. However, this assumption is not always met. My objective in Chapter 2 was to review the published literature, and determine what factors are most likely to cause differing trappability in small mammals. I found that in addition to the type of trap used, both weather factors (cloud cover, precipitation, and lunar phase), and social factors (intra- and interspecific dominance relationships) can affect the trappability of small mammals, and that these factors may interact with each other and the habitat type to further complicate an assessment of the trappability of a complete small mammal community. The dominant hypothesis to explain the increased activity levels (and consequent increased trappability) of rodents with increased cloud cover, increased precipitation, and decreased moonlight, is that

individuals are attempting to minimize their predation risk. However for shrews, a hypothesis that increased precipitation increased prey availability, and decreased water stress on foraging individuals, consequently resulting in increased activity following precipitation, was proposed. In several cases there was documented evidence of both inter- and intraspecific dominance relationships, which affected the trappability of both the dominant and subordinate individuals. The effect of trap type on trappability was the most frequently evaluated single phenomenon, perhaps because it was the easiest factor for researchers to vary. Due to the susceptibility of the treadle mechanism to wear and tear or jamming, the Longworth live-trap may be a more appropriate trap than the Sherman trap for the smallest members of small mammal communities, however, there was no clear evidence as to which type of live trap was most appropriate, in general.

Pitfall vs. Longworth live-traps

Contrary to my hypothesis, in Experiment 1, the Longworth live-trap captured significantly more shrews than pitfall traps. This was surprising given that pitfall traps are often assumed to be the most effective trap type for capturing shrews. However, this was the first study to attempt to use live traps in conjunction with drift-fences. The use of drift-fences with pitfall traps may contribute to their greater success at capturing shrews than other types of traps not used with drift-fences. However, the results from Experiment 2, that attempted to test the effect of drift fences on trapping efficiencies of pitfall and Longworth traps were equivocal, owing in part to a small sample size. The use of mealworms as bait to provide food for shrews, and the addition of a midday trap check, so that traps were not left unchecked for more than 8 h, reduced trap mortality of vagrant shrews (*Sorex vagrans*) from nearly 60% to less than 10%. This effect should be

similar for other species of *Sorex*, provided that an appropriate amount of food (approximately equal to the trapped species body weight) is included when larger species are trapped.

Management Recommendations

Longworth live-traps have several advantages over pitfall traps. Pitfall traps were labour intensive to install, and when operated as live-traps, no gains were made in efficiency, as reported when pitfalls are used as continuous removal traps, and require checking only once or twice weekly. Also, even when equipped with a large cover board several centimeters above the opening, pitfall traps were still subject to flooding during even moderate rainfall. Water was observed to enter traps via overland flow, and in some cases, drift fences served to direct water into the pitfall traps. Even when equipped with a small sponge to absorb excess moisture the cotton fibre used as bedding material was still found to be damp to the touch, which may contribute to trap mortality. Also, pitfall traps act as multiple capture traps, whereas Longworth traps are single capture only. Although desirable when used as removal traps, many small mammals are territorial and will fight, injure, and kill one another when kept confined in a small space such as a pitfall trap. It was observed that in pitfall traps that captured more than one shrew at a time, only a single shrew was left alive at the trap check, with the other one (or several) having been killed, and often eaten. Although some studies have reported that pitfall traps are very efficient at capturing shrews, the disadvantages discussed here make the pitfall trap an inappropriate trap type for use in livetrapping of shrews, particularly where species of special concern are present. My work indicates that Longworth traps may be more efficient, or at least equivocal, to the pitfall trap for capturing shrews, and thus provides a

suitable alternative to the pitfall trap for mark-recapture study of shrew populations. Many factors affect the activity level of small mammals, and thus, their trappability. To minimize the effect of weather, on trapping, spreading trapping out over as long a period as possible, (i.e., by having several short trapping periods) may more effectively sample complete small mammal communities. Current best management practices for the Pacific water shrew (Craig and Vennesland 2005) recommend a minimum sampling effort of one pitfall trap placed as near as possible to the stream edge, every 15 m for a minimum of 500 m or up to a third of the entire water body, whichever is greater up to a maximum of 1 km. The best management practices guidelines also recommend the use of drift-fences a minimum of 3 m in length wherever there is not a suitable piece of large woody debris available for use as a natural drift-fence. The minimum time period for trapping Pacific water shrews as recommended by the best management practices guidelines is seven consecutive days. The use of drift-fences has been shown to be effective at improving capture rates of shrews in pitfall traps and should work in the same manner with livetraps, however, further work to demonstrate this effect is required given the low capture rates in my study. Given the difficulties in using pitfall traps and the results of my Experiment 1, combined with the need to refine my Experiment 2, my recommendation for improving livetrapping methods for Pacific water shrews are threefold:

1. The minimum food requirement for livetrapping shrews is the body weight of the largest species expected to be captured (for Pacific water shrews approximately 15 g of bait is required). I used mealworms, however, raw beef, pork, or wet cat food have also been used successfully.

- 2. The maximum interval between trap checks for livetrapping shrews was 8 h, however, due to flooding of pitfall traps, much more frequent checks (i.e., every 3 h) are required if pitfall trapping is to be conducted in periods with moderate to high rainfall.
- Due to the disadvantages of pitfall traps, and the apparently superior efficiency of Longworth traps, the Longworth trap should be the standard live-trap used to sample Pacific water shrews.
- 4. To minimize potential weather effects on the trappability of Pacific water shrews trapping should be spread out over as long a period as possible. Ideally several trapping periods over a period of several months, incorporating at least one session following rainfall during a time of year when populations are potentially at a peak (late summer) would provide for a more reliable evaluation of this elusive species' habits.

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