DEER MOUSE PREDATION ON THE BIOLOGICAL CONTROL AGENT, *UROPHORA* SPP., INTRODUCED TO CONTROL SPOTTED KNAPWEED

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ABSTRACT—Field observations made in 1993 suggested that rodents were preying on spotted knapweed (*Centaurea maculosa*) seedheads, possibly targeting the gall fly larvae (*Urophora* spp.) which overwinter within them. I conducted a brief study to determine the cause of seedhead predation and quantify gall fly predation. Stomachs were examined from 19 deer mice (*Peromyscus maniculatus*) captured in the fall of 1993 and winter of 1997. All individuals had preyed upon gall fly larvae. The mean number of gall fly larvae found in 10 deer mouse stomachs in the winter of 1997 was 212.8. The minimum number of larvae consumed by these 10 animals for 1 night of foraging was 2686. Availability of a concentrated protein that is a readily accessible and abundant resource during winter may elevate deer mouse populations in knapweed-infested habitats. Increases in densities of deer mice due to gall fly presence could bring about shifts in composition of small mammal communities.

Key words: *Peromyscus maniculatus, Urophora, Centaurea maculosa,* deer mouse, gall fly, spotted knapweed, predation, biological control

Spotted knapweed (*Centaurea maculosa*) is 1 of the fastest-spreading rangeland weeds in Montana (Story and Nowierski 1984). Since it was 1st recorded in the state in 1927, it has taken over more than 800,000 ha of rangeland, pasture, and disturbed areas (Story and others 1987). In an attempt to control the spread of spotted knapweed, a European species of tephritid fly (*Urophora affinis*) was released in westcentral Montana in 1973 (Story and Anderson 1978). Another species of tephritid, *U. quadrifasciata,* which had been released in British Columbia in 1972 (Story and others 1987), was reported to have spread to Montana by 1981 (Story 1985) and has since become established in northwest and westcentral Montana (Story and others 1987). Though *U. affinis* initially dispersed very slowly from its release sites (Story and Nowierski 1984), it is now the dominant gall fly in westcentral Montana (Story and others 1987, 1995). Both species of tephritids lay eggs in the seedheads of spotted knapweed. The larvae induce galls in the seedhead reducing overall seed production (Story and others 1987; Harris 1980). Gall infestation rates of *U. affinis* following their release in western Montana varied by site and year and ranged from 0.8 to 9.3 galls per seedhead (Story and Nowierski 1984).

Few wild or domestic herbivores consume spotted knapweed due to its toxicity and high fiber content (Maddox 1979; Strange and others 1979). This situation has contributed greatly to its spread. However, Story and Nowierski (1984) observed signs of rodent predation on gall fly larvae during the winters of 1979 to 1981 at 2 *U. affinis* release sites in western Montana. To determine the cause, they set out 7 live traps baited with knapweed seedheads for 10 days and captured 7 *P. maniculatus* at 1 of these sites. Their results suggest that *P. maniculatus* may have learned to prey on gall fly larvae as early as 6 years after the initial introduction (if not sooner). Story and others (1995) have since implicated *P. maniculatus* in foraging on knapweed seedheads at 19 locations in western Montana, based on bite marks on knapweed stems and the presence of foraging piles. Using this methodology, they attributed 25% of seedhead removal to *P. maniculatus,* 25% to black-capped chickadees (*Parus atricapillus*), 24% to white-tailed deer (*Odocoileus virginianus*), 2% to other small mammals, and 24% to unknown sources.

To date, no one has directly measured *P. maniculatus* predation on *Urophora* larvae by analyzing stomach contents. Furthermore, the importance of this phenomenon has not been recognized beyond its implications for the biological control of spotted knapweed. In this paper I present results from stomach content analysis of *P. maniculatus* and estimate rates of *Urophora* larvae consumption by this species.

STUDY AREA AND METHODS

In September 1993, I observed piles of predated spotted knapweed seedheads scattered throughout knapweed stands and knapweed-infested grasslands on the west face of Mt. Sentinel overlooking the city of Missoula, Montana. Inspection revealed that each pile was composed of multiple seedheads that had been severed ≥2 cm below the base of the receptacle and dismembered. Remains of open galls were evident in many piles. These observations suggested that gall fly larvae were being preyed upon and that the predator was likely a rodent. Although black-capped chickadees feed upon gall fly larvae in this area, they generally do not feed far from tree or shrub cover (Story and others 1995; pers. obs.).

In October 1993, I attempted to determine whether rodents were preying on gall fly larvae and to identify which species were responsible. I set out 20 clean, unbaited, snap traps (10 museum special traps and 10 smaller Victor mouse traps) 5 m apart along a transect parallel to the slope in an area of abundant feeding sites. The transect was at approximately 1115 m elevation on the west aspect of Mt. Sentinel due east of and overlooking Missoula, MT. The habitat is palouse prairie (Peter Stickney, U. S. Forest Service, Rocky Mountain Research Station, Missoula, MT, pers. comm.), but in the area trapped, spotted knapweed makes up approximately 20 to 70% of the vegetative cover. I trapped the site for 2 days (40 24-hr trapnights) from 25 to 27 October, checking traps once each day early in the morning. Although *P. maniculatus* was the most likely predator, I used large and small unbaited snap traps set out over full 24-hr periods to reduce the potential for biasing the trapping sample. I removed stomachs from each individual and recorded the presence or absence of gall fly larvae.

In February 1997, I trapped an area about 150 m from the original transect with the intention of targeting *P. maniculatus* to quantify their consumption of gall fly larvae. I set out 20 Victor snap traps, baited with peanut butter and spaced 10 m apart along a transect running perpendicular to the slope. The elevation of the transect ranged from approximately 1130 to 1300 m. Trapping lasted 5 days from 3 to 8 February resulting in 100 24-hr trapnights. Traps were checked in the afternoon each day.

Due to low ambient temperatures, specimens were frozen when collected; they were placed in a freezer until stomach contents could be examined. All stomach contents were analyzed within a week of capture. I inverted each stomach and cecum, carefully transferring all contents into separate Petri dishes containing water. I placed Petri dishes on a light table to backlight the contents and counted the number of gall fly larvae as I removed each with forceps. Larval remains were identified by the presence of black head capsules attached to the remnants of skin. Contents of the cecum were more thoroughly digested, but could be identified using the same method. Volumes of each of 3 categories (gall fly larvae, vegetative material, other) were estimated from the contents of each stomach. Jim Story (Western Agriculture Research Center, Corvallis, MT) positively identified the larvae as *Urophora* spp.

RESULTS

In October 1993, 7 *P. maniculatus* were collected (5 males, 2 females). No other species were captured during the 40 trapnights. All 7 stomachs contained numerous gall fly larvae.

In February 1997, I captured 12 *P. maniculatus* during 100 trapnights (7 males and 5 females). Eighty-three percent of the stomachs and 100% of the ceca contained gall fly larvae. Two stomachs contained no larvae. One of these was completely empty, and the other contained only peanut butter. After excluding these 2 individuals from the sample, there were 212.8 ± 151.7 ($\bar{x}$ ± SD) larvae per stomach (range = 22 to 553). The number of larvae from stomachs and ceca combined was 268.6 ± 169.8 (30 to 650). The total number of gall fly larvae consumed by the 10 individuals based on stomachs and ceca was 2686. Gall flies made up about 90% of stomach contents by volume after excluding trap bait. Vegetative material was the 2nd most important category averaging about 9%. Other materials identified included downy

fibers and scales from knapweed seedheads, remains of gall shells, 3 live nematodes, hair, and unidentified material.

Discussion

The high proportion of *P. maniculatus* stomachs (90%) that contained ≥90% gall fly larvae suggests that these insects, released for biological control of spotted knapweed, may be an important component in the winter diet of *P. maniculatus* living in knapweed-infested habitats. Although these data do not indicate what proportion of the gall fly population is depredated by *P. maniculatus*, they do suggest that *P. maniculatus* may be an important predator on gall fly larvae. In the equivalent of 1 night of foraging, 10 individuals consumed at least 2686 gall fly larvae. Based on the average number of larvae consumed per animal per night observed in this study, a single *P. maniculatus* could destroy a minimum of 8058 gall fly larvae per month (30 days). Extrapolating this estimate to a population of *P. maniculatus* at a moderate density of 10 animals per ha, 80,580 gall fly larvae would be consumed per ha in 30 days on Mt. Sentinel. This estimate is likely conservative because animals will generally not be caught at the end of their foraging bouts, and high protein foods such as larvae are quickly digested (2 to 5 hr) in an omnivore's digestive tract (Robbins 1981).

After capturing 7 individuals while live trapping an area of foraging sites using traps baited with knapweed seedheads, Story and Nowierski (1984) concluded that *P. maniculatus* preyed upon *Urophora* spp. However, capturing *P. maniculatus* in this manner does not provide conclusive evidence that this species preys on gall fly larvae, because *P. maniculatus* readily enter unbaited traps (pers. obs.). Story and others (1995) provided more convincing evidence that *P. maniculatus* preyed on gall fly larvae in a follow up study when they fed knapweed seedheads to caged animals and studied the resulting bite patterns. They then sampled knapweed stems at 19 locations and concluded, from bite patterns and foraging piles, that *P. maniculatus* was responsible for 25% of the observed predation at 1 site.

The data presented here support the conclusions of Story and others (1995) by using a more direct means of assessing *P. maniculatus* predation on gall fly larvae. Moreover, these data assess the individual foraging potential of *P. maniculatus* on *Urophora* larvae and show that the behavior is not limited to a subset of individuals within a population. All individuals captured on Mt. Sentinel during the fall of 1993 and the winter of 1997 had consumed gall fly larvae. The gall fly larvae numbers observed in 10 of the stomachs indicate that *P. maniculatus* can consume vast quantities of *Urophora* over a relatively short time and are most certainly targeting this abundant food resource. This predatory potential and the wide-spread nature of the phenomenon as reported by Story and others (1995) suggest that gall fly predation by *P. maniculatus* may have extensive implications for native grassland communities and the ability of *Urophora* spp. to biologically control spotted knapweed.

Peromyscus maniculatus may impact knapweed and its tephritid biological controls in 2 ways. First, *P. maniculatus* predation could potentially reduce gall fly populations and their spread. Story and Nowierski (1984) suggested that the lower densities of *U. affinis* observed at 1 release site could have been partly attributable to rodent predation at this site. However, *P. maniculatus* are also important seed predators (Radvanyi 1973; Sullivan 1979) and may consume knapweed seeds while foraging on gall fly larvae. As a result, *P. maniculatus* predation on spotted knapweed could further reduce abundance of knapweed seeds. This predation could result in the destruction of the surviving seeds within a seedhead if it occurs in August and September before knapweed seeds disperse (Watson and Renney 1974). Therefore, the complimentary effect of *U. affinis* and *U. quadrifasciata* described by Harris (1980) and Myers and Harris (1980) on reducing knapweed seed production could be further augmented by *P. maniculatus* predation on gall fly larvae if predation occurs in late summer. However, predation during this period has not yet been documented.

If food is the primary limiting resource for *P. maniculatus*, especially during winter, which is the population bottleneck for most temperate zone rodents (Pearson 1999), an abundant, high protein food supply that is accessible in winter and remains readily obtainable above and below the snow surface will likely favor higher *P. maniculatus* population densities. This could alter the composition of small mammal commu-

nities in knapweed-infested grasslands as compared to native grasslands. Higher *P. maniculatus* densities could also increase the incidence of hantavirus within their populations (Mills and others 1995).

Story and others (1995) determined that chickadees and *P. maniculatus* were each responsible for about 25% of the seedhead predation observed and that white-tailed deer had taken 24%. They observed that chickadees spent 64% of their foraging time feeding on gall fly larvae. However, as Story and others (1995) reported, chickadees do not forage far from shrub or tree cover and are therefore restricted from large, open expanses of knapweed. This is not the case for *P. maniculatus*, which can persist anywhere that knapweed becomes established. Additionally, the intensity of *P. maniculatus* predation reported here emphasizes the proficiency with which this species preys upon *Urophora* larvae. *Peromyscus maniculatus* may have been largely responsible for the 24% of larval predation observed by Story and others (1995) that could not be attributed to any of the aforementioned predators. I suggest that *P. maniculatus* may be the single most important predator of *Urophora* spp. identified to date.

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