AN ABSTRACT OF THE THESIS OF

Carol S. Bell for the degree of Masters of Science in
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Title: The Distribution, Larval Survival, and Impact of a
Tip Moth Guild (Lepidoptera: Tortricidae: *Rhyacionia*
species) in the Northern Plains

Signature redacted for privacy.

Abstract approved:_____
                        Timothy D. Schowalter

        A guild of three and possibly five tip moths
(*Rhyacionia* spp.) occurs on ponderosa pine (*Pinus ponderosa*)
in southeastern Montana, northwestern South Dakota, and
southwestern North Dakota. Trapping results indicated that
many of these species may be flying simultaneously, and
individual species relative abundances showed west-to-east
trends.

        Tip moth larvae became increasingly concentrated in the
tops of trees as the summer progressed. A significant
percentage of larvae in infested shoots were parasitized or
died before pupating. Parasitism rate was higher in larvae
collected later in the growing season. Tip moth larval
survival rate was affected by larval location within the
tree and the date of collection.

        Seedlings and saplings studied had fewer branches on
average than ponderosa pines in other regions. The percent
of apical shoots infested per tree (API) was strongly
correlated with the total percent of shoots infested per
tree (PI) as long as API was less than 50%. Neither API nor
PI was strongly correlated with total linear shoot growth
(linear growth). Linear growth was affected by tree
deformity and available site moisture. Wetter sites also
had higher mean PI.

Aspect, slope, regenerating tree density, horizontal configuration, topography, and habitat types were examined for effects on tip moth activity. Impact measures such as API and PI were not strongly affected by these characteristics. PI appeared to be higher in areas that retain moisture, i.e. concave or horizontal land form, than in areas that do not, i.e. convex or slope land form. Abundant precipitation may mask this relationship.

Management implications are discussed.

The Distribution, Larval Survival, and Impact of a Tip Moth
Guild (Lepidoptera: Tortricidae: *Rhyacionia* species)
in the Northern Plains

by

Carol S. Bell

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The Distribution, Larval Survival, and Impact of a Tip Moth Guild (Lepidoptera: Tortricidae: *Rhyacionia* species) in the Northern Plains

Chapter 1:

Introduction

Tip moths, *Rhyacionia* spp. (Lepidoptera: Tortricidae), are common on the Ashland and Sioux Ranger Districts (RDs) of the Custer National Forest in southeastern Montana and northwestern South Dakota. Recently, increased demand for timber resources from these districts has forced land managers to look at the tip moth situation more closely. Managers' concerns are focused in two areas: 1) effects of tip moths on advanced natural ponderosa pine (*Pinus ponderosa*) regeneration, and 2) effects of tip moths on artificial (planted) ponderosa pine regeneration.

Preliminary studies found multiple species of tip moths infesting both newly planted areas and advanced regeneration over the Crow Indian Reservation (IR), Northern Cheyenne IR, Ashland RD, Sioux RD, and Medora RD. However, virtually nothing is known about the distribution or importance of tip moths in this area. Effective management of the forest resources requires appropriate information on tip moth distribution, mortality agents, and impacts. This study was initiated to provide information on tip moths in this region. Three objectives were addressed: 1) to clarify which tip moth species are present, their geographic distribution, and relative abundance across the five management areas; 2) to study the survival of tip moth larvae in infested shoots on trees; 3) to address the land managers' concerns by determining the current infestation rates, assessing the level of tip moth-caused deformity on trees, and testing for correlation between tip moth activity and pine growth. In order to accomplish these objectives, I studied the severity and distribution of tip moth activity

in relation to certain site and stand characteristics.

The Study Area (Figure 1):

The Crow IR, located in southeastern Montana, contains part of the Pryor, Bighorn, Wolf, and Rosebud Mountains to the west and the lowlands of the Great Plains to the east. The highest portions of the reservation are rolling plateaus at 2,000 m (7,000 feet) elevation. As a consequence of their relatively low elevations, the Pryors support only montane and lower subalpine forest types characterized by the *Pinus ponderosa, Pseudotsuga menziesii,* and *Abies lasiocarpa* forest types.

All Northern Cheyenne IR lands are located in southeastern Montana and are part of the Great Plains, except for the western-most fringe in the Wolf Mountains. A multitude of drainages have incised the area, leaving little in the way of bench lands or plateaus and producing a convoluted topography. In general, forests are better developed on slopes, exclusive of areas where scoria beds or calcareous outcrops occur. The lowest elevations (approximately 900 m (3,000 feet)) and smallest aerial extent of forested lands are found along the southern and eastern reservation boundaries; both elevation and forested area increase gradually to the west, where the highest point is Crazy Horse Lookout at 1,460 m (4,792 feet) (Cooper and Pfister 1985).

The Ashland and Sioux RDs lie within the Great Plains of southeastern Montana and northwestern South Dakota. They are characterized as an upland plain interrupted by table lands, drainage ways, streams, and rivers. The dominant features are rolling, terrace like steppes.

The Ashland RD is located in the Rosebud and Powder
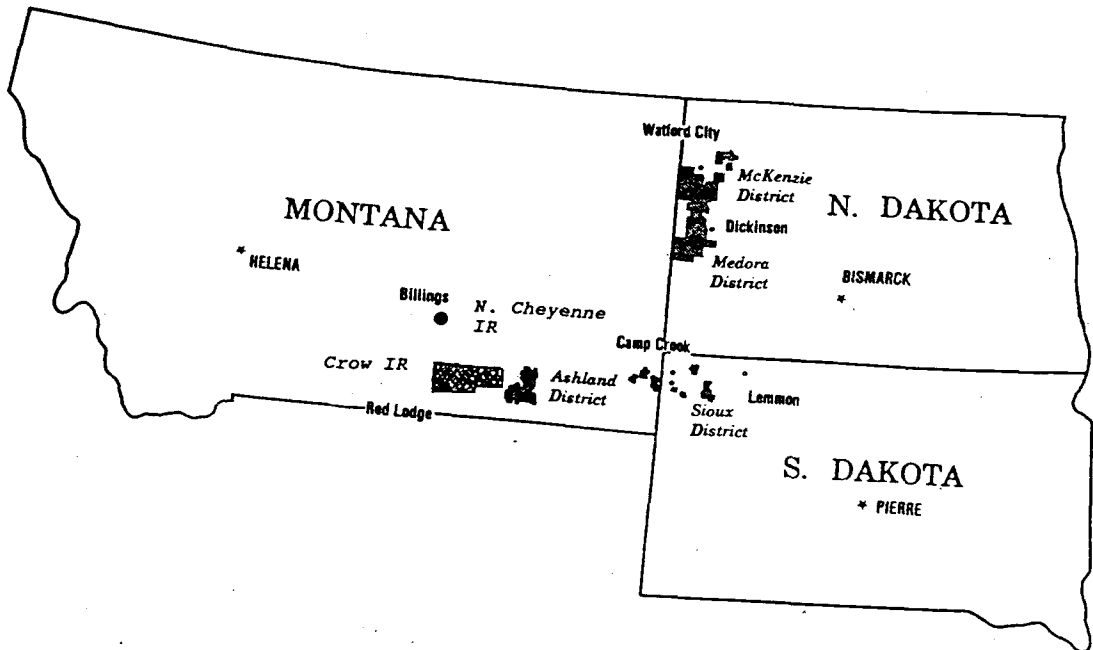
Figure 1: The general area for the *Rhyacionia* spp. studies in 1991 and 1992. From west to east within this area are the Crow Indian Reservation, the Northern Cheyenne Indian Reservation, and the Ashland, Sioux, and Medora Ranger Districts.

River counties of southeastern Montana. It has a highly
irregular topography, and common landscape features are
badlands, sandstones, shale escarpments, and scoria beds.
Main drainages are the Tongue and Powder Rivers which flow
northward to the Yellowstone River.

The Sioux RD is in Carter County of southeastern
Montana and Harding County of northeastern South Dakota. It
is composed of eight land units that rise 100-300 m (300-900
feet) above the surrounding plains. The main drainages are
the Grand and Moreau Rivers that flow eastward and the
Little Missouri that flows northward to the Missouri River
(Hansen and Hoffman 1988).

The Medora Ranger District is part of the Little
Missouri National Grassland in western North Dakota. It is
located in the south central portion of the Williston Basin
and overlies approximately 4,200 meters of sedimentary
formations.

Climate:

The two reservations and three ranger districts have a
xeric continental climate. They have long, cold winters and
short, warm summers. In a normal year 75% of the annual
precipitation falls during the growing season from April
through September, and 50% falls during April, May, and
June. The average recorded rainfall ranges from 318 mm
(12.5 inches) in Birney (Cooper and Pfister 1985) to 412 mm
(16.2 inches) in Ashland (Hansen and Hoffman 1988). The
amount of annual precipitation varies greatly with
topography, and forested lands likely receive greater
amounts of precipitation than recorded at weather stations,
all located at lower elevations. Orographically enhanced
precipitation for these higher elevation areas may be
greater by 50-100 mm (2-4 inches) (Cooper and Pfister 1985).

The importance of increased precipitation and lower air temperatures to forest development can be seen in the restriction of forest stands to higher elevations and protected north and east facing aspects at lower elevations (Cooper and Pfister 1985).

The Forests:

Ponderosa pine forest is the only commercial forest type on the Ashland and Sioux RDs. In these districts ponderosa pine forests form a mosaic interspersed with steppe and shrub-steppe (Hansen and Hoffman 1988). Stand structure ranges from open, savanna-like, multi-aged woodlands on bunchgrass-dominated drier sites to dense canopied, even-aged, shrub-dominated forest on more mesic sites (Cooper and Pfister 1985). *Pinus ponderosa* and *Juniperus scopulorum* are the only successfully reproducing trees in these forests (Pfister et al. 1977, Cooper and Pfister 1985).

Historically, fire was an important factor in these forests (Arno 1976, Davis et al. 1980). Fire and harsh site conditions maintained open stands by killing weak or crowded saplings and pole-sized trees. Pine-bunchgrass habitat types are well adapted to frequent understory burns with average intervals between fire from 6 to 20 years. Intervals between fires are longer in the tall shrub (mesic) habitat types (Arno 1976) and these types are capable of generating fuel ladders which lead to stand-replacing fires.

The soils in this region are quite variable but are not strongly correlated with changes in vegetation. Most vegetational variation is due to local topographic influences on available moisture (Cooper and Pfister 1985).

Timber productivity in open bunchgrass-pine habitat types is low, with low densities of trees with low growth

rates and poor growth form. Most mesic pine habitat types have high timber productivity. Forage productivity, especially in the bunchgrass-dominated community types, is above average for cattle and big game. The shrub-dominated plant communities provide moderate forage potential for livestock and big game, and seral ponderosa pine stands can produce abundant herbage (Hansen and Hoffman 1988). In this region management activities are oriented towards range activities. The reservations and ranger districts have unrestricted cattle grazing.

Natural pine regeneration success depends on simultaneous seed crop production and soil moisture. Exposed mineral soil seedbeds and reduced competition for soil moisture are the most favorable conditions for successful seedling establishment (Harrington and Kelsey 1979). Natural pine regeneration is abundant throughout the study area.

Chapter 2:

Distribution of Tip Moth Species (Lepidoptera: Tortricidae: *Rhyacionia* spp.) on Ponderosa Pine in the Northern Plains

Introduction

Tip moths (*Rhyacionia* spp.) are common pests of young pine. In many regions, it is difficult to diagnose the tip moth species responsible for damage because more than one species is present (Miller and Wilson 1964, Berisford 1974, Bear and Berisford 1975, Staines et al. 1984). Seven species of tip moth may occur on ponderosa pine (*Pinus ponderosa*) in the northern Plains: *R. buoliana*, *R. fumosana*, *R. neomexicana*, *R. zozana*, *R. busckana*, *R. bushnelli* (Powell and Miller 1978), and *R. granti* (Miller 1985, Miller 1991). Of these seven, three were trapped during a West-wide survey (Stevens et al. 1980). Most are considered minor pests. However *R. buoliana*, the European pine shoot moth, and *R. bushnelli*, the western tip moth, are major pests in the Midwest and Central Plains, respectively (Miller 1967b, Swenk 1927, Dix and Jennings 1982).

Pheromone trapping has been used successfully to detect, identify, and calculate the relative abundance of an individual species across a landscape (Berisford 1982, Miller 1991, Canalos and Berisford 1980, Daterman 1974, Daterman and McComb 1970). In a preliminary pheromone study in 1991, multiple species of tip moth were caught in southeastern Montana, but we were not able to identify species or compare relative abundance. This study was designed to clarify species occurrences, geographic distribution, and relative abundance across five management areas in the northern Plains: the Crow and Northern Cheyenne Indian Reservations (IR) of southeastern Montana, and the Ashland, Sioux, and Medora Ranger Districts (RDs) of the Custer National Forest.

Materials and Methods

Pheromone traps were distributed evenly throughout ponderosa pine forests within the management areas. The number of trapping sites located within the management areas (RDs and IRs) was determined by three factors: the total acreage of ponderosa pine, the degree of management concern, and accessibility (Table 1). Synthetic pheromone baits were used to determine which species were present and their relative abundances between the management areas.

All identified *Rhyacionia* pheromones are 12-carbon alcohols or acetates. Some pheromone compounds attract more than one species (Berisford et al. 1978). I used four pheromone compounds as baits: E,E8, 10-12Ac; E9-12Ac: Z9-12Ac; E9-12 Ac:E9-12OH; E9-12Ac:E9,11-12Ac. These baits can attract the seven species believed to occur in the study area (Powell and Miller 1978, Miller 1992, Niwa 1992, Stevens et al. 1980)(Table 2). The first three baits were formulated in 3x5 mm polyvinyl chloride pellets containing 0.035 mg of attractant (Niwa 1992). *Rhyacionia bushnelli* and *R. frustrana* have the same pheromone components (Berisford 1989). Therefore, a commercial *R. frustrana* bait was used to trap *R. bushnelli*. The commercial bait was formulated in hollow fibers and contained 4.26 mg of attractant.

Traps were placed in clusters of four at each location; each bait was presented in one trap. Pheromone baits may draw males from some distance (Wilson and Bossert 1963) and certain tip moth pheromones have been shown to inhibit the response of other tip moth species (Berisford and Brady 1973, Berisford et al. 1974, Berisford 1977, Berisford and Hedden 1978). Therefore, traps were hung 30 meters apart.

In South Dakota, near the study area, tip moth flight does not begin until early April (Pasek 1992). The first

Table 1: Number of pheromone trapping sites placed within each management area for evaluation of *Rhyacionia* species composition, abundance, and geographical distribution in southeastern Montana, northwestern South Dakota, and southwestern North Dakota in 1992.

Management Area:	Land Unit	# Trap Site:
Crow IR (Mt)		14
N. Cheyenne IR (Mt)		14
Ashland RD (Mt)		35
Sioux RD	Chalk Buttes (Mt)	1
	Ekalaka Hills (Mt)	6
	Long Pines (Mt)*	12
	East Short Pines (Mt)	1
	Cave Hills (SD)	2
	Slim Buttes (SD)	3
Medora RD (ND)		2

*The Long Pines land unit is undergoing artificial reforestation and is of particular management concern. Mt= Montana, SD=South Dakota, ND= North Dakota.

Table 2: Chemicals and formulation of pheromone baits, species attracted, and identifying male characteristics for *Rhyacionia* spp. pheromone traps placed in southeastern Montana, northwestern South Dakota, and southwestern North Dakota in the spring and summer of 1992.

Pheromone Baits:	Species:	Male Description:
100% E,E8,10-12 AC 0.1% formulation	*R. fumosana*	medium/large gray wings with reddish tips *antennae w/o long ciliation
	R. granti	medium gray wings with reddish tips *antennae w/ long ciliation
80:20% E9-12AC:Z9-12AC 0.1% formulation	*R. neomexicana*	large gray wings with reddish tips *forked black line in the wing
97:3% E9-12AC:E9-12OH 0.1% formulation	*R. buoliana*	medium reddish wings
	R. busckana	medium (6-10mm) gray wings with reddish tips
	R. zozana	sm/med - med/lg gray wings with reddish tips
95:5% E9-12AC:E9,11-12AC 0.1% formulation	*R. bushnelli*	small reddish wings

* A key identifying characteristic.

set of traps was placed in the field during the week of March 23, 1992. All traps were replaced once during spring of 1992 to assure that the pheromone baits were effective throughout the flight period. Traps were collected and replaced during the week of May 11, 1992. *Rhyacionia bushnelli* traps were replaced twice on the Ashland and Sioux RDs to detect if *R. bushnelli* had two generations per year as found by Swenk (1927) and Pasek (1992). The second set of traps was collected and *R. bushnelli* traps replaced on the Ashland and Sioux RDs during the week of June 22, 1992. The third set of *R. bushnelli* traps was collected during the week of July 20, 1992.

Recovered traps were stored in freezers until captured moths could be identified. The number of each tip moth species per trap was recorded.

Species identification was facilitated by pheromone specificity and discrete morphological characteristics (Table 2). E,E8,10-12Ac attracted both *R. fumosana* (Stevens et al. 1980) and *R. granti* (Stevens et al. 1980, Miller 1985). Antennal pecten length of the male *R. granti* is at least two times the length of an antennal segment (Miller 1985) whereas the antennal pecten on male *R. fumosana* is short (Powell and Miller 1978). A sub-sample of 30 moths was examined closely to determine the ratio of *R. granti* to *R. fumosana* in E,E8,10-12Ac baited traps.

Rhyacionia neomexicana was the only species attracted to E9-12Ac:Z9-12Ac. It is a large tip moth and has a distinctive black forked vein on its wing.

Rhyacionia buoliana, R. zozana, and *R. busckana* were all attracted to E9-12Ac:E9-12OH (Niwa 1992, Gray et al. 1984, Grant et al. 1985, Niwa et al. 1987). *Rhyacionia buoliana* is considerably smaller than either *R. zozana* or *R. busckana,* and has orange forewings with silvery white crossbands compared to the reddish forewings with white crossbands of the latter two species (Powell and Miller

1978). *Rhyacionia zozana* and *R. busckana* can be distinguished only by careful examination of genitalia (Powell 1992, Miller 1992). We were not able to use genitalia to distinguish species in our study because trapped moths were not in suitable condition. All possible *R. zozana* and *R. busckana* were counted and recorded as *R. zozana/R. busckana*.

E9-12Ac:E9,11-12Ac is attractive to both *R. frustrana* and *R. bushnelli* (Berisford 1989), which are morphologically identical except that *R. bushnelli* tends to be larger. Their separate species status is not certain (Pasek 1991, Berisford 1989, Powell and Miller 1978). Species determination often is based upon geographic location, and *R. bushnelli* is the only member of this pair recorded in Montana and the Dakotas (Powell and Miller 1978).

Analyses of variance (ANOVA) were used to evaluate significance of differences in abundance of individual species between management areas. Data were sorted by bait formulation and transformed as necessary to meet the assumptions of Fisher's protected least significant difference (LSD) test (Table 3). For significant effects of management areas on relative abundances, means for each management area were compared at the experiment-wise 0.05 error level. All analyses were preformed with SAS software (SAS Institute 1988).

In a different study (Chapter 4), a subsample of 40 pheromone trap locations was randomly selected to represent habitat types from the Ashland and Sioux RDs and assessed for tip moth impact. A habitat type is a classification of an area based upon existing vegetation (Chapter 4, Appendix 1). Fisher's protected LSD analysis was used to determine if pheromone trap catches were affected by habitat type (Table 4).

Table 3: Sources of variation and associated degrees of freedom for data analysis using Fisher's protected LSD of the effect of management area on *Rhyacionia* spp. relative abundance as determined by pheromone trap catches in southeastern Montana, northwestern South Dakota, and southwestern North Dakota in the spring and summer of 1992.

Source	DF
MODEL	38
Management Area	4
Trapping Sites	34
ERROR (District x Site)	51
TOTAL	89

Table 4: Sources of variation and associated degrees of freedom for data analysis using Fisher's protected LSD of the effect of habitat type on *Rhyacionia* spp. relative abundance as determined by pheromone trap catches in southeastern Montana, northwestern South Dakota, and southwestern North Dakota in the spring and summer of 1992.

Source	DF
Model (Habitat Type)	4
Error (Trapping Sites)	35
Total	39

Results

Rhyacionia fumosana, R. neomexicana, and R. bushnelli
were present in all management areas. Rhyacionia zozana
and/or R. busckana also were present in all management
areas.

Of the 30 moths examined in E,E8,10-12Ac baited traps,
none had the long antennal ciliation of R. granti. Either
R. granti was not sufficiently abundant for detection or R.
fumosana was the only species present. Numbers of R.
fumosana ranged up to 272 per trap. No R. buoliana were
trapped in E9-12Ac:E9-12OH baited traps. Rhyacionia zozana
or R. busckana, or both, was present in each management area
and was trapped in numbers up to 260 per trap.

E9-12Ac:E9,11-12Ac attracted only R. bushnelli. Moths
were not caught in large numbers, numbers per trap ranging
up to 47. Individuals were trapped in each management area
(Table 5).

The majority of moths (> 90%) were caught during the
early period (March 23 through May 11, 1992) (Figure 2,
Tables 5-8) for all baits in every management area except
for R. neomexicana traps in the N. Cheyenne IR and the Sioux
RD. Fourteen percent of this species in the N. Cheyenne IR
and 39% in the Sioux RD were caught during the second period
(May 11 through June 22, 1992) (Table 8). Flight periods
for R. neomexicana are apparently longer or delayed in these
management units. Only one R. bushnelli moth was caught
during the third trapping period. Trapping results in this
study did not indicate that R. bushnelli was either abundant
or had a second generation in contrast to the findings of
Swenk (1927) and Pasek (1992).

Significant differences (P < 0.05) in mean numbers of
moths were found between management areas for the first two
and total trapping periods, with the exception of R.
fumosana traps in the second period (Tables 6-8).

Collection Period

▨ 3/23-5/11   ■ 5/11-6/22   ✳ 3/23-6/22
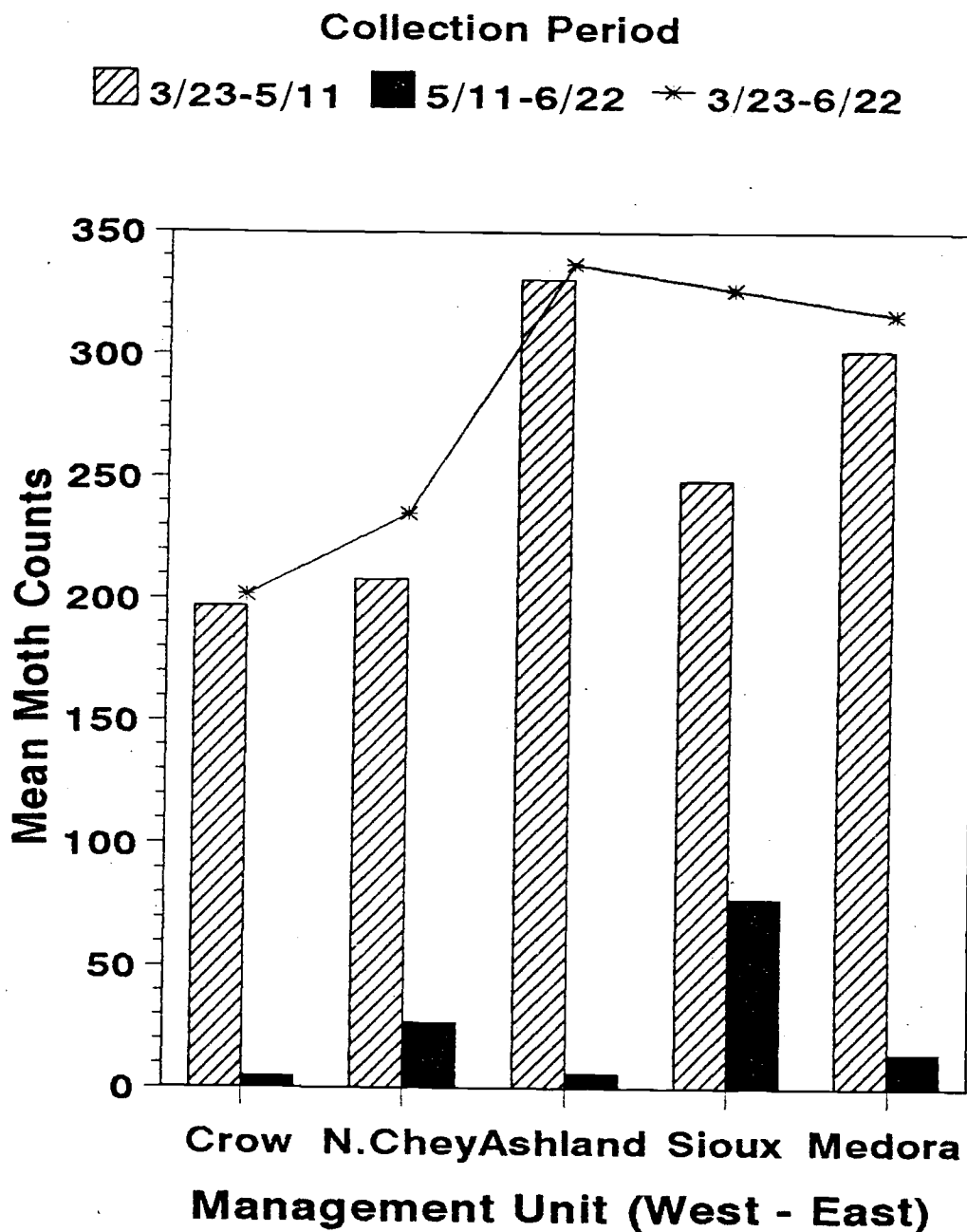
Figure 2: Mean *Rhyacionia* spp. moth catches in pheromone baited traps over the Crow and Northern Cheyenne Indian Reservations and the Ashland, Sioux, and Medora Ranger Districts for the trapping periods 3/23-5/11, 5/11-6/22, and 3/23-6/22 of 1992.

Table 5: Mean *Rhyacionia bushnelli* pheromone trap catches in the Crow and N. Cheyenne Indian Reservations and the Ashland, Sioux, and Medora Ranger Districts for 3/23-5/11, 5/11-6/22, and 3/23-7/14, 1992.

District:	3/23-5/11		5/11-6/22		3/23-7/14	
	N	X (SD)	N	X (SD)	N	X (SD)
Crow	14	3.50(4.20)	14	3.14(4.38)	28	6.64(7.06)
N.Cheye	14	2.71(3.73)	13	1.31(1.60)	27	3.93(4.60)
Ashland	35	0.89(1.51)	35	4.51(6.14)	98	5.49(6.25)
Sioux	25	0.24(1.01)	24	6.83(10.87)	69	6.80(11.07)
Medora	2	0.50(0.71)	2	3.50(3.54)	4	4.50(2.12)

Table 6: Mean cumulative adult *Rhyacionia* spp. catches between management areas in southeastern Montana, northwestern South Dakota, and southwestern North Dakota for the entire trapping period: March 23-June 22, 1992.

District	*R. fumosana* X (SEM) [1]	*R. neomexicana* X (SEM) [2]	*R. zoz/busk* X (SEM) [3]
Crow	106.5(18.3)a	32.36(5.95)a	52.43(8.74)
N.Chene	32.50(8.36) b	78.79(6.40) b	97.36(9.01)
Ashland	80.49(7.70)a	104.3(2.68) b	141.8(8.31)a
Sioux	11.76(1.84) c	144.3(11.3) c	160.6(6.35)a
Medora	23.50(7.43)abc	104.5(11.7)abc	184.0(55.2)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).
[1] $F=2.84$, $df=37$, $P=0.0004$
[2] $F=2.31$, $df=38$, $P=0.0028$
[3] $F=2.34$, $df=38$, $P=0.0024$

Table 7: Mean cumulative adult *Rhyacionia* spp. catches between management areas in southeastern Montana, northwestern South Dakota, and southwestern North Dakota for the first trapping period: March 23-May 11, 1992.

District	R. fumosana X (SEM) [1]	R. neomexicana X (SEM) [2]	R. zoz/busk X (SEM) [3]
Crow	106.0(25.0)a	32.29(8.40)	55.15(12.8)
N.Chene	32.50(11.6) b	75.50(8.53)a	97.36(12.5)
Ashland	85.03(11.0)a	102.9(3.66) b	141.7(7.28)a
Sioux	10.44(2.54) c	90.16(7.30)ab	147.6(8.24)a
Medora	23.50(10.5)abc	95.50(14.5)ab	182.0(78.0)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).
1 F=1.87, df=36, P=0.0198
2 F=2.52, df=38, P=0.0011
3 F=1.82, df=38, P=0.0237

Table 8: Mean cumulative adult *Rhyacionia* spp. catches between management areas in southeastern Montana, northwestern South Dakota, and southwestern North Dakota for the second trapping period: May 11-June 22, 1992.

District	*R. fumosana* X (SEM) *[1]	*R. neomexicana* X (SEM) *[2]	*R. zoz/busk* X (SEM) *[3]
Crow	0.43(0.25)a	0.07 (0.07)	1.21 (0.60) bc
N.Chene	3.31(3.31)a	11.08(7.33)	11.31(11.3) c
Ashland	0.31(0.17)a	1.41 (0.38)	0.09 (0.05) c
Sioux	1.38(0.44)a	56.38(10.2)a	13.13(3.34)a
Medora	0.00(0.00)a	9.00 (2.00)a	2.00 (0.00)ab

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).
1 $F=1.39$, $df=38$, $P=0.1383$
2 $F=9.20$, $df=38$, $P=0.0001$
3 $F=1.96$, $df=38$, $P=0.0144$

Pasek (1992) previously used E9-12Ac:E9,11-12Ac baited traps and found them to have little reliability for monitoring *R. bushnelli*. Therefore, the relative abundance of *R. bushnelli* was not assessed in this study. Relative abundances of other *Rhyacionia* spp. in each management area are shown in Figures 3-5. The results show trends from east to west in the relative abundance of each species over the study area.

Results from the first and total trapping periods are similar, except that in the first period the mean number of moths for the N. Cheyenne IR (32.50, SD = 43.43) was not significantly higher than that for the Sioux RD (10.44, SD = 12.71) (Tables 6-7).

Habitat type did not have an experiment wide significant effect on the relative abundance of any *Rhyacionia* species trapped (Table 9).
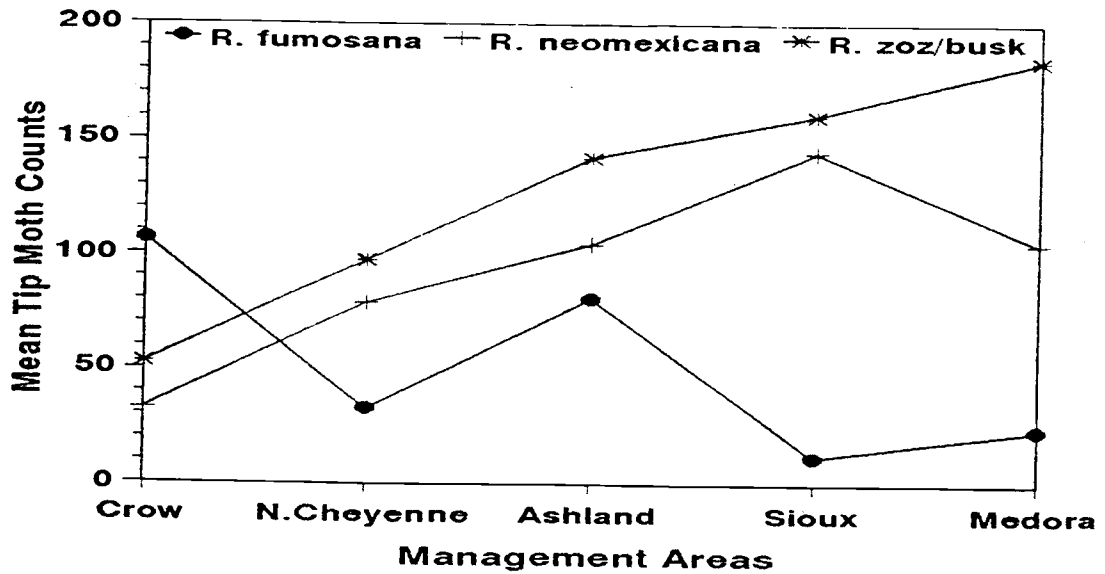
WEST   EAST

Figure 3: West to East trends in *Rhyacionia* spp. relative abundances over the Crow and Northern Cheyenne Indian Reservations and the Ashland, Sioux and Medora Ranger Districts as determined by pheromone trapping for the entire trapping period March 23-June 22, 1992.
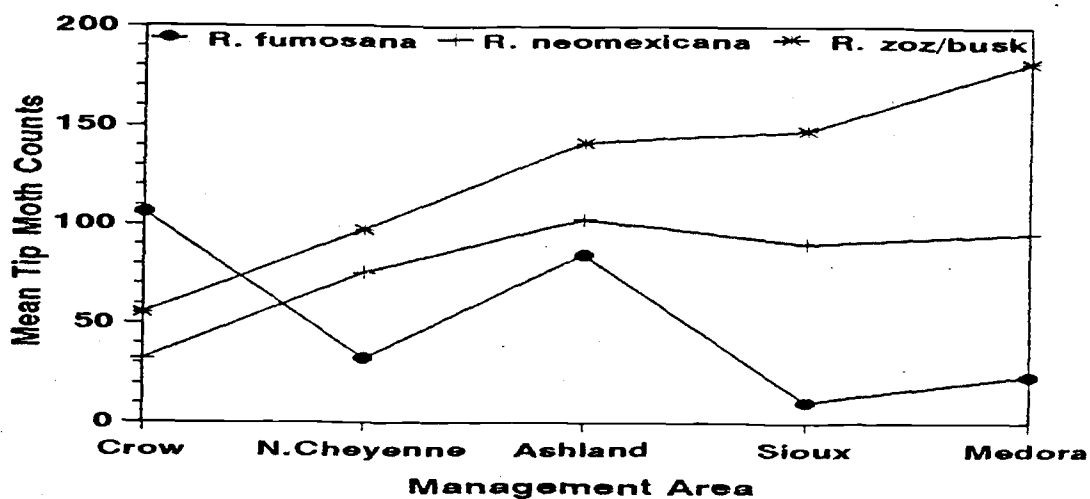
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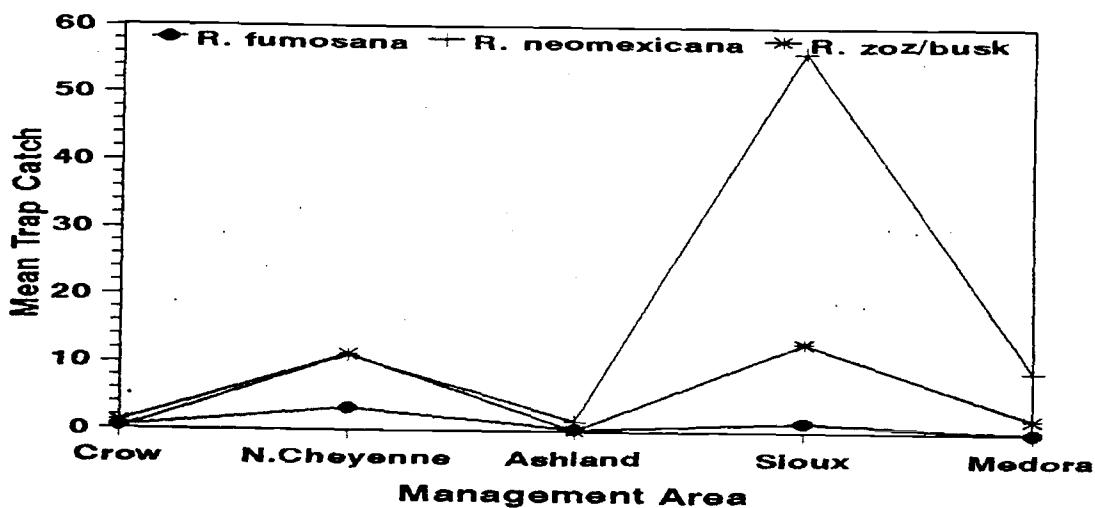
Figure 5: West to East trends in *Rhyacionia* spp. relative abundances over the Crow and Northern Cheyenne Indian Reservations and the Ashland, Sioux and Medora Ranger Districts as determined by pheromone trapping for the trapping period May 11-June 22, 1992.

Table 9: Mean cumulative adult *Rhyacionia* spp. catches between habitat types in southeastern Montana, northwestern South Dakota, and southwestern North Dakota for the entire trapping period: March 23-June 22, 1992.

Habitat	*R. fumosana* X (SEM) *	*R. neomexicana* X (SEM) *	*R. zoz/busk* X (SEM) *
AGSP	52.01(12.6)a	136.2(12.2)a	158.2(11.9)a
AND	92.80(30.6)a	116.0(30.3)a	139.3(13.2)a
FEID	83.50(30.5)a	109.7(7.35)a	122.7(17.1)a
PRVI	5.6(1.32)a	139.0(29.9)a	155.2(18.4)a
SYAL	49.80(25.2)a	116.2(22.5)a	181.8(22.3)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

AGSP- *Agropyron spicatum*; AND- *Andropogon* species; FEID- *Festuca idahoensis*; PRVI- *Prunus virginiana*; SYAL- *Symphorocarpus albus*.

Discussion

This study demonstrates that four to five *Rhyacionia* species occurred in the study area and showed numeric distributions among management units suggesting west-east trends. These maybe correlated with climatic or other factors varying in the districts. Since data were collected only for one growing season these data might not reflect general patterns that could only be detected by sampling over many seasons.

A group of species which exploit a common resource in a similar manner is known as a guild (Root 1973). Tip moth guilds are relatively common in the Southeast but none apparently have had more than four species living sympatrically over a large area, (Miller and Wilson 1964; Bear and Berisford 1975; Staines et al. 1984; Yates 1966). In this study at least three of the five tip moth species were trapped throughout the study area.

Strong isolation mechanisms must be in place to insure the integrity of members of tip moth guilds. Berisford (1974) described four isolation mechanisms in the *R. frustrana* /*R. rigidana* guild in the Southeast: morphological differences in genitalia, species-specific sex pheromones, reciprocal inhibition of male responses, and time of female calling. Since the pheromone baits used in this study, with the possible exception of E9-12Ac:E9-12OH, attracted only one species of tip moth, pheromone specificity likely plays a role in species isolation. If E9-12Ac:E9-12OH did attract both *R. zozana* and *R. busckana*, differences in their genitalia would preclude mating. Reciprocal pheromone inhibition may occur in the study area, but this was not studied.

The number of moths collected in the first collection period was more than 10 times the number of moths caught in the second period for all baits across all management areas,

except for *R. neomexicana* on the N. Cheyenne IR and Sioux RD. Peak flight periods for all members of the guild likely occurred within the first 6-week trapping period. If the average flight period for tip moth males is two to three weeks (Miller 1967a, Berisford 1988, Stevens 1965, Jennings 1975), males of two or more species probably fly at the same time over portions of the study area. In this situation, female calling times during the day and reciprocal pheromone interactions may be crucial in preventing interspecific matings.

A significant portion of *R. neomexicana* moths were caught during the second period in two management areas. Mean counts on the Sioux RD and N. Cheyenne IR for the second period represented 33% and 14% of the total moths, respectively. These areas do not differ significantly from surrounding areas. Factors delaying or extending *R. neomexicana* flights in the two management areas are unknown. Nevertheless, pheromone trapping for monitoring purposes would be most efficient during the first 6 week trapping period, during which 90% of the adult moths were caught.

Certain synthetic baits attract target species more effectively than others because they more closely simulate the natural pheromone. As a result, pheromone trap data alone cannot be used to compare relative abundance of different species within a management area. Conclusions about relative abundance of individual tip moth species between management areas are possible because individual bait formulations were standardized and forest structure was similar over the entire trapping area. Analysis of trapping data for each tip moth species indicates certain trends in relative abundance over the study area.

Rhyacionia fumosana populations generally decreased in relative abundance from west to east. Two of the three western management areas had significantly higher means than an eastern management area and the remaining western

management area. The number of *R. fumosana* trapped on the
N. Cheyenne IR was significantly lower than the other two
western management areas. The reason for this is not clear.
Forest habitat types are similar over the entire study area
and did not have a significant effect upon trap catches.

Differences in pupating behavior may explain in part
why trap numbers for the N. Cheyenne IR were lower.
Rhyacionia fumosana overwinters in the duff, and *R.
neomexicana* (bait B) and *R. zozana* (one of two that are
attracted to bait C) both overwinter at the root collar.
Studies have established a correlation between soil
conditions and tip moth populations (Hood et al. 1988, White
et al. 1984). However, soil surveys of Harding and Powder
River counties (Fountain 1988, USDA Soil Conservation
Service 1971) indicate that the N. Cheyenne IR, Crow IR, and
Ashland RD have similar soils. Alternatively, *R. fumosana*
moth catches on the Ashland RD may be unusually high for
some unknown reason.

A large portion of the N. Cheyenne IR pine forest was
burned in 1988, and it is possible that the fire reduced *R.
fumosana* populations. At the time of the burn, however,
Rhyacionia species were feeding in the shoots. Therefore,
the abundance of other tip moth species should also have
been affected. This was not apparent in the trapping data.

An alternative hypothesis is that management
differences between management areas may have influenced the
population. None of the management areas are currently
using prescribed burning and N. Cheyenne IR management
practices do not differ appreciably from the Crow IR or
Ashland RD (Corbin 1992).

R. neomexicana, which is attracted to E9-12Ac:Z9-12Ac,
and *R. zozana* and/or *R. busckana*, which are attracted to E9-
12Ac:E9-12OH, decreased in relative abundance from east to
west. This trend may have influenced, or been influenced
by, the relative abundance of *R. fumosana*. In the

Southeast, Baer and Berisford (1975) found that *R. rigidana* populations tend to increase with decreasing *R. frustrana* populations; reduced competition may be responsible for the *R. rigidana* increase.

Most theories about population dynamics are either inclusive, applicable to all species, or specific, applicable to one species. Guild populations fall between in that they represent more than one species but only one functional unit (Miller and Epstein 1986). Detection of synchronous population fluctuations among co-existing herbivore species would imply guild population regulation mechanisms at work. Population fluctuations of interest occur over a period of years, not within a season. If the trends shown by this study are consistent through time, the tip moth guild in the study area may represent a unique opportunity to study two types of synchrony. The first type, congruent synchrony, is characterized by positively correlated concurrent inter-specific population densities (as in *R. neomexicana* and *R. zozana/R. busckana*), perhaps reflecting similar responses to environmental conditions. The second type, incongruent negative, is characterized by negatively correlated concurrent inter-specific population densities (as in *R. fumosana* and the tip moth species trapped by E9-12Ac:Z9-12Ac and E9-12Ac:E9-12OH baits).

Rhyacionia bushnelli data were not analyzed. The literature indicated that the pheromones for *R. frustrana* and *R. bushnelli* are identical (Berisford 1989). Commercial *R. frustrana* baits should also effectively attract *R. bushnelli*. The baits we employed for *R. bushnelli* were more concentrated than the baits we employed for the other species. Niwa (1993) explained that the bait formulations approached what she and others have used for mating disruption. There could have been some negative response by the moths to such a strong lure.

Conclusions and Future Studies

A guild of at least four and possibly five different
tip moth species was collected by pheromone trapping on
ponderosa pine trees in southeastern Montana and the western
Dakotas. Species identified include *R. fumosana*, *R.
neomexicana*, *R. bushnelli*, and *R. busckana* and/or *R. zozana*.
The peak flight period for these species on most management
areas occurred between March 23 and May 11, 1992, indicating
a target for integrated pest management monitoring. *R.
neomexicana* flights were prolonged on the N. Cheyenne IR and
Sioux RD. Future studies should indicate the extent to
which this prolonged flight is typical on these management
areas.

Data indicated that several species may be flying
simultaneously. Future studies should monitor traps more
closely to determine if this is so. More work is needed to
describe the isolation factors responsible for maintaining
species integrity, specifically focusing on reciprocal
pheromone inhibition.

Rhyacionia bushnelli catches did not indicate high
populations or a second generation. Observations by Pasek
(1992) did indicate both high populations and a second
generation. Future studies should focus on improved
trapping of this species and describing its relative
abundances in the management areas.

Rhyacionia fumosana catches were significantly lower on
the N. Cheyenne IR than on the two management areas
bordering it on the east and west. Future studies should
address whether populations were unusually low on the N.
Cheyenne IR, unusually high on the Ashland RD, or if this
difference is consistent over a number of flight periods.

The five management areas in the study provide a unique
opportunity to examine tip moth guild dynamics. Results
suggest certain guild regulation factors. Trapping efforts

should be continued to establish whether the trends detected in 1992 are consistent through time. If these trends are consistent, future studies exploring factors maintaining population synchrony should be conducted to help population biologists explain this phenomenon.

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Chapter 3:

Survival of Tip Moth (*Rhyacionia* species) Larvae in Infested Ponderosa Pine Shoots in the Northern Plains.

Introduction

Tip moth (*Rhyacionia* species) larval feeding on ponderosa pine (*Pinus ponderosa*) can significantly affect growth rate and form, depending on larval distribution and survival among shoots. Many species of tip moth early instar larvae feed outside the shoot and migrate toward the expanding bud (Miller and Haynes 1958, 1961, Butcher and Haynes 1960, Swenk 1927, Graham and Baumhofer 1927, Koehler and Tauber 1964). They tend to move along and between branches as the shoots develop. Needle or external shoot feeding is indicated by a small web tent typically attached to a needle sheath and extending down and over a portion of the shoot. External shoot migrations may occur for three to four weeks after eclosion (Yates 1967). Larvae then begin boring into nearly full grown shoots. All migration ceases when the larvae begin boring into the shoot.

Multiple larvae can infest a shoot. As many as 27 *R. pasadenana* larvae in California (Koehler and Tauber 1964) and 15 *R. frustrana* larvae in the Southeast (Yates et al. 1981) were reported in individual shoots. One study in Arkansas found an average of 1.4 *R. frustrana* larvae per shoot (Stephen and Wallis 1978).

In the Southeast, tip moth populations tend to be concentrated in the top half of trees less than three meters in height (Anderson et al. 1984, Gargiullo and Berisford 1981, Gargiullo et al. 1983). Shoots in the top two whorls of a tree had a 10% greater infestation rate than the shoots in the 30 cm section below, and approximately 35% higher infestation rates than shoots in the lowest section of the tree (Berisford and Kulman 1967).

Studies of *R. buoliana* in the Midwest indicate a

spatial population shift during the course of the growing season (Miller 1967). Early instar populations were evenly distributed throughout the tree. The distribution of successive instars tended to be concentrated in the upper two-thirds of the tree, the top two whorls, and the topmost whorl, indicating a net upward shifting of the population. Upward shifting could result from higher survival rates of tip moths near the top of the tree or from upward migration. Pointing (1963) and Miller (1967) found that larval migration was responsible.

Even though migration is responsible for the upward shift, parasites can affect population levels. Freeman and Berisford (1979) compared larval emergence rates of three generations of *R. frustrana* and 27 members of its parasitoid complex in the Georgia piedmont. The parasitism rate of three generations in this study was 42%. McKnight (1973) and Kearby and Taylor (1975) found a sizeable complex of primary and secondary parasitoids associated with *R. bushnelli* in the Great Plains. However, parasitoids did not exert sufficient control to prevent significant tip moth damage.

Monitoring and management of tip moths requires information on larval distribution within trees and on the timing and impact of natural mortality factors. Larval distribution and survival have not been studied in the northern Great Plains. This study was designed to assess larval survival rates within infested shoots. Parasitism, mortality, and pupation rates of larvae collected from infested shoots and subsequently reared in a laboratory were used to estimate larval survival in the field. The effects of larval collection time and location of infested shoots within the tree on larval survival rates were examined.

Methods

Four or five tip moth species infest ponderosa pine trees in the study area (Chapter 2). Multiple species may be present on the same tree. I was unable to distinguish larval species for this study. Rather, results indicate overall distribution of tip moths within trees.

Branches were collected three times during the summer: the weeks of June 22, July 6, and July 21. Collection dates were selected so that the first and second collections would consist primarily of early instar larvae and the third collection would consist of late instar larvae. During the first collection 3 branches were clipped from each of four trees in four areas on the Ashland ranger district (RD). The second and third collections were far more extensive and were taken near pheromone trapping plots (Chapter 2). For the second set I sampled trees near 24 of 35 pheromone trapping sites on the Ashland RD and 20 of 25 pheromone trapping sites on the Sioux RD. For the third set, I sampled all 35 pheromone trapping sites on the Ashland RD, and 20 of 25 pheromone trapping sites on the Sioux RD. I attempted to sample the same areas for the second and third collections. However, I was unable to sample all plots twice because of time constraints. In plots that were sampled twice, different trees were sampled for the third collection.

I wanted to assure that the presence of pheromone traps would not affect the larval data in any way by impacting adult distribution. Sower (1993) found that, in a large area of continuous forest type, pheromone baits sufficient to disrupt *Rhyacionia* spp. mating were effective for only about 100 m; the number of male moths was only slightly reduced and the number of female moths was unaffected beyond a 100 m radius. Pheromone baits used in Sower's (1993) mating disruption trials were approximately 10 times more

concentrated than the pheromone baits I employed.
Therefore, the effective radius of my baits should be much
less than 100 m. I selected sample trees > 100 m from any
pheromone trap to insure minimal pheromone effects.

Three trees per site were sampled for the second and
third collections. Gargiullo et al. (1983) and Gargiullo
and Berisford (1981) found that within-tree stratification
by height can improve precision in the estimation of tip
moth populations. Tip moth variation within the tree crown
results in higher numbers of larvae per shoot and higher
variances in upper strata than in lower strata. Two of the
trees were less than 1.5 m in height. I chose a third tree
with two distinct strata, i.e. taller than 1.5 m (Gargiullo
and Berisford 1981), to assess differences in larval
survival between strata.

From each of the smaller trees, I collected two
branches with one or more shoots that had small web tents
indicative of tip moth feeding (Yates 1967). I collected
the first two branches I observed that showed evidence of
feeding. I divided the third, taller tree into two strata
by drawing an imaginary boundary on the main stem just below
the first and sometimes the second node below the terminal
whorl (Gargiullo et al. 1983). I collected the first two
branches in each stratum that had web tents.

Branches were clipped approximately 12.5 cm from the
tip. Two branches, representing either a tree or a stratum,
were placed in a plastic bag and kept cool until they could
be processed. Keeping the branches cool reduced the amount
of larval movement between shoots on a branch, or between
branches.

Pines do not grow with distinct shoots. Shoots were
delineated using Gargiullo and Berisford's (1981) method and
had approximately the same amount of foliage and at least
one bud. I counted the number of collected shoots with
evidence of tip moth activity per infested branch, then

counted larvae inside or outside the shoot. All larvae,
dead and alive, were removed from the shoots and placed in
petri plates on artificial diet (Niwa 1992). Dead larvae
were examined periodically for parasite emergence.

Some larvae (< 5%) were killed or escaped during
removal from branches. Because of this, the total number of
larvae observed on the branches differed from the number of
tip moths reared in petri plates.

The numbers of larvae that died, pupated, or had a
parasite emerge were recorded. Adult parasites were killed
in the freezer to facilitate preparation for later
identification. After pupation, tip moth larvae were placed
in a cold treatment of 10°C for one week, then 4-5°C for an
additional 3-4 months (Niwa 1992). Some larvae had not
pupated by late September. They were placed in a cold
treatment of 10°C to induce pupation. Most of these larvae,
after a week of cold treatment, either died, pupated, or had
parasites emerge. I calculated percentages of reared larvae
that pupated, were parasitized, or died for each stratum,
district, and collection time.

Data were transformed to their arsine square-roots and
analyzed by ANOVA using a split plot design to test for
significant differences in the number of tip moths collected
and percentages pupated, parasitized, and dead between
districts, collection times, and strata. I analyzed trees
with only one stratum separately from trees with two strata
(Tables 10 and 11). All analyses were conducted using SAS
software (SAS Institute 1988).

Table 10: Sources of variation and degrees of freedom for analysis of variance of effects of district, collection time, and plot on the number of *Rhyacionia* spp. larvae collected and percentages pupated, parasitized, and dead in trees with one stratum on the Ashland and Sioux Ranger Districts, 1992.

Source	Degrees of Freedom
MODEL	70
District	1
Collection Time	2
Collection Time x District	1
Plot	34
Collection Time x Plot	32
ERROR TERM = PLOT	
District	1
ERROR TERM= COLLECTION TIME x PLOT	
Collection Time	2
Collection Time x District	1
ERROR	31
TOTAL	101

Table 11: Sources of variation and degrees of freedom for analysis of variance of effects of district, collection time, strata, and plot on the number of *Rhyacionia* spp. larvae collected and percentages pupated, parasitized, or dead in trees with two strata on the Ashland and Sioux Ranger Districts, 1992.

Source	Degrees of Freedom
MODEL	95
District	1
Plot	34
Strata	1
Strata x District	1
Strata x Plot	31
Collection Time	1
Collection Time x District	1
Collection Time x Plot	23
Collection Time x Strata	1
CollTimexDistrictxStrata	1
ERROR TERM = PLOT	
District	1
ERROR TERM = STRATA X PLOT	
Strata	1
Strata x District	1
ERROR TERM = COLLECTION X PLOT	
Collection Time	1
Collection Time x District	1
ERROR	65
TOTAL	160

Results

Shoots were still elongating during the first and second collections. By the third collection, the shoots had completed elongation and formed buds. Most of the larvae collected in the first and second collections were feeding under tents, but had not yet started boring into the shoot. By the third collection time, most of the larvae were found inside the shoot, though some were still moving on the outside of the branch. The number of larvae per infested shoot ranged from 0 to 15. The average number of larvae per infested shoot for all collections was 1.09 (SD 1.16).

For trees with only one stratum, the mean number of tip moth larvae collected per plot was 1.13 (SD 1.11); the mean percent that pupated (percent pupated) was 55% (SD 30%); the mean percent that were parasitized (percent parasitized) was 13% (SD 13%); and the mean percent that died prior to pupation (percent dead) was 32% (SD 24%) (Table 12).

Results from the first collection date for trees with one stratum show a larger number of larvae collected from infested shoots (F = 2.41, df = 2, P = 0.1059), a lower percentage that pupated (F = 2.89, df = 2, P = 0.0701), an intermediate percentage that were parasitized (F = 11.94, df = 2, P = 0.0001), and a higher percentage that died (F = 3.64, df = 2, P = 0.0376) compared to subsequent dates. The data from the first collection date represent a small sample size that may not accurately reflect larval conditions at this time.

Between the second and third collection dates the number of larvae collected from infested shoots in trees with one stratum decreased on the Ashland RD and increased on the Sioux RD (collection time x district interaction F = 9.12, 1 df, P = 0.0049). Percentages of larvae that pupated or died decreased on both districts between the second and third collection dates (F = 2.89, 2 df, P = 0.0701 for

Table 12: Mean and standard deviation of number of tip moth larvae, % pupated, % parasitized, and % dead per infested shoot on trees with one stratum in the Ashland and Sioux Ranger Districts of the Custer National Forest in 1992.

Coll. Time[1]	Dst [2]	N	#Larvae X (SD)	%Pupated X (SD)	%Parasit X (SD)	%Dead X (SD)
1	A	4	6.0(2.2)	30%(7%)	12%(16%)	57%(20%)
2	A	23	5.2(2.9)	69%(24%)	0% (0%)	31%(24%)
	S	20	5.2(3.3)	54%(25%)	5% (9%)	41%(25%)
3	A	35	4.4(2.3)	56%(38%)	20%(19%)	24%(26%)
	S	20	6.0(1.7)	44%(34%)	24%(20%)	32%(22%)

[1] 1=6/22/93; 2=7/6/93; 3=7/21/93
[2] A=Ashland; S=Sioux

percent pupated; F = 3.64, 2 df, P = 0.0376 for percent dead). The percent of larvae that were parasitized increased on both districts between the second and third collection dates (F = 11.94, 2 df, P = 0.0001).

The means for the number of larvae per infested shoot and percentages that pupated, died, and were parasitized varied significantly with district, collection time, and stratum for trees with two strata (Table 13). The mean number of larva collected from infested shoots per stratum in each plot (number of larvae/ stratum) for trees with two strata was 2.43 (SD 2.20) for the upper stratum and 1.70 (SD 1.44) for the lower stratum. The mean percent pupated in trees with two strata was 50% (SD 36%) in the upper stratum and 75% (SD 34%) in the lower stratum; mean percent parasitized was 23% (SD 32%) in the upper stratum and 8% (SD 19%) in the lower stratum; and mean percent dead was 20% (SD 25%) in the upper stratum and 17% (SD 34%) in the lower stratum (Table 13).

Between the second and third collection dates the number of larvae decreased on the Ashland RD and increased on the Sioux RD in both strata (collection time x district interaction F = 9.95, 1 df, P = 0.0044). No significant differences in the number of larvae occurred by district or collection time alone.

More larvae were collected from infested shoots in the upper stratum than in the lower stratum for both districts on both collection dates (F = 4.31, 1 df, P = 0.0462). The percentage of larvae that pupated decreased in the upper and lower strata on both districts between the second and third collection dates (F = 14.27, 1 df, P = 0.0007). The percentage of larvae that were parasitized increased in the upper and lower strata on both districts between the second and third collection dates (F = 11.41, 1 df, P = 0.0026). A larger percentage of larvae were parasitized in the upper stratum than in the lower stratum for both districts (F =

Table 13: Mean and standard deviation of number of tip moth larvae, % pupated, % parasitized, and % dead per infested shoot on trees with two strata in the Ashland and Sioux Ranger Districts of the Custer National Forest in 1992.

Coll. Time[1]	Dst Str	N	#Larvae X (SD)	%Pupated X (SD)	%Parasit X (SD)	%Dead X (SD)
2	A/U	22	3.1(1.7)	57%(21%)	9% (19%)	34%(25%)
	A/L	23	2.2(1.7)	84%(26%)	2% (7%)	14%(23%)
	S/U	19	2.1(3.3)	51%(44%)	29%(40%)	20%(36%)
	S/L	19	1.3(1.0)	85%(38%)	8% (28%)	8% (28%)
3	A/U	35	1.8(1.8)	44%(45%)	39%(38%)	17%(24%)
	A/L	34	1.6(1.6)	77%(34%)	7% (21%)	15%(27%)
	S/U	20	3.2(2.5)	50%(31%)	40%(29%)	10%(16%)
	S/L	20	1.7(1.3)	52%(40%)	16% (21%)	33%(31%)

[1] 1=6/22/93; 2=7/6/93; 3=7/21/93
A = Ashland, S = Sioux.
U = Upper Stratum, L = Lower Stratum.

34.47, 1 df, P = 0.0001). Between the second and third
collection dates, the percentage of larvae that died
decreased in the upper stratum and increased in the lower
stratum in both districts (collection time x stratum
interaction F = 3.29, 1 df, P = 0.0795).

Discussion

This study indicated changes in larval distribution, parasitism, and survival in infested shoots during larval development. Results indicate that sampling for assessment of larval impact and parasitism rate could focus on upper strata of infested trees.

Pine shoot elongation and tip moth phenologies in this study were consistent with Yates (1967) observation that larvae feed outside the shoot and periodically migrate during shoot elongation, but cease migration when shoot growth is nearly complete. The larvae then bore into the shoot and continue to feed internally.

Number of larvae collected from infested shoots on young ponderosa pine trees decreased on the Ashland RD and increased on the Sioux RD between the second and third collection dates. Perhaps some factor(s) affected the numbers in ways not reflected by laboratory reared larvae. Predators may have been responsible for the decrease on the Ashland RD. I observed many types of predacious arthropods foraging on ponderosa pine branches during the summer. A variety of spiders, insects, and birds have been observed feeding on tip moth larvae in other regions (Eikenbary and Fox 1968, Juliette 1961, Collenge 1915). Another explanation is that the larvae on the Ashland RD may drop to the soil to pupate earlier than the larvae on the Sioux RD. The Ashland and Sioux RDs are separated by roughly 225 km. These districts differ in elevation, and in the distribution of their forests. Ashland RD's forest is relatively continuous and tends to occur at higher elevations whereas the Sioux RD has forested lands on each of eight land units widely separated by prairie. However, laboratory reared larvae from Ashland RD did not exhibit this tendency and it is not clear why this may have occurred in the field.

Larval migration also might have affected numbers

collected. Miller (1967) describes an upward population shift in *R. buoliana* during the growing season in the Midwest. Since I collected the first two branches I encountered with web tents, I tended to collect branches that were higher up on the tree and potentially overlooked larvae foraging on shoots without web tents. If the larvae were actively migrating up the tree between the second and third collections, the upward shift would lead to an increase in the mean number of larva collected for the third set. Increased or earlier larval movement on the Ashland RD may have masked this phenomenon as eaten or moving larvae would not be present on webbed shoots. Another explanation could be differences in phenological development of tip moth species between the Ashland and Sioux RDs.

Significant differences occurred between collection times in the percentages of larvae that pupated, were parasitized, or died among trees with one stratum. Larvae collected on the first and second dates spent more time under artificial conditions than did larvae collected on the third date. Longer exposure in the field to parasites and other mortality factors likely explains the increase in percentage parasitized and dead.

I found more larvae in infested shoots in the upper stratum than in the lower stratum. These data are consistent with Anderson et al. (1984) who observed that larvae tend to be concentrated in the tops of trees in the Southeast. The percentage of larvae that pupated was significantly higher in the lower strata and the percentage parasitized was significantly higher in the upper strata. When these percentages are multiplied by the average number of larvae collected per stratum, the number of larvae surviving to pupation was higher in the lower strata for the Ashland RD on both collection dates and the Sioux RD for the second collection date, but not the third. Though more larvae were found in the upper strata, they apparently were

subject to increased risk of parasitism. This suggests that parasites capitalize on the tendency of larvae to migrate towards the top of trees.

A larger percentage of larvae collected in the upper stratum of trees with two strata died on the Ashland RD than on the Sioux RD. The percentage of larvae from the lower stratum that died in the third collection for the Sioux RD was more than two times that from the Ashland RD. The combination of these two trends led to a significant district x stratum interaction term. Mortality factors may be affecting upper stratum larvae more in the Ashland RD and lower stratum larvae more in the Sioux RD. The third collection results for the Sioux RD imply that between the second and third collections, some mortality factor(s) other than parasites or predators attacked lower stratum larvae. The parasitism rate of lower stratum Sioux RD larvae decreased by 30% between the second and third collection and the percentage of larvae that died increased by 25% between the collection dates. Since predation did not occur in the lab, some other mortality factor, such as a virus or fungal disease, may have been at work. Laboratory conditions can promote disease development.

Conclusions and Future Study

Larvae appear to forage on needles and move outside shoots until shoot growth nears completion. When shoot elongation stops, larvae begin to bore into the shoot. Future studies should examine the extent to which this behavior is applicable to all species of tip moths in the study area.

Significantly more larvae were collected from trees in the Sioux RD than in the Ashland RD, and a larger number of larvae in the upper stratum of trees with two strata died before pupating in the Ashland RD than in the Sioux RD. Future studies should examine predation and identify predators on these districts and causes for the increased mortality rates in the upper stratum of trees on the Ashland RD. Future studies should also compare the phenological development of larvae on both districts.

Larvae on trees in both districts tended to be concentrated in the tops of trees, even though parasitism rates were higher and pupation rates were lower. This indicates that tip moth monitoring efforts should concentrate on the upper stratum of ponderosa pine saplings. Future studies should look at this phenomenon and try to identify the benefits of this migrating behavior. Some benefits may be reduced predation, increased nutritional quality, larger shoots, and better thermal regulation.

More larvae collected from the lower stratum of trees later in the season died before pupating on the Sioux RD than on the Ashland RD. At the same time, the percentage of larvae parasitized in the lower stratum from the third collection on the Sioux RD declined by 30% from the percentage parasitized in the second collection. It is possible that the larvae which died prior to pupation were parasitized and that the parasite failed to emerge. In the lab, many parasites did not emerge from their hosts until

after the third collection date. Future studies should
focus on identifying the mortality factors responsible for
the decrease in parasitism.

A second field season of data is needed to validate the
observations in my study.

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Chapter 4:

Damage Assessment and Effects of Stand Characteristics on Tip Moth (*Rhyacionia* species) Populations in Ponderosa Pine in the Northern Plains.

Introduction

Tip moths (*Rhyacionia* species) commonly infest shoots on the terminal and lateral branches of ponderosa pine (*Pinus ponderosa*) trees in southeastern Montana, northwestern South Dakota, and southwestern North Dakota. Many shoots elongate normally in spite of infestation, but some are killed or deformed. The proportion and location of the infested shoots may affect tree growth rate and form. Studies of tip moth impact have been conducted in pine plantations in Nebraska, but the relevance of these data to natural stands to the north and west is uncertain (Dix and Jennings 1982, Swenk 1927).

A single tip moth larva may damage many shoots (Stephen and Wallis 1978). Larvae rarely affect 100% of shoots on an individual tree in one season, because interior shoots, though counted as available shoots, are not used by female tip moths during oviposition and are rarely damaged by larvae. Lower whorls, which have more interior shoots, tend to have a lower percent of infested shoots than higher whorls (Lashomb et al. 1980).

Tip moth feeding in the apical bud cluster causes stem deformities (Heikkenen 1960). Three classes of deformity are induced by tip moths: 1) pruning, 2) crooking and forking, and 3) bushing and top kill.

Pruning occurs if lateral buds in a terminal cluster are killed, leading to fewer branches per whorl. This injury does not leave a branch stub, and the wound closes quickly. If all of the lateral buds are killed, the bud scales remain as evidence of the internode until the bark sloughs off. Pruning does not lead to crook development.

Crooks and forks result when the terminal bud is destroyed. An undamaged lateral bud usually replaces the lost terminal. The resulting change in growth form depends on the degree to which a lateral shoot is offset from vertical and the number of laterals that continue height growth. If one lateral assumes dominance, the result is a crook; if two or more, a fork. Partial destruction of the developing terminal shoot also may result in a crook because a hollow shoot may slump, unable to support additional growth in a vertical position.

Bushing and top kill may result when the terminal and lateral buds on the terminal shoot are destroyed. When terminal growth stops, adventitious or lateral buds form. If the adventitious buds successfully initiate growth and vie for dominance, then the resulting mass of shoots is referred to as a bush. If adventitious buds do not form, the result is top kill. Bushing is the most reliable indicator of past tip moth damage (Heikkenen 1960). However, bushing may result from other causes, such as deer browsing.

Trees tend to correct deformities induced by tip moth (Heikkenen and Miller 1960, Talerico and Heikkenen 1962). Crooks are the most frequent residual deformity from tip moth feeding, but, due to the formation of compression wood, the final offset is usually less than the original. Crook recovery rate is greater immediately after crook formation because radial growth is at its maximum. Bushes tended to become forks, which tended to disappear as one of the co-dominant shoots became dominant (Heikkenen and Miller 1960).

Nevertheless, tree injury caused by tip moths can be detrimental to some forest management goals. Effective management of injury levels requires focused attention to situations in which injury is most likely to occur. Hazard rating systems for insect management are based on

conditions that predispose a site to damage. Hazard rating systems provide additional information that managers use to identify and rank stands that may require special monitoring, preventative treatments, accelerated suppression, or post damage appraisal (Hicks et al. 1987). A variety of site or stand characteristics, such as aspect or habitat type, may be correlated with insect damage. Development of hazard rating systems involves identifying site and stand attributes correlated with the level of tip moth impact.

The purpose of this study was to determine the current tip moth infestation rates, assess the level of tip moth deformity on trees, and test for correlation between tip moth activity and pine growth in the Crow and Northern Cheyenne Indian Reservations and the Ashland, Sioux, and Medora Ranger Districts of the Custer National Forest. In order to accomplish these objectives, I studied the severity and distribution of tip moth activity in relationship to certain site and stand characteristics. In this paper I report results of studies to evaluate relationships between site and stand factors and level of tree injury by tip moths in southeastern Montana and northwestern South Dakota.

Materials and Methods

The stand characteristics I tested as hazard rating criteria were percent slope, aspect, regenerating tree density, topography, horizontal configuration, and habitat type. Percent slope, measured in degrees, is the extent to which a plot deviates from horizontal, affecting angle of solar radiation and hydrology. Aspect, measured in cardinal directions, is the direction a slope faces, affecting intensity and duration of solar radiation. Topography (ridge, upper slope, mid slope, lower slope, bench or flat, stream bed) refers to the slope position of the site, and affects moisture availability and intensity and duration of solar radiation. Horizontal configuration (convex, concave, flat, or undulating) is a description of relief and often affects moisture availability. Habitat type reflects vegetation composition, affecting plant competition and habitat for predators.

Three habitat type classification systems have been proposed for southeastern Montana and northwestern South Dakota (Pfister et al. 1977, Cooper and Pfister 1985, Hansen and Hoffman 1988). The Ashland and Sioux Ranger Districts (RDs) have not adopted any of these systems and currently use regionally accepted habitat types, most akin to Pfister et al. (1977). Grazing disturbance is universal on these districts and complicates habitat designation, which requires undisturbed sites.

In 1991, I established 48 paired plots greater than 100 meters apart in 24 stands evenly distributed among the five ponderosa pine habitat types described by Hansen and Hoffman (1988). I added additional stands to achieve equal sample sizes between habitat types. By the end of 1991 I decided to find a different habitat type system which better described the vegetation in the area. For each of the 48 plots established in 1991 I completed a habitat type data

sheet used on the Sioux RD to quantify the percent coverage of certain indicator species used in the three proposed habitat typing systems. I discovered, however, that none of the habitat typing systems alone adequately distinguished vegetational composition of plots. Therefore, based on the information in the sheet, I determined the habitat type of plots according to each of the three habitat typing systems proposed for this area (Pfister et al. 1977, Cooper and Pfister 1985, Hansen and Hoffman 1988). All of the study plots fit one of five associations described by one or more of the proposed systems: 1) *Prunus virginiana* (PRVI), 2) *Symphorocarpus albus* (SYAL), 3) *Festuca idahoensis* (FEID), 4) *Agropyron spicatum* (AGSP), and 5) *Andropogon* species (AND). These habitat types are described in Appendix 1. After this reclassification, the paired plots often fell into different habitat types. Since the paired plots no longer represented replication within a habitat type, I treated them as independent plots for analysis purposes. Sabin (1993) indicated that there was no statistical procedure to test the assumption of independence in this situation, but if the P-value of the ANOVA is less than 0.05, the assumption of independence is of limited importance.

An additional 40 impact plots were established in 1992, 20 in each of the two RDs (Figures 6-7). The new plot locations were randomly chosen from pheromone trapping sites described in Chapter 2. Only one plot was located in each of the new areas. To avoid pheromone interference with the impact study, the plots were located at least 100 m from the pheromone traps; none of the trees sampled in the larval study (Chapter 3) were inside these plots. The number of trees ≤ 5 cm in diameter at breast height (DBH) and three meters in height in all plots ranged from 3 to 288. Plots were located randomly, but replicated all hazard rating criteria (Table 14).

↑North
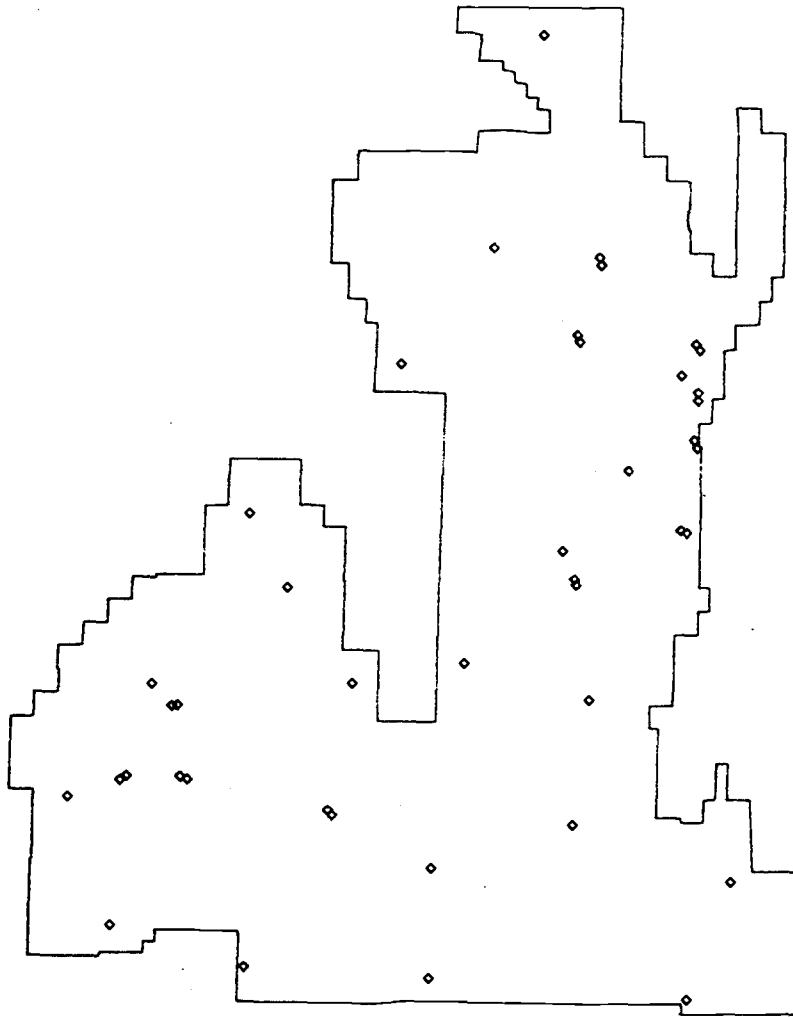
Map Scale:
1:500,000
1 cm = 2.5 km

Figure 6: Ashland Ranger District Tip Moth Impact Plot
Locations, 1992.

<- North

Map Scale:
1:700,000
1 cm = 3.5 km
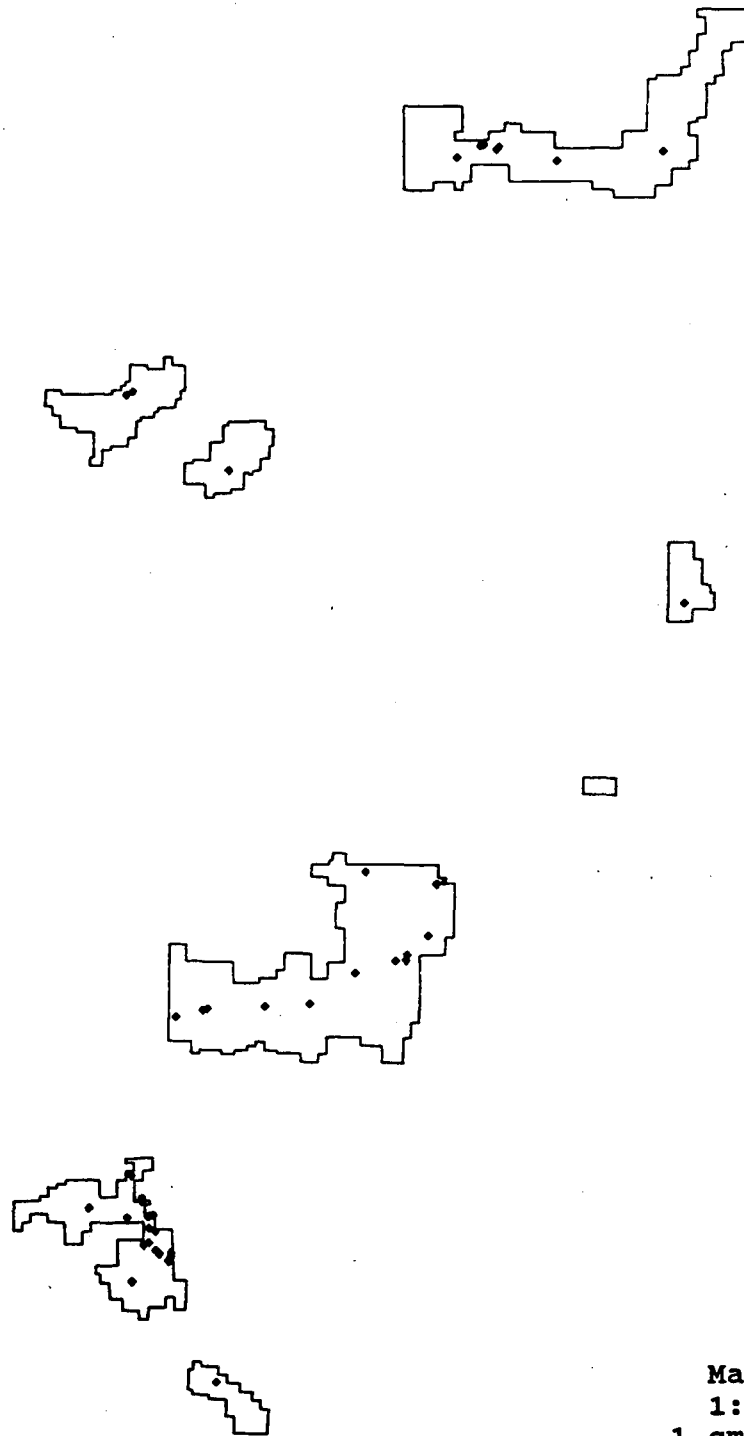
Figure 7: Sioux Ranger District Tip Moth Impact Plot
Locations, 1992.

Table 14: Number of plots for each value of hazard rating criteria tested with multi-variate analysis for effect on the level of tip moth impact on the Ashland and Sioux Ranger Districts of the Custer National Forest in 1991 and 1992.

Measurement:	N:		Ashland:		Sioux:	
	1992	1991	1992	1991	1992	1991
Topography:						
1 Ridge:	0*	0*	0*	0*	0*	0*
2 Upper Slope:	17	8	7	5	10	3
3 Mid Slope:	44	22	27	12	17	16
4 Lower Slope:	15	11	7	8	8	3
5 Bench or Flat:	9	4	2	1*	7	3
6 Stream Bottom:	1	1	1*	1	0*	0*
Configuration:						
1 Convex (Dry):	63	45	36	23	27	12
2 Straight:	7	2	1*	1*	6	1*
3 Concave (Wet):	11	8	2	2	9	6
4 Undulating:	5	1*	5	1*	0*	0*
Aspect:						
North:	29	16	12	9	17	7
South:	9	4	4	2	5	2
East:	23	12	16	8	7	4
West:	18	10	9	5	9	5
Habitat Type[1]:						
PRVI:	15	10	5	5	10	5
SYAL:	19	10	11	8	8	2
FEID:	10	6	10	6	0*	0*
AGSP:	31	15	13	7	18	8
AND:	11	5	5	1*	6	4

*No replication in these criteria for this district.
1 Habitat type abbreviations: PRVI = *Prunus virginiana*, SYAL = *Symphorocarpus albus*, FEID = *Festuca idahoensis*, AGSP = *Agropyron spicatum*, AND = *Andropogon* species.

Plot centers were representative of the entire plot and were marked with wooden stakes. A plot was designated by a 3.2 m radius. Aspect and percent slope were measured at plot center. Topography and horizontal configuration were characterized using the codes in the timber management handbook (USDAFS-R1 1989). The habitat type for the plot was determined as described above. The number of seedlings and saplings ≤ 5 cm DBH and ≤ 3 m in height in the plot was counted. Larger trees occurred infrequently and were excluded from sampling.

Each seedling and sapling was tagged with a numbered clothespin. Six numbers were randomly selected by drawing corks from a bag. The corresponding trees were labeled 1 through 6.

Each of the marked trees was measured in 1991 and 1992. Measurements included: 1) number of whorls, 2) number of branches per whorl, 3) number of live shoots per whorl, 4) number of infested (i.e., had web tents, frass, or other evidence of tip moth foraging during the season) live shoots per whorl, and, in 1992, 5) defect per whorl and 6) vertical height.

More than one defect class can occur at a whorl. Seven defect classes and combinations were noted for each whorl: 1) prune, 2) prune/crook, 3) crook, 4) prune/fork, 5) fork, 6) bush, 7) top kill. Prune was defined as a whorl with fewer than three branches; crook was a whorl where the main stem departed abruptly from vertical; fork was a whorl where two or more leaders originated; bush was a whorl with eight or more branches; and top kill was a dead top (Miller and Schallau 1963).

Percent infested shoots per tree (PI) was calculated by dividing the number of infested shoots by the total number of live shoots. Percent infested apical shoots per tree (API) was calculated by dividing the total number of infested shoots growing from the apical whorl by the number

of live shoots growing from the apical whorl.

In addition, linear growth measurements were made on tree numbers one through four. Linear growth was the sum of all shoot growth on a tree in a year. Two live shoots per whorl were randomly selected and the current year's growth measured from last year's node to the newly set bud. The two measurements were averaged and multiplied by the total number of live shoots for the whorl. Total linear growth was then calculated as the sum for all the whorls on the tree.

The three impact measures, API, PI, and linear growth were averaged for trees in a plot. T-test procedures were used to test for significant differences ($P < 0.05$) in these measures by district, year, and district x year interaction. T-test procedures also were used to see if API and PI were significantly different. Relationships between API, PI, and linear growth were examined using regression analysis with SAS software (SAS Institute, 1988).

The number of whorls exhibiting pruning, crooking, forking, and bushing was totaled for each tree in 1992. This number was divided by the total number of whorls on the tree, and the resulting percentages were averaged over a plot. Since an individual whorl could have more than one deformity, the sum of percentages for deformities could add up to more than 100% for a tree. Top kill only affects the top whorls of a tree. Therefore, top kill was not expressed as a percentage of whorls affected, but as a number of trees affected.

T-test procedures were used to determine if significant differences occurred in the percent of deformity per whorl between districts. The relationships between percent of each deformity per whorl and the average height growth per whorl and linear growth per whorl were analyzed using regression analysis with SAS software (SAS Institute 1988). Data were transformed as necessary to meet the assumption of

the statistical procedures used.

Relationships between damage by tip moths and aspect, slope, topography, horizontal configuration, regenerating tree density, and habitat type were analyzed using analysis of variance procedures (ANOVA) with SAS software (SAS Institute 1988). District, site condition, and the district x condition interaction were tested for effects on damage by tip moths. The significance of each site condition was measured using the district x condition interaction as the error term. If the mean square term for the district x condition interaction was smaller than the error term, it did not have a significant effect and was dropped from the model (Sabin 1992). For significant effects, means were compared at the experiment-wise 0.05 error level using Fisher's Protected LSD procedure.

Results

The average tree in 1991 had 9.0 whorls (SD = 3.7), 11 branches (SD = 6.9), and 25 shoots (SD = 31). In 1992, the average tree had 10 whorls (SD = 7.4), 12 branches (SD = 7.3), and 34 shoots (SD = 42). The average number of branches per whorl is less than two on both districts for both years. Many whorls had no branches. There were typically 2 to 3 shoots per branch. The increase in the number of shoots from 1991 to 1992 is much smaller on the Ashland RD (approximately 6 shoots) than on the Sioux RD (approximately 12 shoots).

API was 7% higher in 1991 than in 1992 (Table 15). API decreased 13% on the Ashland RD but remained constant on the Sioux RD from 1991 to 1992 (Table 16). PI remained relatively constant from 1991 to 1992 (Table 15-16). API was significantly higher than PI in 1991 (45 DF, T = 0.0001), 1992 (86 DF, T = 0.0001), and for combined 1991 and 1992 data (131 DF, T = 0.0001) (Table 15).

Linear growth increased by 40% from 1991 to 1992 (Table 15). It increased by 20% on the Ashland RD and 60% on the Sioux RD from 1991 to 1992 (Table 16).

Regression analysis showed that API was strongly correlated with PI in 1992 (F = 1.97, 49 df, P = 0.018, R^2 = 0.73) and for combined 1991 and 1992 data (F = 3.02, 53 df, P = 0.0001, R^2 = 0.68) (Figures 8-9). Analysis by district in 1991 showed that API and PI were strongly correlated on the Sioux RD (F = 1854, 16 df, P = 0.0001, R^2 = 0.9998), but not on the Ashland RD (F = 2.53, 17 df, P = 0.092, R^2 = 0.84).

Of the 442 trees examined in 1992, 40 (9%) had top kill, 18 on the Sioux RD and 22 on the Ashland RD. Only three trees had bushed whorls, 1 on the Sioux RD and 2 on the Ashland RD. On each of these three trees, only one whorl was bushed.

Table 15: Means and standard deviation for 1991, 1992, and combined 1991 and 1992 tip moth impact measure data on the Ashland and Sioux Ranger Districts of the Custer National Forest.

	Year:	N:	Mean:	S.D.:	P>¦T¦
API[1]	1991	45	0.53	0.19	0.0569
	1992	86	0.46	0.20	
	Average	131	0.48	0.20	
PI[2]	1991	45	0.29	0.10	0.9680
	1992	86	0.30	0.13	
	Average	131	0.29	0.12	
LnGr[3]	1991	45	0.98	1.12	0.0887
	1992	86	1.38	1.31	
	Average	131	1.24	1.26	

[1] API = percent of apical shoots infested.
[2] PI = total percent of infested shoots.
[3] LnGr = total amount of shoot growth.

Table 16: Means and standard deviation for tip moth impact measurements in 1991, 1992, and combined 1991 and 1992 data on the Ashland and Sioux Ranger Districts of the Custer National Forest.

Percent of Apical Shoots Infested (API):

District	1991			1992*			Mean 1991/92		
	N	X	SD	N	X	SD	N	X	SD
Ashland	26	0.55	0.19	44	0.42	0.20	70	0.47	0.21
Sioux	19	0.50	0.18	42	0.50	0.20	61	0.50	0.19
Combined	45	0.53	0.20	86	0.46	0.19	131	0.48	0.20

Total Percent Infested (PI):

District	1991			1992*			Mean 1991/92*		
	N	X	SD	N	X	SD	N	X	SD
Ashland	26	0.28	0.09	44	0.25	0.11	70	0.26	0.11
Sioux	19	0.32	0.11	42	0.34	0.14	61	0.33	0.13
Combined	45	0.29	0.10	86	0.30	0.13	131	0.29	0.12

Linear Growth of Shoots:

District	1991			1992			Mean 1991/92		
	N	X	SD	N	X	SD	N	X	SD
Ashland	26	0.96	1.25	44	1.16	1.21	70	1.08	1.22
Sioux	19	1.02	0.94	42	1.61	1.38	61	1.42	1.28

*Indicates that means differed significantly between districts ($P < 0.05$).

$$Y = 1.01X + 0.17$$

Plot of API*PI.   Legend: A = 1 obs, B = 2 obs, etc.
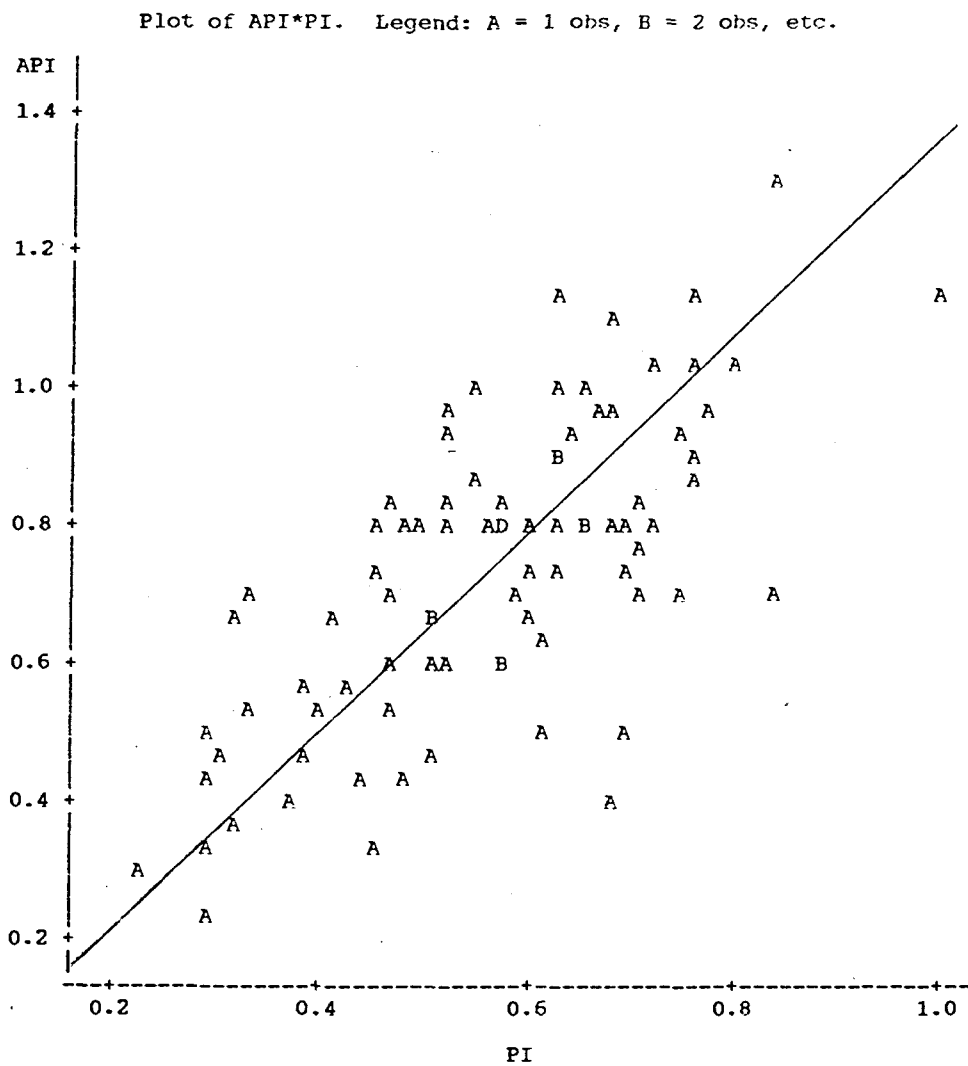
Figure 8: The relationship between arcsine (square root (mean percent of apical shoots infested by tip moths per plot (API))) and arcsine (square root (mean total percent of shoots infested by tip moths per plot (PI))) on the Ashland and Sioux Ranger Districts, 1992 data.

$$Y = X + 0.19$$

Plot of API*PI. Legend: A = 1 obs, B = 2 obs, etc.
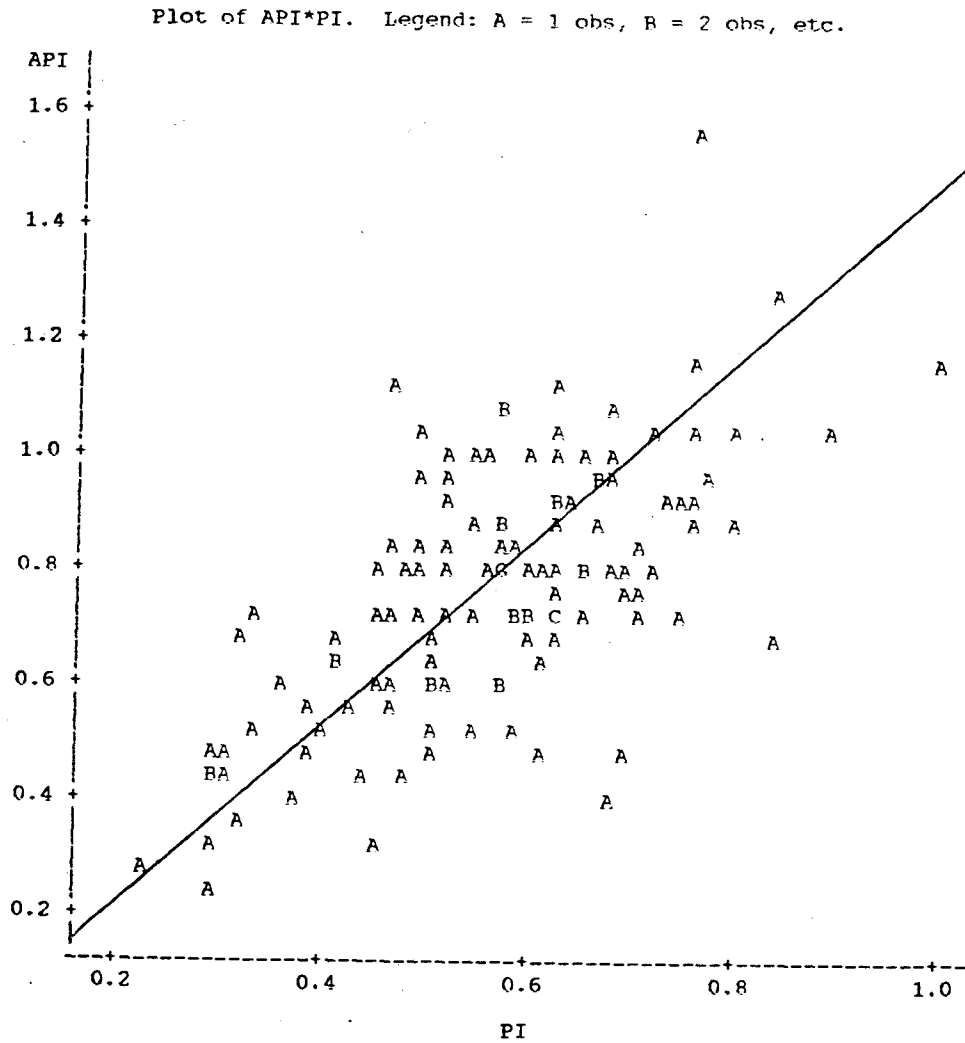
Figure 9: The relationship between arcsine (square root (mean percent of apical shoots infested by tip moths per plot (API))) and arcsine (square root (mean total percent of shoots infested by tip moths per plot (PI))) on the Ashland and Sioux Ranger Districts, combined 1991 and 1992 data.

The remaining three deformity classes; pruning, crooking, and forking, were common on both districts. Though the frequency of pruning was significantly higher on the Ashland RD than the Sioux RD (P = 0.0003), and the frequency of forking was significantly higher on the Sioux RD than the Ashland RD (P = 0.0018), the difference between districts was less than 10% (Table 17). Data were not blocked by district for further analysis.

Pruning was the most frequently encountered deformity with 86% of all whorls affected. Crooking was second with 44% of whorls affected and forking was third with 9% of whorls affected (Table 17).

Regression analysis indicated that percent pruned whorls negatively affected both height growth per whorl (F = 1.88, 31 df, P = 0.0209, R^2 = 0.5188) and linear growth per whorl (F = 3.02, 31 df, P = 0.0002, R^2 = 0.6342). As the percent forked whorls increased, linear growth per whorl increased (F = 2.41, 19 df, P = 0.0044; R^2 = 0.4099).

Mean API, PI, and linear growth values per plot by hazard rating criteria are found in Tables 18-29. Of the six factors tested as potential hazard rating criteria, three were significantly related to tip moth impact and three; 1) horizontal configuration, 2) topography, and 3) regenerating tree density. PI varied significantly (F = 2.70, 3 df, P = 0.05) with topography in 1992 and with horizontal configuration for combined data (F = 2.77, 4 df, P = 0.03), but not for 1991 or 1992 individually. Mean linear growth varied significantly with regenerating tree density in 1991 (F = 4.32, 36 df, P = 0.0251), and for combined 1991 and 1992 (F = 4.35, 53 df, P = 0.0001), but not for 1992 (F = 1.13, 52 df, P = 0.3610).

Trees on plots with a concave horizontal configuration had significantly higher PI than those on plots with a convex horizontal configuration in 1992. For combined 1991/1992 data, trees on flat slope positions had

Table 17: Percent of tree whorls pruned, crooked, forked on the Ashland and Sioux Ranger Districts of the Custer National Forest in 1992.

District	Prune*			Crook			Fork*		
	N	X	SD	N	X	SD	N	X	SD
Ashland	44	0.89	0.08	44	0.44	0.15	44	0.08	0.05
Sioux	42	0.82	0.09	42	0.43	0.19	42	0.11	0.05
Average	86	0.86	0.09	86	0.44	0.19	86	0.09	0.05

*Indicates that district means were significantly (P < 0.05) different.
[1]Average refers to the average values over the Ashland and Sioux Ranger Districts for prune, crook, and fork.

Table 18: Mean percentage of ponderosa pine sapling apical shoots infested by tip moths (*Rhyacionia* spp.)(API) by aspect on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Value:	Dist[1]	1991 API			1992 API		
		N	X (SD)	*	N	X (SD)	*
North	Ash	9	0.64(0.20)	a	12	0.44(0.26)	a
	Sioux	7	0.43(0.19)	a	17	0.52(0.20)	a
South	Ash	2	0.33(0.00)	a	4	0.34(0.06)	a
	Sioux	2	0.73(0.02)	a	5	0.52(0.09)	a
East	Ash	8	0.49(0.20)	a	16	0.36(0.19)	a
	Sioux	4	0.51(0.18)	a	7	0.50(0.21)	a
West	Ash	5	0.57(0.16)	a	9	0.47(0.16)	a
	Sioux	5	0.46(0.20)	a	9	0.48(0.22)	a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.

Table 19: Mean percentage ponderosa pine sapling apical shoots infested by tip moths (*Rhyacionia* spp.)(API) by topography on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Topography Value[2]:	Dist[1]	N	1991 API X (SD) *		N	1992 API X (SD) *	
2	Ash	5	0.52(0.16)a		7	0.42(0.20)a	
	Sioux	3	0.43(0.31)a		10	0.43(0.18)a	
3	Ash	12	0.45(0.20)a		27	0.40(0.21)a	
	Sioux	10	0.50(0.17)a		17	0.49(0.20)a	
4	Ash	8	0.65(0.20)a		7	0.45(0.22)a	
	Sioux	3	0.42(0.17)a		8	0.60(0.16)a	
5	Ash	1	0.43(.) a		2	0.57(0.06)a	
	Sioux	3	0.63(0.11)a		7	0.47(0.23)a	
6	Ash	1	0.75(.) a		1	0.33(.) a	
	Sioux	.	. .		.	. .	

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Topography: 2 = Upper Slope; 3 = Mid-slope; 4 = Lower Slope; 5 = Bench or Flat; 6 = Stream Bottom.
. indicates that no data were available.

Table 20: Mean percentage ponderosa pine sapling apical shoots infested by tip moths (*Rhyacionia* spp.)(API) by habitat type on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Habitat Value[2]:	Dist[1]	1991 API		1992 API	
		N	X (SD) *	N	X (SD) *
AGSP	Ash	7	0.47(0.18)a	13	0.38(0.20)a
	Sioux	8	0.57(0.18)a	18	0.55(0.19)a
AND	Ash	1	0.81(.) a	5	0.40(0.17)a
	Sioux	4	0.39(0.17)a	6	0.51(0.23)a
FEID	Ash	6	0.56(0.15)a	10	0.41(0.12)a
	Sioux	.	. .	.	. .
PRVI	Ash	5	0.57(0.33)a	5	0.49(0.37)a
	Sioux	5	0.44(0.19)a	10	0.43(0.17)a
SYAL	Ash	8	0.52(0.17)a	11	0.45(0.20)a
	Sioux	2	0.54(0.18)a	8	0.44(0.22)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Habitat type abbreviations: PRVI = *Prunus virginiana*, SYAL = *Symphorocarpus albus*, FEID = *Festuca idahoensis*, AGSP = *Agropyron spicatum*, AND = *Andropogon* species.
. indicates that no data were available.

Table 21: Mean percentage ponderosa pine sapling apical shoots infested by tip moths (*Rhyacionia* spp.)(API) by horizontal configuration on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Configuration Value[2]:	Dist[1]	1991 API			1992 API		
		N	X (SD)	*	N	X (SD)	*
1	Ash	23	0.53(0.21)	a	36	0.41(0.21)	a
	Sioux	12	0.50(0.22)	a	27	0.48(0.20)	a
2	Ash	1	0.43(.)	a	1	0.52(.)	a
	Sioux	1	0.53(.)	a	6	0.44(0.24)	a
3	Ash	2	0.54(0.29)	a	2	0.33(0.00)	a
	Sioux	6	0.47(0.13)	a	9	0.57(0.14)	a
4	Ash	1	0.71(.)	a	5	0.51(0.20)	a
	Sioux	.	.	.	.	.	.

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Configuration: 1 = Convex; 2 = Straight; 3 = Concave; 4 = Undulating.
. indicates that no data were available.

Table 22: Mean percentage ponderosa pine sapling shoots infested by tip moths (*Rhyacionia* spp.)(PI) by aspect on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Aspect Value:	Dist[1]		1991 PI		1992 PI
		N	X (SD) *	N	X (SD) *
North	Ash	9	0.30(0.11)a	12	0.28(0.13)a
	Sioux	7	0.30(0.13)a	18	0.34(0.15)a
South	Ash	2	0.18(0.08)a	4	0.19(0.09)a
	Sioux	2	0.43(0.25)a	5	0.39(0.14)a
East	Ash	8	0.26(0.09)a	16	0.23(0.09)a
	Sioux	4	0.30(0.06)a	7	0.32(0.10)a
West	Ash	5	0.28(0.09)a	9	0.30(0.09)a
	Sioux	5	0.30(0.05)a	9	0.28(0.11)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.

Table 23: Mean percentage ponderosa pine shoots infested by tip moths (*Rhyacionia* spp.) (PI) by topography on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Topography Value[2]:	Dist[1]	1991 PI N	X (SD) *	1992 PI N	X (SD) *
2	Ash	5	0.29(0.08)a	7	0.28(0.09)a
	Sioux	3	0.27(0.03)a	10	0.32(0.15)a
3	Ash	12	0.24(0.08)a	27	0.24(0.12)a
	Sioux	10	0.27(0.08)a	17	0.31(0.12)a
4	Ash	8	0.31(0.12)a	7	0.26(0.13)a
	Sioux	3	0.38(0.12)a	8	0.40(0.17) b
5	Ash	1	0.34(.) a	2	0.33(0.01)a
	Sioux	3	0.44(0.15)a	7	0.37(0.12) b
6	Ash	1	0.22(.) a	1	0.25(.) a
	Sioux	.	. .	.	. .

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Topography: 2 = Upper Slope; 3 = Mid-slope; 4 = Lower Slope; 5 = Bench or Flat; 6 = Stream Bottom.
. indicates that no data were available.

Table 24: Mean percentage ponderosa pine sapling shoots infested by tip moths (*Rhyacionia* spp.)(PI) by habitat type on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Habitat Value[2]:	Dist[1]	1991 PI			1992 PI		
		N	X (SD)	*	N	X (SD)	*
AGSP	Ash	7	0.26(0.08)a		13	0.22(0.10)a	
	Sioux	8	0.37(0.13)a		18	0.41(0.13)a	
AND	Ash	1	0.20(.) a		5	0.22(0.12)a	
	Sioux	4	0.29(0.07)a		6	0.26(0.10)a	
FEID	Ash	6	0.31(0.06)a		10	0.28(0.09)a	
	Sioux	.	.	.	.	.	.
PRVI	Ash	5	0.29(0.14)a		5	0.30(0.19)a	
	Sioux	5	0.28(0.11)a		10	0.33(0.14)a	
SYAL	Ash	8	0.26(0.10)a		11	0.26(0.11)a	
	Sioux	2	0.25(0.03)a		8	0.25(0.10)a	

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Habitat type abbreviations: PRVI = *Prunus virginiana*, SYAL = *Symphorocarpus albus*, FEID = *Festuca idahoensis*, AGSP = *Agropyron spicatum*, AND = *Andropogon* species.
. indicates that no data were available.

Table 25: Mean percentage ponderosa pine sapling shoots infested by tip moths (*Rhyacionia* spp.)(PI) by horizontal configuration on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Config. Value[2]:	Dist[1]	1991(PI)			1992(PI)		
		N	X (SD)	*	N	X (SD)	*
1	Ash	23	0.28(0.10)	a	36	0.24(0.11)	a
	Sioux	12	0.30(0.12)	a	27	0.31(0.13)	a
2	Ash	1	0.34(.)	a	1	0.32(.)	a
	Sioux	1	0.33(.)	a	6	0.34(0.15)	a
3	Ash	2	0.23(0.01)	a	2	0.24(0.01)	a
	Sioux	6	0.34(0.10)	a	9	0.42(0.14)	a
4	Ash	1	0.28(.)	a	5	0.35(0.08)	a
	Sioux	.	.	.	.	.	.

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Configuration: 1 = Convex; 2 = Straight; 3 = Concave; 4 = Undulating.
. indicates that no data were available.

Table 26: Mean ponderosa pine sapling linear shoot growth (LNGR) by aspect on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Aspect Value:	Dist[1]	N	1991 LNGR X (SD) *	N	1992 LNGR X (SD) *
North	Ash	9	1.48(0.97)a	12	1.48(0.99)a
	Sioux	7	0.83(0.81)a	18	1.14(0.80)a
South	Ash	2	1.90(1.12)a	4	1.04(1.27)a
	Sioux	2	0.84(0.66)a	5	1.58(1.03)a
East	Ash	8	1.17(0.75)a	16	1.33(0.73)a
	Sioux	4	1.52(1.37)a	7	1.80(1.41)a
West	Ash	5	1.05(0.70)a	9	1.61(0.98)a
	Sioux	5	1.26(0.67)a	9	1.12(0.95)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.

Table 27: Mean ponderosa pine sapling linear shoot growth (LNGR) by topography on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Topography Value[2]:	Dist[1]	1991 LNGR N	X (SD)	*	1992 LNGR N	X (SD)	*
2	Ash	5	0.69(0.69)	a	7	0.88(0.70)	a
	Sioux	3	0.40(0.18)	a	10	1.62(1.80)	a
3	Ash	12	0.39(0.24)	a	27	1.06(1.14)	a
	Sioux	10	1.17(0.80)	a	17	1.67(1.13)	a
4	Ash	8	1.45(1.33)	a	7	1.43(1.65)	a
	Sioux	3	0.42(0.29)	a	8	0.96(0.75)	a
5	Ash	1	5.20(.)	a	2	2.68(2.05)	a
	Sioux	3	1.72(1.73)	a	7	2.17(1.77)	a
6	Ash	1	0.55(.)	a	1	0.78(.)	a
	Sioux	.	.	.	.	.	.

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Topography: 2 = Upper Slope; 3 = Mid-slope; 4 = Lower Slope; 5 = Bench or Flat; 6 = Stream Bottom.
. indicates that no data was available.

Table 28: Mean ponderosa pine sapling linear shoot growth (LNGR) by habitat type on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Habitat Value[2]:	Dist[1]	1991 LNGR		1992 LNGR	
		N	X (SD) *	N	X (SD) *
AGSP	Ash	7	0.60(0.34)a	13	1.17(1.29)a
	Sioux	8	1.08(1.12)a	18	1.65(1.25)a
AND	Ash	1	1.86(.) a	5	2.10(1.44)a
	Sioux	4	0.51(0.48)a	6	1.13(0.99)a
FEID	Ash	6	1.68(1.87)a	10	1.30(1.17)a
	Sioux	.	. .	.	. .
PRVI	Ash	5	0.43(0.41)a	5	0.46(0.27)a
	Sioux	5	0.99(0.88)a	10	1.76(1.79)a
SYAL	Ash	8	0.90(1.42)a	11	0.90(1.20)a
	Sioux	2	1.85(0.91)a	8	1.69(1.49)a

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).
[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Habitat type abbreviations: PRVI = *Prunus virginiana*, SYAL = *Symphorocarpus albus*, FEID = *Festuca idahoensis*, AGSP = *Agropyron spicatum*, AND = *Andropogon* species.

. indicates that no data were available.

Table 29: Mean ponderosa pine sapling linear shoot growth (LNGR) by horizontal configuration on the Ashland and Sioux Ranger Districts of the Custer National Forest, 1991 and 1992.

Config. Value[2]:	Dist[1]	1991 LNGR			1992 LNGR		
		N	X (SD)	*	N	X (SD)	*
1	Ash	23	0.65(0.55)	a	36	1.06(1.09)	a
	Sioux	12	1.16(1.13)	a	27	1.64(1.52)	a
2	Ash	1	5.20(.)	a	1	4.13(.)	a
	Sioux	1	0.89(.)	a	6	1.74(1.42)	a
3	Ash	2	0.44(0.16)	a	2	0.49(0.41)	a
	Sioux	6	0.75(0.50)	a	9	1.43(0.96)	a
4	Ash	1	4.40(.)	a	5	1.53(1.61)	a
	Sioux	.	.	.	.	.	.

* Means in columns followed by the same letter do not differ at the experiment-wise error rate of 0.05 (Fisher's Protected LSD).

[1] Dist= District; Ash = Ashland RD; Sioux = Sioux RD.
[2] Configuration: 1 = Convex; 2 = Straight; 3 = Concave; 4 = Undulating.
. indicates that no data were available.
1992 data, trees on flat slope position had significantly higher PI than those on an upper slope or mid slope. Trees on lower slopes had significantly higher PI than those located mid slope.

Regenerating tree density was negatively correlated with tree linear growth for 1991 data (F = 4.21, 37 df, P = 0.0269, R^2 = 0.9570) and the combined 1991 and 1992 data (F = 1.27, 54 df, P = 0.1651, R^2 = 0.4748).

significantly higher PI than those on an upper slope or mid slope. Trees on plots on a lower slope had significantly higher PI than those located mid slope.

Regenerating tree density was negatively correlated with tree linear growth for 1991 data (F = 4.21, 37 df, P = 0.0269, R^2 = 0.96) and the combined 1991 and 1992 data (F = 1.27, 54 df, P = 0.1651, R^2 = 0.47).

Discussion

This study indicated a significant impact of tip moths on ponderosa pine growth and form in this area and suggested site factors associated with increased impact. These data will be useful for future management of tip moths in this region.

The average pine seedling or sapling on the Ashland and Sioux RD had fewer branches and shoots than do trees in other parts of the country. Of the trees sampled, the average number of branches per whorl was less than two. Miller and Schallau (1963) define a normal ponderosa pine whorl as having at least three branches. Branches averaged 2 to 3 shoots on the Ashland and Sioux RDs. The smaller number of branches in this study may have increased the number of shoots accessible to female tip moths for ovipositing and increased use of shoots in the lower whorls of the trees. It is unclear whether this reduced number of branches and shoots in the study area is natural, a result of tip moth activity, or due to other agents.

Various measures are used to monitor tip moth infestations and impact. The three measures I used were percent total shoots infested per tree (PI), percent apical shoots infested per tree (API), and total linear shoot growth per tree (linear growth). Fox and King (1963) have shown that sampling the top portion of trees gives as accurate a portrayal of tip moth impact as sampling the entire tree. I hoped that by measuring linear growth in addition to API and PI, I could characterize the effect of different infestation rates on tree growth.

The Ashland and Sioux RDs are separated by roughly 225 km. These districts differ in elevation, and in the distribution of their forests. Ashland RD's forest is relatively continuous and tends to occur at higher elevations whereas the Sioux RD has forested lands on each

of eight land units widely separated by prairie. These differences may have caused district effects in data analyses.

API declined about 13% from 1991 to 1992 on the Ashland RD but remained constant on the Sioux. PI was relatively constant on the two districts from 1991 to 1992.

Typically, in the southeastern U.S. API reaches 100% during a growing season, while PI varies. Within its natural range, *R. frustrana*'s life cycle is synchronized with its primary host to produce a new generation of egg laying adults each time a new growth flush occurs, up to 6 times in one season (Berisford 1988). Since tip moth larvae tend to be more prevalent in the tops of trees (Anderson et al. 1984) the upper shoots are preferentially damaged.

Berisford and Kulman (1969) suggested that there may be some population levels at which API would be strongly correlated with PI. In my study area there are fewer generations of tip moths per year. Therefore, though apical shoots are preferred, this preference is less apparent and API and PI are correlated to a point. The regression analysis supported this hypothesis over both districts for 1992 and combined 1991 and 1992 data.

In 1991, API on the Ashland RD was 10% higher than on the Sioux RD. When the 1991 data were analyzed by district, the correlation between top and total percent infested was significant on the Sioux RD, but not on the Ashland RD. Apparently, once API increases above 50%, infestation of lower shoots increases disproportionately and the correlation between API and PI disappears. Infestation rates in whorls 3-6, with more shoots and a lower probability of infestation, were consistently correlated with PI in *R. bushnelli* infested trees in the Central Plains (Dix and Jennings 1982). I believe that in heavily infested stands, the small number of shoots in the apical portion of the tree is an inadequate representative sample of all the

shoots on a tree.

Linear shoot growth increased on both districts from 1991 to 1992, most likely in response to rainfall patterns and the increased number of shoots which emerged from buds set in 1991. In 1990, the amount of precipitation in the study region was 10.19 cm (4.01 inches) below the average 34.33 cm (13.73 inches). In 1991, rainfall was 7.04 cm (2.77 inches) above normal, and in 1992, rainfall was slightly below average (approximately 2.5 cm or 1 inch) (Borgum 1993). The unusually low precipitation in 1990 likely stressed the trees. Though rainfall was above average in 1991, the trees most likely were still responding to the water stress of 1990 and were unable to utilize the extra water for growth. However, the trees were not under water stress by the close of 1991. In 1992 the rainfall was closer to normal and the trees, with the help of the additional rainfall in 1991, were able to grow. Infestation rates were higher on lower slopes and flats where moisture was more available.

Surprisingly, linear growth was not correlated with either API or PI. As PI increased, linear growth should have decreased because more shoots have stopped growing. However, linear growth depends on the number of live shoots, which in turn depends on the number of branches and the number of whorls. Linear growth depends more on the number of shoot-bearing branches than on the percent of infested shoots. Therefore, linear growth is better suited to rating the effect of tip moth on tree growth than for measuring tip moth impact for one season.

Many years after damage has occurred, it is difficult to determine what caused it. Tip moth damage is often indistinguishable from damage caused by other agents (Heikkenen and Miller 1960). Miller and Schallau (1963) found pruning, crooking, forking, and bushing in detectable levels in plantations that were never infested by tip moths.

The biggest impact of tip moths on the host is loss of height growth (Williston and Barras 1977). The amount of growth loss increases with the abundance of deformities (Lessard and Jennings 1976). Lessard and Buffam (1976) found that cumulative height and radial growth decreased for ponderosa pine trees in Arizona as *R. neomexicana* damage increased. Pruning was correlated with the largest loss in height growth, likely because damage to lateral branches prevents growth of new foliage and reduces total photosynthetic area (necessary for new shoot growth) in moderate to heavily infested trees (Hedden et al. 1981). Reduction in photosynthetic area has also been found to reduce diameter growth (Johnson et al. 1985). When tip moth populations are reduced, tree height, diameter, and growth rates increase (Williston and Barras 1977, Lashomb et al. 1978, Young et al. 1979, Cade and Hedden 1987).

Over 80% of tree whorls on the Ashland and Sioux RD were pruned. Pruning can result from tip moth feeding, but also from cattle grazing and other factors. Cattle rub against young ponderosa pine trees, often breaking branches off in the process. Usually, when cattle rub branches off a small tree, they leave an obvious scar. Most of the trees examined did not show such scarring, indicating that most pruning was due to other causes such as porcupine foraging and tip moth feeding.

The incidence of pruning in the study area is high when compared to studies in other areas (Lessard and Jennings 1976, Heikkenen 1960, Miller and Schallau 1963). This is the most prevalent deformity, followed by crooking, and then forking.

Crooks were the most common residual deformity from tip moth feeding. In almost all cases, the severity of the crook diminishes over time due to the formation of compression wood, but this persists as a defect in wood quality (Heikkenen and Miller 1960). Approximately 40% of

the whorls examined were crooked. Most of the trees examined were < 2 m in height. Lessard and Jennings (1976) found that as trees increased in height, especially above 1.5 meters, the number of crooked whorls decreased. If this is the case on the Ashland and Sioux RDs, then the number of crooked whorls will decrease as the tree grows, and the existing crooks will decrease in severity. By the time of harvest, the total wood defect probably will be negligible.

Forking occurred on about 10% of whorls. Forked whorls eventually become crooked as one branch assumes dominance. Like crooks, forking severity will decrease over time as the tree forms compression wood, a defect in wood quality (Heikkenen and Miller 1960). The recovery rate is greater in the years immediately following crook formation due to increased radial growth. Because it often takes a few years for one of the forked leaders to assume dominance, by the time a fork becomes a crook, vital recovery time has been lost and a more pronounced defect will likely remain.

As the percent of forked whorls increased, so did linear growth. This is likely due to additional growth and branching as other shoots vied for dominance.

Pruning does not cause a defect in the wood, but it does reduce growth rate. As percent pruned whorls increased, linear and height growth decreased. This is consistent with Lessard and Jennings' (1976) observations. A pruned whorl has fewer needles and a lower total photosynthetic area. The carbohydrates produced in photosynthesis fuel tree growth. Therefore, although a pruned tree may maintain perfect form, it will take longer to reach a harvestable size (Hedden et al 1981, Johnson et al. 1985). This may be an advantage in variable environments.

Bushing was extremely rare, and 9% of the trees sampled had top kill. Top kill often so severely deforms a sapling that it is culled.

Impact measures such as API and PI were not strongly affected by potential hazard rating criteria, i.e., the site factors evaluated in this study. PI appeared to be higher in areas that retain moisture, i.e. concave or horizontal land form, than in areas with a convex or upper slope condition. Abundant precipitation may have masked significant correlations between PI and water retaining sites in 1991.

These findings are consistent with Ross and Berisford's (1990) observation that tip moth populations increase following silvicultural treatments that increase water and nutrients available to young loblolly pine. Plots located in areas that hold moisture have more tip moth activity. However, trees growing faster due to the additional moisture are better able to outgrow tip moth damage.

The negative correlation between regenerating tree density and linear shoot growth is also likely related to moisture and/or nutrient availability. As tree density (and competition for resources) increased, linear growth decreased significantly for 1991 and for combined 1991 and 1992 data. This correlation was not evident in 1992 when moisture was more plentiful. This relationship likely reflects plant physiology, not tip moth pressure.

There were no significant differences in API and PI among habitat types. Several studies have found correlations between tip moth populations and factors such as canopy coverage, tree density, stand structure, site preparation, and vegetative competition in the eastern U.S. (Berisford and Kulman 1967, White et al. 1984, Hood et al. 1988, Long and Wagner 1992, Hertel and Benjamin 1977, Ross et al. 1990). Habitat types are perceived to reflect the most meaningful integration of the environmental factors affecting vegetation (Pfister et al. 1977). Cattle grazing and fire suppression on the Ashland and Sioux RDs may have altered vegetation patterns and obscured habitat types.

Historically fire is the major vegetation control agent in ponderosa pine systems (Arno 1976, Davis et al. 1980). Over the past 50 years, land managers on the Ashland and Sioux RDs have aggressively suppressed fire. Fire was replaced by cattle as the primary vegetation control agent. These two management practices may have promoted the tip moths in the following manner.

Several authors have found that tip moth infestation rates increase as the intensity of vegetation control increases (Ross et al. 1990, Miller and Stephen 1983, Hertel and Benjamin 1977). Miller and Stephen (1983) noted that cattle grazing in young plantations often is associated with extreme tip moth damage, perhaps because cattle reduce grasses and other annuals more drastically than other forms of vegetation control and may cause soil compaction. Vegetation control may result in a lack of habitat for tip moth predators and parasites and/or create a more favorable environment for tip moths by promoting more shoot growth. Hertel and Benjamin (1977) found that where burning was the only form of site preparation, tip moth populations were lower compared to sites where no site preparation was used for a period of at least three years after planting. Fire might create a negative environment for the tip moth by affecting soil/litter conditions where the tip moth pupates.

Conclusions and Future Studies

The average seedling and sapling on the Ashland and
Sioux RD has fewer branches and shoots than do trees in
other parts of the country. This may be a result of tip
moth activity in the area. A tree with fewer branches and
shoots has a smaller photosynthetic area that produces fewer
carbohydrates. Lower carbohydrate production results in
lower height and diameter growth rates. Future studies
should investigate the relationships between tip moth
activity, branch and shoot numbers, and height and diameter
growth in the study area.

API and PI are strongly correlated in the study area
for API < 50%. Future studies should verify, as Dix and
Jennings (1982) report, the extent to which other whorls are
more consistently correlated with the PI. Linear shoot
growth reflects the integrated effects of tree form and
environmental conditions on a tree in a given season.
Deformity caused by tip moths is likely responsible for a
considerable reduction in growth rate and some loss in wood
quality on the Ashland and Sioux RDs. Future study should
quantify interaction among deformity, linear shoot growth,
and environmental factors, especially with respect to
developing hazard rating systems for prediction of tip moth
infestation.

Finally, tip moth populations may have been favored by
vegetation and/or soil conditions resulting from 50 years of
fire suppression and cattle grazing on the Ashland and Sioux
RDs. Future studies should closely examine the effect of
grazing and fire suppression on tip moth populations.

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Chapter 5:

Management Implications

Damage to ponderosa pine regeneration as a result of tip moth feeding can be detrimental to some forest management goals. Monitoring and management of tip moth populations will contribute to the accomplishment of forest management goals.

Pheromones provide a tool for assessing tip moth populations. Once managers recognize a tip moth problem in a stand, a variety of pheromone baits should be used to detect all *Rhyacionia* species present. If a species goes undetected, the manager may underestimate the management effort required to address the problem.

When designing a pheromone trapping plan, the potential for pheromone interactions should be recognized and addressed. Certain *Rhyacionia* pheromones have been shown to inhibit the response of other *Rhyacionia* spp. (Berisford et al. 1974, Berisford and Brady 1973, Berisford 1977, Berisford and Hedden 1978). Though studies have not been conducted on interactive effects of tip moths in southeastern Montana, traps should be placed far enough apart to assure that interaction is minimized.

Bait formulation also should be checked. The baits employed in this study for *R. bushnelli* may have been too concentrated for detection purposes, resulting in misleading results.

Once tip moths have been trapped, specimens should be positively identified by a qualified taxonomist. Cross attraction among species does occur (Berisford et al. 1978) so it is important to verify species identification.

The threat to forest resources of each species of a tip moth guild should be assessed. Some species of tip moth may be capable of causing more damage than others, due to their

life histories, feeding habits, or abundance. Therefore, managers may decide to focus control activities on the individual or small group of species within the guild that pose the greatest threat to the resource.

The success of direct control and suppression strategies may depend on the accurate timing of control activities. Mating disruption via pheromones and direct control via chemical spraying techniques have been successfully employed to control tip moth populations. Both of these approaches are most effective when employed during certain stages in insect development. Managers need to closely monitor the seasonal development of each tip moth species they are planning to control. Systems for timing tip moth control have been based on pheromone trap catches and degree day accumulation for other species of tip moths. Management of multiple species of tip moths requires proper use of pheromones and a knowledge of potential interactions.

Some species of tip moth larvae forage on shoots and branches until shoot elongation is complete. Insecticides that depend on surface contact with the insect for control should be applied while the insects are still feeding outside the shoot. While some larvae may be protected under a web tent, contact insecticides will still be more effective before the insects bore into the shoot. Tip moth parasites may be present in the study area. Any control strategy should attempt to minimize negative impacts on these natural tip moth control mechanisms.

Collection of infested shoots indicated that tip moth larvae become increasingly concentrated in the higher branches of trees during the growing season. The apical whorl of a tree is particularly important to height growth. Control efforts, if necessary, should focus on protecting this whorl from attack.

Ponderosa pine seedling and saplings in the study area had fewer branches and shoots than average. This may be due

to site conditions, tip moth activity, or other factors. Because these trees have fewer branches and shoots, they likely grow at a slower rate than do trees with more branches. In order to increase growth rates, managers should identify and limit factors responsible for reducing the number of branches.

The percent of apical shoots infested per tree (API) and the total percent of shoots infested per tree (PI) are good indicators of current year's tip moth activity. They are strongly correlated for API < 50%. Managers could use API as an indicator of total tip moth activity within a given year as long as API is below 50%. When API exceeds 50%, PI becomes a more reliable indicator of tip moth activity.

Neither API nor PI were strongly correlated with total linear shoot growth (linear growth). Linear growth is an indicator of tree vigor in that vigorous trees are able to initiate more shoot growth. Therefore, API and PI are not good indicators of tree vigor.

Linear growth appears to be strongly correlated with moisture availability. API and PI were higher on moist sites, suggesting that trees on these sites are more attractive and/or suitable for tip moths. Trees growing on moist sites, however, are better able to outgrow any tip moth activity, thereby masking tip moth effects. Managers should not be overly concerned about tip moth activity in these areas.

As the percentages of pruned whorls increased, height and linear growth decreased. Where growth impact is a serious concern, managers should limit the amount of pruning whenever possible.

Crooking leads to compression wood formation, a wood quality defect. As the tree continues to grow, however, the severity of the crook decreases. Tip moth-caused crooking, because it occurs in seedling and saplings, should not be a

major timber management concern because trees will likely outgrow the crooking defect.

As the percent of forking increased, so did the amount of linear growth. Forking produces additional vertical stems which produce more lateral branches and shoots than one vertical stem. The increase in branching and linear growth may lead to bushy trees with poor form from a lumber perspective. These bushy trees, however, may provide special habitat for wildlife and thus may be valuable from a wildlife perspective. Bushing has similar effects. Such trees may also contribute to soil retention by intercepting more precipitation and retarding erosion in these semi-arid environments.

Top kill results in a severe deformity. Though a lateral branch may eventually assume dominance, a severe crook will remain. From a lumber management perspective, top killed seedlings and saplings may be culls, but from other perspectives, these deformed trees can be important habitats.

When regeneration is evaluated, management actions will be affected strongly by stand objectives. If a stand of regenerating trees is being managed for timber production, managers may want to precommercially thin the stand to remove severely deformed trees. If the stand is being managed for other objectives, such as wildlife habitat, managers may choose to leave the deformed trees for habitat enhancement. In the study area the combination of fire suppression and cattle grazing may have favored tip moth activity. In light of management objectives, the application of these two management practices over the study area should be reviewed and opportunities to evaluate the effects of these practices on tip moth damage explored.

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Appendix

Appendix 1: Habitat Types of the Ashland and Sioux Ranger Districts of the Custer National Forest, southeastern Montana and northwestern North Dakota.

Prunus virginiana (Prvi):

The *Prunus virginiana* (Prvi) habitat types described by all three studies: Pfister et al. 1977, Cooper and Pfister 1985, Hansen and Hoffman 1988. The stand structure is variable, some appearing all aged with scattered regeneration and uniform representation of size classes, other stands show two or three distinct size classes. In stands with greater than 75% cover of tall shrubs, ponderosa pine regeneration does not exceed trace amounts. On most other stands ponderosa pine seedlings and saplings were at least common and often well represented to abundant. Advanced regeneration was both clumped and regularly distributed with no clues as to what produced the distribution. Stands with high seedling / sapling cover often have bole and crown deformation caused by heavy snow loads from spring storms. Undergrowth has a distinct two tiered shrub layer, with the top tier dominated by *Prunus virginiana* with *Amalanchier alnifolia*, *Symphoricarpos albus*, and other shrubs, and the lower shrub layer containing *Berberis repens* and other low shrubs.

Symphoricarpos albus (Syal):

The *Symphoricarpos albus* (Syal) habitat type was described by Pfister et al. (1977) and Cooper and Pfister (1985). There is variability in stand structure. Some stands are uniform with a closed canopy and apparently even aged, possibly due to fire history. Other stands are multi-aged, often with many seedling and saplings. Syal and other medium size to low shrubs dominate the undergrowth with many different forbs and gramminoids.

Festuca idahoensis (Feid):

The *Festuca idahoensis* (Feid) habitat type is described by Pfister et al. (1977), Cooper and Pfister (1985), and Hansen and Hoffman (1988). These stands are much more even aged and less savanna like than the *Agropyron spicatum* habitat type, and the ponderosa pine tends to have better form, few and smaller limbs. Feid dominates the undergrowth with *Agropyron spicatum* and *Carex rossii* present in large amounts in areas with low tree coverage. In some Feid habitat types there may be minor coverages of Prvi and other shrubs. Feid habitat types have a richer forb component than the other grass dominated habitat types.

Agropyron Spicatum (Agsp):

The *Agropyron Spicatum* (Agsp) habitat type is described by all three authors and ranges from nearly closed canopy forests to savannas. Agsp is generally well represented and where it is not, it is the dominant undergrowth. *Koeleria cristata*, Feid, *Carex rossii*, *Carex filifolia*, and *Agropyron smithii* are the most common gramminoid associates of this type. *Balsamorhiza sagittata*, *Yucca glauca*, and *Crepis acuminata* are the only forbs of even moderate consistency (50%) and occur with scarce coverage.

Andropogon species (And):

The final habitat type, *Andropogon species* (And) was described by Pfister et al. 1977 and Cooper and Pfister 1985. It is the dry extreme of ponderosa pine habitat types. It is the most open and savanna like habitat in which ponderosa pine occurs. Canopy coverage approach and rarely exceed 35%. The undergrowth is dominated by *Andropogon* species, or, on the driest sites *Bouteloua curtipendula*. Agsp coverage is always less than And, and *Bouteloua curtipendula* coverage rarely exceeds 5%.