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Small Mammal Response to Treated Wastewater Discharge on a Northern Michigan Wetland

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SMALL MAMMAL RESPONSE TO TREATED WASTEWATER DISCHARGE ON A NORTHERN MICHIGAN WETLAND

By

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ABSTRACT

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The impact of wastewater discharge on resident small mammal populations was investigated from May to August 1979 on a wetland in northern Michigan. Victor snap traps and collapsible Sherman live traps were placed on transects located at various distances down-flow from the discharge point in sedge-willow (*Carex* spp., *Salix* spp.) and leatherleaf-low birch (*Chamaedaphne calyculata*, *Betula pumila*) communities. Captures included 352 individuals representing nine species with masked (*Sorex cinereus*) and pygmy (*S. hoyi*) shrews accounting for 89% and 5%, respectively, of the total. Abundance, distribution, sex and age ratios, and reproduction of masked shrews were not altered significantly by the addition of treated effluent. Water depth and cover-water interspersion measurements were highly correlated, and both showed significant inverse linear relationships to masked shrew abundance. Based on these relationships, the continued flooding of the wetland with effluent is expected to result in an eventual decline in masked shrew abundance.

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This manuscript is dedicated to Dale, my husband, with grateful appreciation for his assistance and encouragement throughout the study. And to the Little People who refrained, as much as could be hoped, from mischief.

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ABSTRACT

SMALL MAMMAL RESPONSE TO TREATED WASTEWATER DISCHARGE ON A NORTHERN MICHIGAN WETLAND

By

Mary L. Rabe

The impact of wastewater discharge on resident small mammal populations was investigated from May to August 1979 on a wetland in northern Michigan. Victor snap traps and collapsible Sherman live traps were placed on transects located at various distances down-flow from the discharge point in sedge-willow (Carex spp., Salix spp.) and leatherleaf-low birch (Chamaedaphne calyculata, Betula pumila) communities. Captures included 352 individuals representing nine species with masked (Sorex cinereus) and pygmy (S. hoyi) shrews accounting for 89% and 5%, respectively, of the total. Abundance, distribution, sex and age ratios, and reproduction of masked shrews were not altered significantly by the addition of treated effluent. Water depth and cover-water interspersion measurements were highly correlated, and both showed significant inverse linear relationships to masked shrew abundance. Based on these relationships, the continued flooding of the wetland with effluent is expected to result in an eventual decline in masked shrew abundance.

INTRODUCTION

The use of wetlands for tertiary treatment of domestic sewage effluent is a relatively new concept and little information is available concerning the short- and long-term impacts of this technology on existing plant and animal communities. Potentially, the application of wastewater could affect many components of a wetland system including water quality and levels, plant growth and nutritive quality, and vertebrate and invertebrate species composition and abundance. This study was designed to evaluate the effects of wastewater discharge on small mammals inhabiting a northern Michigan wetland. Specific objectives were to:

1) assess the relative effectiveness of Sherman live traps and snap traps in order to design a sampling scheme for long-term population monitoring on the Houghton Lake wetland,
2) survey the small mammal community and determine species composition and abundance, and
3) evaluate the response of small mammals to the addition of wastewater.

Study Area

This study was conducted on a 716-ha state-owned wetland (Fig. 1) located 2.3 km southwest of Houghton Lake,

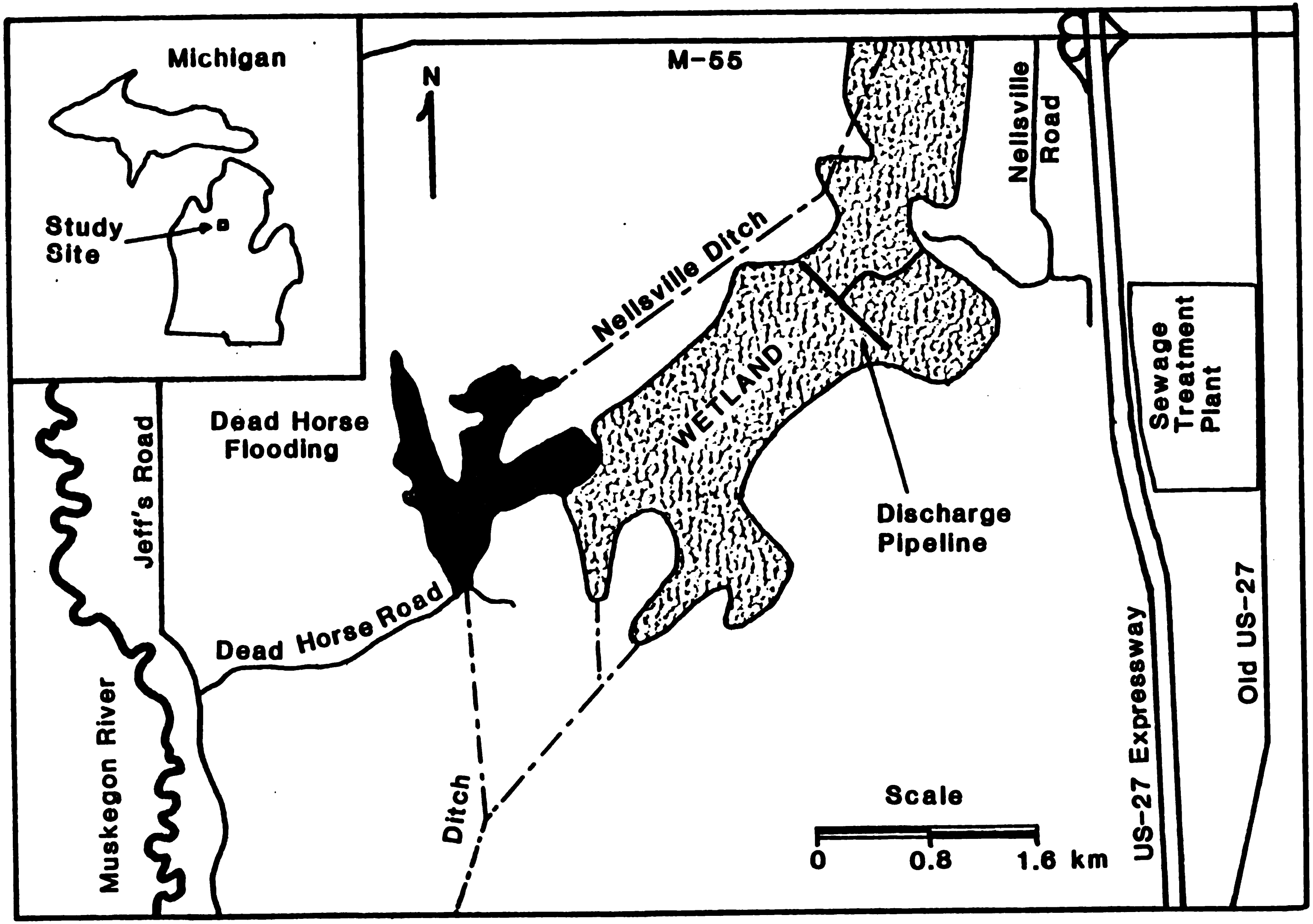

Figure 1. Location of the Houghton Lake sewage treatment system, the wetland, and the discharge pipeline. Patterned area represents the wetland and shaded area represents standing water.

Michigan (Sec. 5,7,8, and 18, T22N, R4W, Roscommon County). The wetland lies within the 4150-ha Michigan Department of Natural Resources Houghton Lake Wildlife Research Area. Topography of the wetland is generally flat with variations in elevation (±15 cm) resulting from hummocks, plant root systems, accumulated detritus, and various human and wildlife trails. Soils are predominately Rifle peat and Houghton muck with underlying Newton loamy sand (Pecor et al. 1973). Peat deposits range from 1-5 m in depth, and contain scattered deposits of sand and gravel. The wetland rests on a thick clay layer which retards surface water percolation into ground water reserves.

Water within the wetland flows from north to southwest and eventually drains into the Muskegon River via an intermittent stream. Water depth typically ranges from 2-8 cm although heavy rains can cause temporary increases of several cm. Generally, levels are highest in spring and lowest in late summer. Annual water level variability is highly dependent on yearly rainfall which averaged 73 cm from 1940-69 (Mich. Dept. of Agric. 1975).

The dominant plant communities on the wetland, sedge-willow (Carex spp., Salix spp.) and leatherleaf-low birch (Chamaedaphne calyculata, Betula pumila), covered 68% and 19% of the area, respectively, prior to effluent discharge (Wentz 1975). Other communities included cattail (Typha spp.) stands associated with depressions in the peatbed, alder (Alnus rugosa), and small scattered stands of aspen

(Populus tremuloides). Each of these covered approximately 2% of the area. Open water areas, which covered 5% of the wetland, supported a wide variety of floating and submersed plants. A unique bog community in late successional stages is located centrally on the wetland (Sec. 7 and 8), and is bounded by sedge-willow on the north and west and by leatherleaf-low birch on the south and east. A mat of vegetation covers the entire bog. Species such as sundew (Drosera sp.), pitcher plant (Sarracenia purpurea), and cranberry (Vaccinium sp.) are found only in this portion of the wetland. Bevis (1981) details the current status of wetland flora, including a refined plant community classification description.

The Houghton Lake Wetland Treatment System

Pilot scale operations (1975-77) conducted by the University of Michigan Wetlands Ecosystem Research Group, demonstrated the peatland's capacity to accept treated wastewater during the summer months with only minor changes in the wetland character (Kadlec et al. 1979). Full-scale discharge of treated effluent began in 1978 and, to date, approximately 380×10^6 l (100×10^6 gal) have been pumped onto the wetland annually (Kadlec and Hammer 1982).

The addition of treated effluent via a 975-m (3200-ft) discharge pipeline (Fig. 1) has altered many features of the wetland system. To document these changes, water chemistry, hydrology, and various plant community parameters are evaluated annually. Water level and plant community changes are thought to have the greatest potential to impact the small mammal community. The following information on these parameters is summarized from Kadlec and Hammer (1981).

Water movement away from the discharge area is slow. This results in water depths that are highest (10-20 cm) along the discharge pipeline and decline in both the up-flow and down-flow directions. In 1979, nitrogen and phosphorus removal were typically 90% complete within 150 m of the discharge pipeline. The line of complete nutrient removal has shifted down-flow each year reaching 800 m in 1981. Plant growth and litter accumulation has increased greatly within the immediate zone of discharge in response to the increased availability of nutrients. Early changes in plant community composition were limited to a duckweed (*Lemna* spp.) intrusion into the cattail area nearest the discharge pipeline. More recently, sedge and leatherleaf were extirpated in some areas due to shading by other plant species; yet at other locations these two species have increased. Grasses (*Poa* spp.) are increasing in the leatherleaf-low birch community near the discharge pipeline (Bevis, pers. commun.). In general, the impacts of effluent addition on the wetland are concentrated in the immediate discharge area with diminishing effect in the down-flow direction.

Initial studies (Rosman 1978, Rabe 1980) of the wetland wildlife community included invertebrates, fish, reptiles, amphibians, insects, birds, and mammals. These broad-based surveys were undertaken to inventory the fauna on the wetland and form a data base for evaluation of long-term impacts on the animal community.

METHODS

Both live traps and snap traps were used to capture small mammals on the wetland. Live-trapping sessions always preceded kill-trapping. This design was used to evaluate the relative usefulness of both trap methods in wetland habitats. All traps were baited with a rolled oats and peanut butter mixture to attract a variety of small mammals, and placed along transects in the two dominant plant communities. Visual uniformity of plant composition was used to determine transect locations. All transects were located in the wetland interior, at least 100 m from upland edges.

Live-trapping Procedures

Three, 200-m paired transects were positioned down-flow and parallel to the discharge pipeline at 15 and 30, 100 and 115, and 500 and 515 m in both the leatherleaf-low birch and sedge-willow communities (Fig. 2). Forty Sherman live traps were spaced evenly (approximately 10 m apart) along each transect pair. Traps were locked open and prebaited with a rolled oats and peanut butter mixture for two days prior to each trapping session. Three consecutive nights of trapping were conducted in both community types between 23-31 May and 10-18 August 1979. Traps were set each evening and closed the next morning. Captured animals were identified to species when possible, weighed, sexed, toe-clipped and released. Females were considered reproductively active if they exhibited any degree of lactation tissue development;

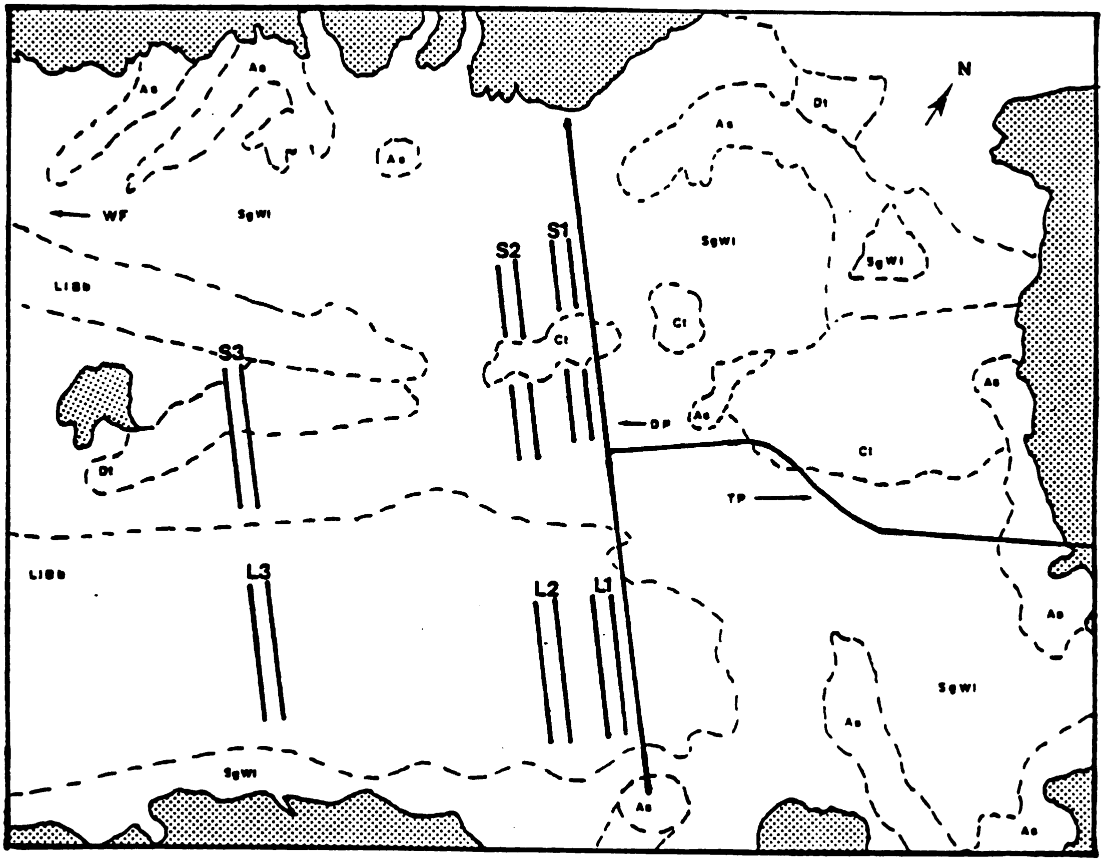

Figure 2. Location of the small mammal livetrap transect pairs (L1, L2, L3, S1, S2, S3) relative to the discharge (DP) and transfer (TP) pipelines, and to the major vegetation types on the wetland: sedge-willow (SgWl), cattail (Ct), leatherleaf-low birch (Ll), aspen islands (As), and dead timber (Dt). Stippled areas represent upland habitats. Scale: 1 mm = 11 m.

males were considered reproductively active when the testes were visibly enlarged. Trap location and date were recorded.

Snap-trapping Procedures

Five, 200-m transects were positioned down-flow and parallel to the discharge pipeline at 15, 125, 250, 375 and 500 m in the leatherleaf-low birch and sedge-willow communities (Fig. 3). Forty snap traps were spaced evenly (approximately 5 m apart) along each transect. Traps were not prebaited and were checked once each day, shortly after sunrise. Two-day (12-13 June) and five-day (19-23 August) trapping sessions were used to sample small mammal populations in both plant communities simultaneously. Snap-trapping in June was limited to two nights to minimize trapping effects for the second sampling period. Each animal collected was tagged with an identification number, date and trap location. Specimens were also weighed, measured (total length and lengths of tail, hind foot and ear), and frozen for later examination.

Laboratory Examination of Shrews

Shrews (*Sorex* spp.) were examined in the laboratory to verify species, and to determine sex, age, and reproductive condition. Differentiation of masked (*S. cinereus*) and pygmy shrews (*S. hoyi*) was based on dentition patterns (Burt 1957). If sex classifications could not be determined using

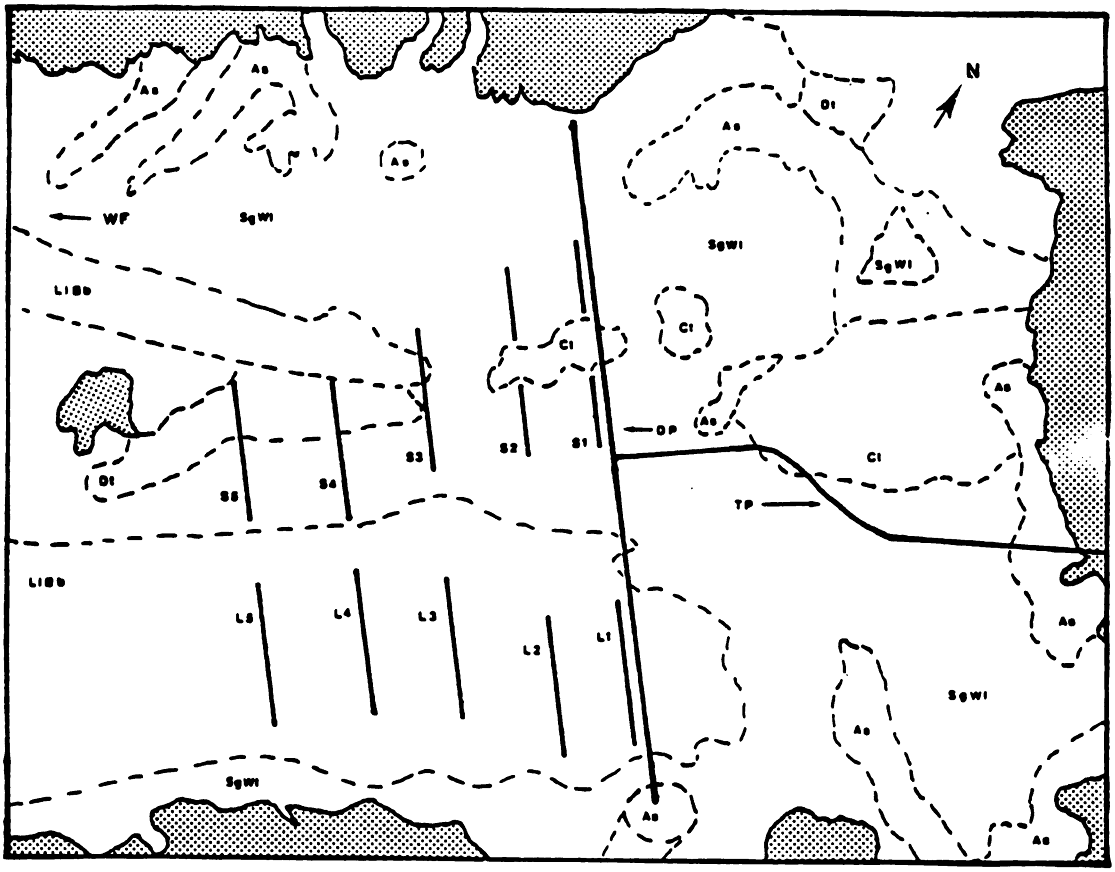

Figure 3. Location of small mammal snap-trap transects (S1-S5, L1-L5) relative to the discharge (DP) and transfer (TP) pipelines and to the major vegetation types on the wetland: sedge-willow (SgWl), cattail (Ct), leatherleaf-low birch (Ll), aspen islands (As), and dead timber (Dt). Stippled areas represent upland habitats. Scale: 1 mm = 11 m.

external characteristics, then internal reproductive organs were examined.

Both external and internal examinations of specimens were used to evaluate reproductive status. Females were considered reproductively active if they exhibited some development of lactation tissue, or if embroyos were present in the uterus. Reproductive status of males was determined by the size and position of the testes, and the visibility of the epididymal tubules (Jameson 1950). Males were considered reproductively active when the testes were enlarged (≥5 mm) and the tubules visibly swollen.

Degree of toothwear and pigmentation were used to age masked shrews (Butterfield 1981). When these criteria failed to classify an individual as a first or second year animal, aging was completed using methods (Appendix I) outlined by Pruitt (1954) and refined by Rudd (1955). Their method accurately classifies individuals into one of four chronological age classes. For analytical purposes, groups one and two, and groups three and four were combined and designated as juveniles and adults, respectively. In this paper, the terms adult and juvenile are used specifically in reference to age. Categories of sexual activity are referenced by the terms breeding and non-breeding.

Skulls and skeletons of masked and pygmy shrew specimens were cleaned using standard museum methods, and were donated to the Michigan State University Museum mammals collection. Study skins of the 18 pygmy shrews (MSU

No. 29083-29100) and one water shrew (S. palustris) (MSU No. 29101) captured on the wetland were donated also.

Habitat Analysis

Habitat measurements were taken along the 10 snap-trap transects to monitor changes in water depth and cover-water interspersion from June to August. Eight randomly-selected sites along each transect were sampled during each trapping session. At each site, a visual estimate of the percentage of open water was recorded using a 0.25 m^2 grid placed at ground level. Human and wildlife trails were considered part of the local microhabitat with importance to individual inhabitants, and no effort was made to avoid these features in the sampling. Water depth was measured at the grid center-point with a ruler. If no surface water was visible within the grid, water depth was recorded as zero. In some cases, emergent vegetation formed thick mats which completely covered the water column. No attempt was made to disturb the vegetative mat to record underlying water conditions.

Data Analysis

Abundance and diversity of small mammals captured on the wetland were examined. Species diversity was calculated using the Shannon Diversity Index (Poole 1974:392). Capture rates (number per 100 trap nights) were used to compare the relative effectiveness of live- and snap-trapping. Abundance, distribution, sex, age and reproductive condition were examined in detail for the masked shrew. Chi-square tests were used to analyze snap-trapping data and examine the impact of sewage effluent disposal on the masked shrew population. Linear regression analysis was used to examine the relationship between habitat measurements (water depth and cover-water interspersion) and numbers of masked shrews captured.

RESULTS

Small Mammal Community Structure

A total of 352 small mammals representing 9 species were captured on the wetland using live and kill traps in May, June and August (Table 1). Of the 6 *Sorex* spp. captured in live traps, 5 died and were identified as masked shrews. The animal that was toe-clipped and released was never recaptured. For analytical purposes, this individual was assumed to be a masked shrew.

Masked shrews were the most abundant small mammal species on the wetland and comprised 89% of the total captures. The remaining captures consisted of pygmy shrews (5%), short-tail shrews (*Blarina brevicauda*) (3%) and meadow voles (*Microtus pennsylvanicus*) (2%) along with single captures of the following species: water shrew, meadow jumping mouse (*Zapus hudsonius*), star-nosed mole (*Condylura cristata*), longtail weasel (*Mustela frenata*), and shorttail weasel (*M. erminea*).

The 18 pygmy shrews included 5 non-scrotal males, 12 non-pregnant females, and one lactating female (collected 23 August). All pygmy shrew specimens, including the one captured in June, were judged to be young of the year based on body weight and position of the first incisor (Diersing 1980). Weight and selected external and cranial measurements are recorded elsewhere (Rabe 1981). All 18 pygmy shrews were trapped in the leatherleaf-low birch community.

Table 1. Distribution and abundance of small mammals trapped on the wetland in major plant communities during 1979.

Species	Live-trapped[a]		Snap-trapped[b]	
	Sedge	Leatherleaf	Sedge	Leatherleaf
Masked shrew	3	3	76	231
Pygmy shrew	0	0	0	18
Short-tailed shrew	1	0	1	8
Water shrew	0	0	0	1
Meadow vole	0	1	3	2
Meadow jumping mouse	0	0	0	1
Star-nosed mole	0	0	0	1
Longtail weasel	0	1	0	0
Shorttail weasel	1	0	0	0

[a] Based on a total of 720 trap-nights in each habitat.

[b] Based on a total of 1400 trap-nights in each habitat.

Shannon diversity index values were 0.31 and 0.53 for sedge-willow and leatherleaf-low birch, respectively, and suggest a significant difference in small mammal diversity between the two habitats ($t=1.76$, $df=170$, $0.05<p<0.1$). The shorttail weasel was the only species captured in sedge-willow and not in leatherleaf-low birch. The water shrew, meadow jumping mouse, longtail weasel and star-nosed mole were never trapped in the sedge-willow. Diversity values were calculated also for each transect in both plant communities (Table 2). Only two or three species were trapped on any one transect, with the exception of the 15 m transect in leatherleaf-low birch, where seven species were captured. The higher capture rate and greater number of species captured on the 15 m transect in leatherleaf in August contributed greatly to the higher diversity values shown for leatherleaf-low birch in previous analyses.

Snap Trap and Live Trap Efficiencies

Comparisons of small mammal captures for each trapping method show that snap traps more effectively captured small mammals on the wetland than live traps. Snap traps captured seven species, while live traps captured five (Table 1). The longtail and shorttail weasels were the only species captured in live traps and not in snap traps, while pygmy and water shrews, meadow jumping mice and star-nosed moles were present only in snap-trap samples. Capture rates also indicate that snap traps were more effective in both sampling periods (Table 3). Live traps consistently

Table 2. Small mammal diversity at measured distances from the pipeline by major community type. Diversity was calculated with the Shannon Diversity Index (Poole 1974).

Distance (m)	Total captures[a]	Species	Diversity Index
Leatherleaf-Low Birch			
15	66	7	0.73
125	54	3	0.27
250	42	2	0.10
375	44	3	0.33
500	61	4	0.58
Sedge-Willow			
15	23	3	0.43
125	21	2	0.17
250	9	1	0.00
375	14	2	0.22
500	18	2	0.19

[a] Includes both live- and snap-trapped animals for May, June, and August 1979 and represents 424 trap-nights at each distance sampled.

captured fewer individuals. In addition, high mortality rates precluded the use of live-trap data for assessment of small mammal movement patterns. When capture rates were calculated exclusively for masked shrews, results again indicated that snap traps effectively trapped more animals than live traps.

Table 3. Comparison of spring and fall small mammal capture rates (number/100 trap-nights) for live-trapping and snap-trapping on the wetland.

Habitat	Live-trapped		Snap-trapped	
	May[a]	August[a]	June[b]	August[c]
Sedge	0.0	1.4	3.5	6.6
Leatherleaf	0.0	1.4	14.0	20.6

[a] Based on 360 trap-nights in each habitat.

[b] Based on 400 trap-nights in each habitat.

[c] Based on 1000 trap-nights in each habitat.

Numbers and Distribution of Masked Shrews

The numbers of masked shrews snap-trapped at various distances from the discharge pipeline are shown in Table 4. There were no significant (X^2=3.59, df=4, p>0.10) differences in the distribution of individuals at the distances sampled in leatherleaf-low birch in June. Likewise, masked shrew captures did not vary significantly in sedge-willow (X^2=7.25, df=4, p>0.10) or leatherleaf-low birch (X^2=2.01, df=4, p>0.10) during August. The low number of captures in sedge-willow in June precluded a valid statistical analysis of those data.

Contingency analysis was used to test for proportional changes in the numbers captured on transects in leatherleaf-low birch from June to August. Again, no significant (X^2=2.95, df=4, p>0.10) differences were found. These results suggest that the abundance and distribution of masked shrews on the wetland remained constant from June to August at the various distances sampled.

Sex Ratios of Masked Shrews

Of the 307 masked shrews captured on the wetland, 4 could not be reliably sexed due to predation or an advanced stage of decomposition. These were excluded from subsequent analyses.

In June, males were captured more frequently than females in both sedge-willow and leatherleaf-low birch (Fig. 4). The reverse trend was true in August. However, a Chi-square test of the numbers of males and females captured

Table 4. Distribution of masked shrews snap-trapped on the wetland during June and August 1979.

Distance from discharge pipeline	June		August	
	Sedge	Leatherleaf	Sedge	Leatherleaf
15	0	11	18	42
125	2	10	17	37
250	2	9	7	32
375	4	8	9	32
500	4	16	13	34

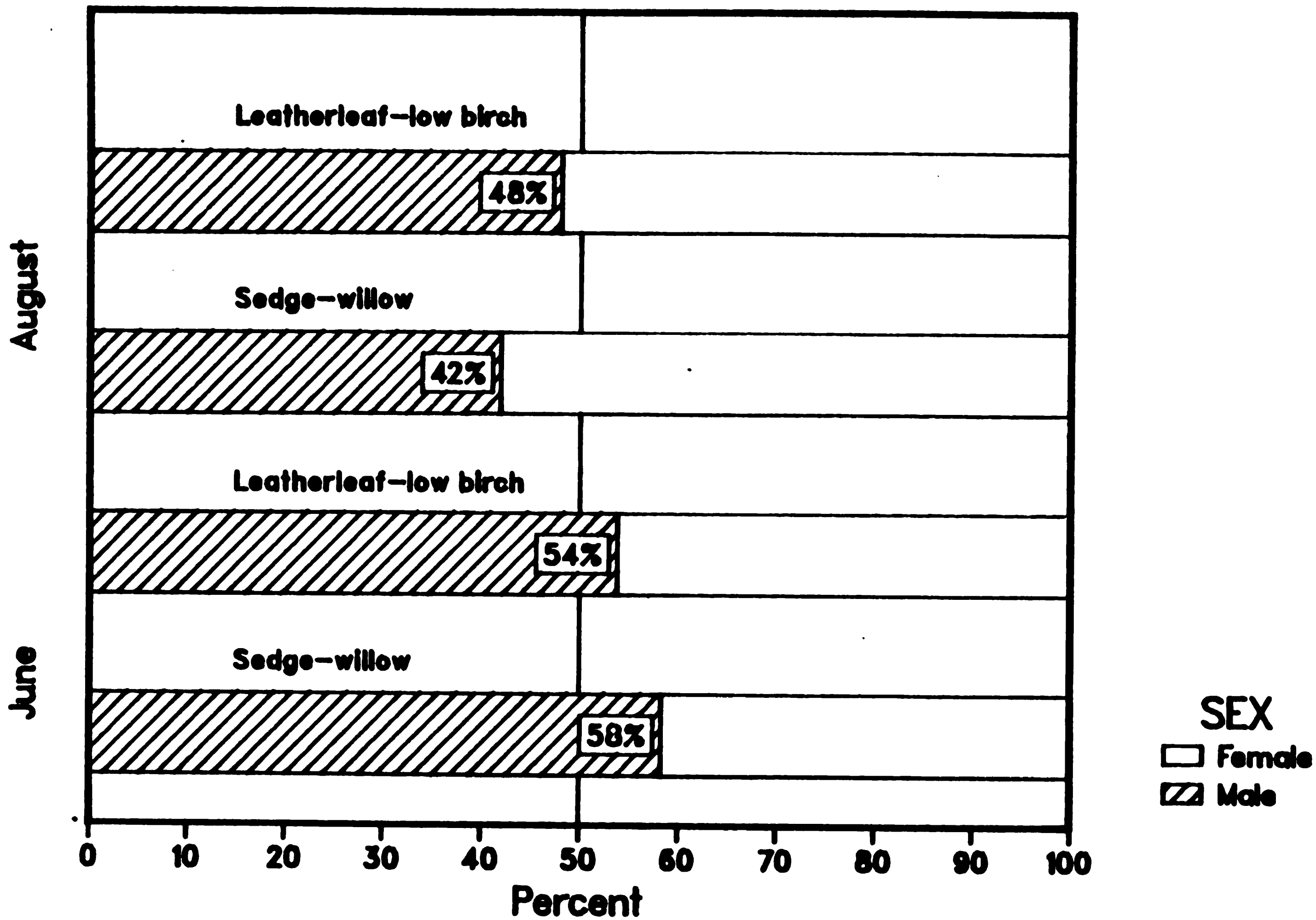

Figure 4. Percentages of male and female masked shrews captured in each plant community during June and August 1979.

in the two communities showed that in all cases, the observed values do not differ significantly from a theoretical 1:1 ratio ($p>0.10$).

Sex ratios were also calculated for the various distances sampled in June and August without regard to vegetation type (Table 5). In June, no significant differences were found in the numbers of males and females captured at the various distances ($X^2=4.8$, df=4, $p>0.5$). In August, however, significant differences ($X^2=10.2$, df=4, $p<0.05$) were found. Fewer males were trapped on the 500-m transect, and fewer females were captured at 250 m and 375 m.

Table 5. Sex ratios (males:females) of masked shrews snap-trapped on the wetland at various distances from the discharge pipeline during June and August 1979.

Distance	June	August
15	1:1.0	1:1.1
125	1:1.0	1:1.4
250	1:0.4	1:0.6
375	1:0.4	1:0.8
500	1:1.5	1:2.4

Reproductive Status of Masked Shrews

The distribution of breeding masked shrews in each plant community shows that both males and females were generally more active in June than August (Table 6). Fewer reproductively active females than males were captured in June in both plant communities. Numbers of breeding males and females were more nearly equal in August. The percentage of breeding animals was higher in sedge-willow than leatherleaf-low birch in August. The numbers of breeding males and females were analyzed at all distances in June and August and no statistically significant trends were evident.

Age Structure of Masked Shrew Population

At this time, 37 (14%) of the masked shrews captured on the wetland are unavailable for aging. In most cases, missing data make up no more than 15% of the total for any one distance sampled in June or August. Results from June trapping in sedge were not considered to be representative as small sample sizes magnified the effect of missing data. In August, 29% of the individuals trapped in sedge-willow at 250 m were not aged. While these limitations preclude strong conclusions, it is still useful to examine the available data for population trends.

Individuals classified into age groups 3 and 4 comprised 23% and 19% of the masked shrews captured in leatherleaf-low birch and sedge-willow communities, respectively. Therefore, capture data were combined for both plant communities to examine distribution patterns of juvenile (age classes 1 and 2) and adult masked shrews snap-trapped in June and August (Table 7). Numbers of juvenile

Table 6. Number (and percentage) of reproductively active masked shrews snap-trapped during June and August 1979.

Sex	June		August	
	Sedge	Leatherleaf	Sedge	Leatherleaf
Male	5 (71)	22 (79)	6 (23)	10 (12)
Female	1 (20)	12 (50)	10 (28)	8 (9)

Table 7. Numbers (and percentage) of juvenile and adult masked shrews snap-trapped in June and August at various distances from the discharge pipeline.

Distance	June		August	
	Juvenile	Adult	Juvenile	Adult
15	4 (17)	6 (17)	42 (22)	8 (33)
125	3 (12)	7 (20)	46 (25)	5 (17)
250	4 (17)	7 (20)	29 (16)	4 (17)
375	5 (21)	5 (14)	31 (16)	5 (21)
500	8 (33)	10 (29)	39 (21)	2 (8)

and adult animals were not significantly different at any distance from the discharge in either month ($p>0.50$).

Cross-examination of age and reproductive classifications produced some interesting relationships. In August, 53% of the total breeding female population were classified into age groups one and two. Only one of the nine breeding juvenile females was trapped in the leatherleaf-low birch community. The remaining eight were trapped in sedge at the following distances: 2 at 15 m, 2 at 125 m, 1 at 250 m, 2 at 375 m, and 1 at 500 m. Breeding females in June were classified into either age group 3 or 4, as were breeding males in both months.

Masked Shrew-Habitat Relationships

Both water depth and the amount of open water (interspersion of water and vegetative cover) showed consistent trends for each season and plant community type (Table 8). Generally, water depths were greater in August than in June, and greater in sedge-willow than in leatherleaf-low birch. The lowest average water depths occurred in June in leatherleaf-low birch at distances greater than 375 m down-flow from the discharge pipeline. Water levels were generally higher in areas near the discharge pipeline. The amount of open water increased from June to August on nearly all transects. In addition, values in sedge-willow exceeded values on corresponding transects in leatherleaf-low birch. Both water depth and the interspersion of cover and water, were influenced by the

Table 8. Water depth and surface coverage ($\bar{x} \pm$ S.E.) along trap-lines during June and August (n=8).

Transect distance (m)	Water Depth (cm)		Open Water (%)	
	June	August	June	August
		Leatherleaf		
15	2.0 ± 0.6	5.0 ± 1.4	15.6 ± 7.8	16.0 ± 7.1
125	1.2 ± 0.7	4.3 ± 1.4	6.2 ± 3.4	20.6 ± 9.9
250	1.2 ± 0.6	5.5 ± 1.6	3.8 ± 2.4	26.2 ± 8.2
375	0.8 ± 0.5	4.4 ± 1.1	4.4 ± 2.6	13.8 ± 4.2
500	0.8 ± 0.4	1.8 ± 0.7	7.5 ± 3.7	5.0 ± 1.9
		Sedge		
15	5.2 ± 1.0	13.8 ± 2.0	36.2 ± 4.2	40.0 ± 4.6
125	5.0 ± 1.8	11.1 ± 1.1	37.5 ± 8.6	43.8 ± 3.8
250	5.0 ± 1.2	10.5 ± 1.3	46.2 ± 7.3	52.5 ± 4.5
375	3.9 ± 0.9	13.1 ± 1.4	33.8 ± 6.8	61.2 ± 4.8
500	3.6 ± 1.0	8.0 ± 1.7	37.5 ± 4.5	33.8 ± 9.6

addition of effluent up to 375 m down-flow from the discharge pipeline.

Correlations between water depth and open water were found to be highly significant in both June ($r=0.96$, $p<0.001$) and August ($r=0.91$, $p<0.001$) (Fig. 5). Although significantly correlated, data points in June tended to cluster at both ends of the regression line. This relationship further emphasizes the consistency of these parameters within a plant community type, and the dissimilarity that occurs between types. Data points for August were spread more evenly across the range of possible values. While the two variables were highly correlated for each month, the regression lines appear to be non-parallel which would indicate that the relationship is not constant on a seasonal basis. A unit increase in water depth in June represented a greater increase in the amount of open water than a corresponding increase in water depth in August.

Masked shrew captures were standardized to adjust for the unequal trapping effort between seasons, and regressed against water depth and percent open water for both trapping sessions. Water depth was significantly correlated with masked shrew captures in June ($r=-0.90$, $p<0.001$) and August ($r=-0.82$, $p<0.01$) (Fig. 6). The regression lines, which are parallel, may indicate that masked shrew tolerance to water depth varies seasonally. Extrapolation of these lines to the x-axis indicates that shrews would tolerate only 6 cm of

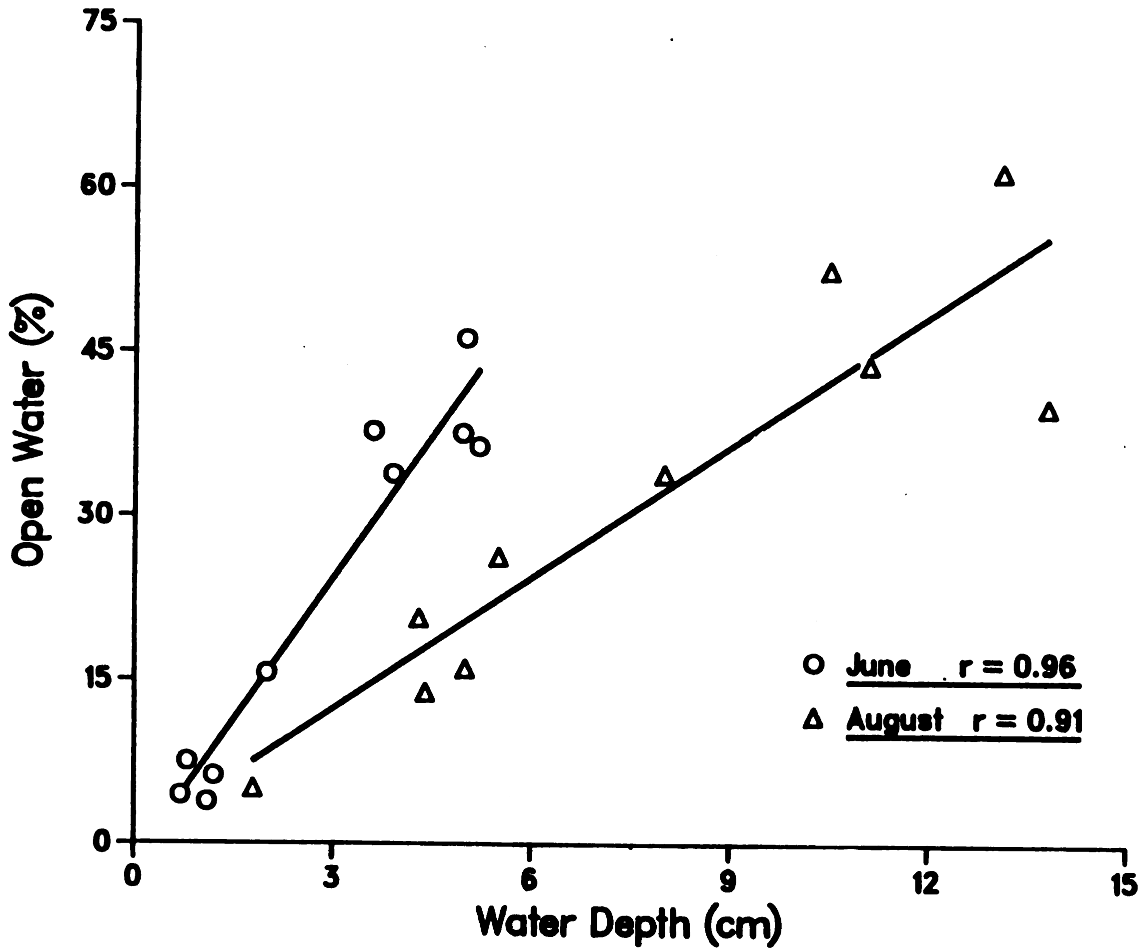

Figure 5. Relationship of water depth to percentage of open water present on the wetland in June and August.

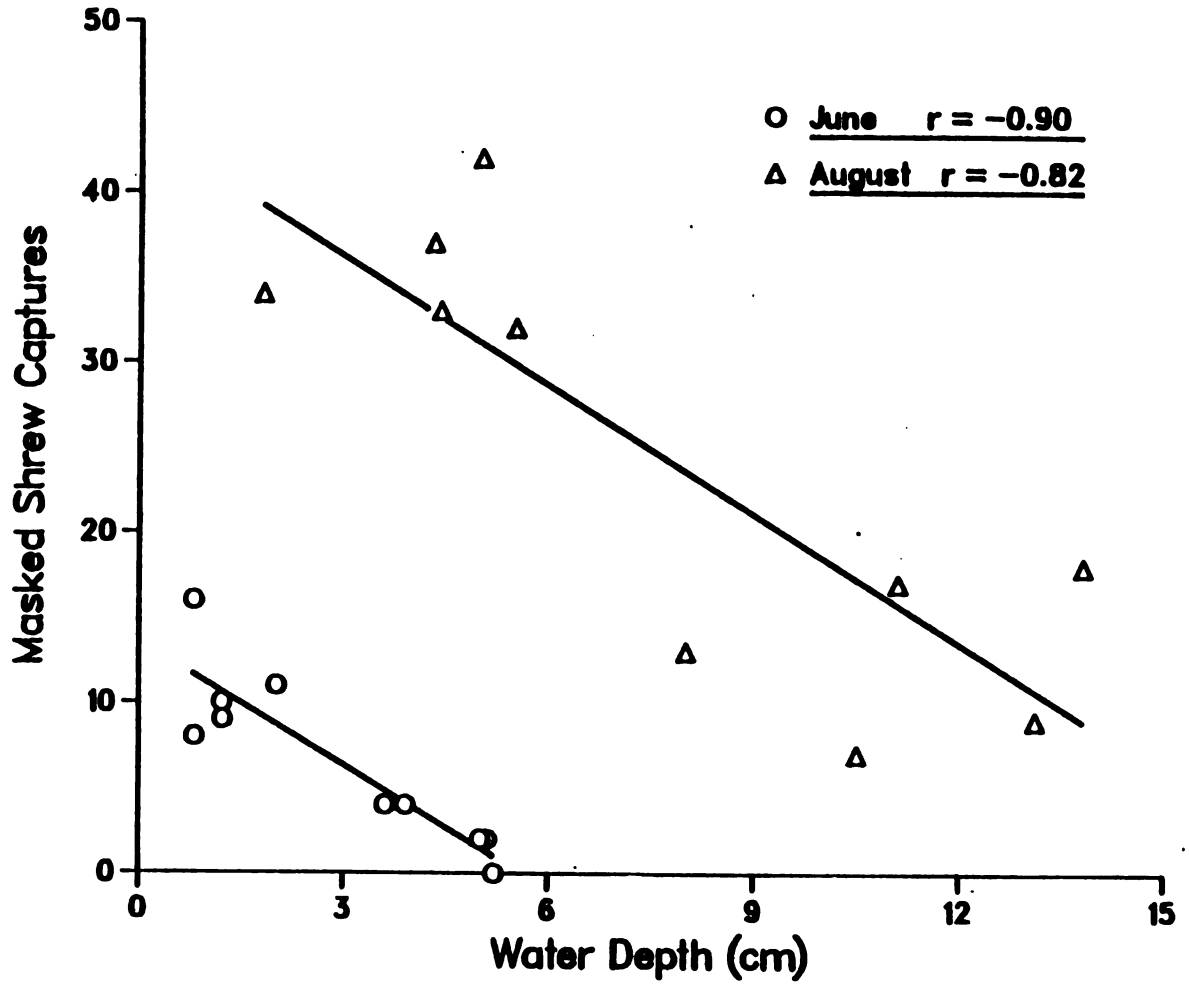

Figure 6. Relationship of water depth to masked shrew captures on the wetland in June and August 1979.

water in June while their tolerance increases to 17 cm in August.

Finally, regression analysis between masked shrew captures and cover-water interspersion produced significant relationships in both June ($r=-0.84$, $p<0.001$) and August ($r=-0.89$, $p<0.001$) (Fig. 7). Unlike the regression lines in Figure 6, the two in Figure 7 are not parallel. When projected to the x-axis, they cross at values of 49% and 70%. Masked shrews would most likely not be found in wetland plant communities where the amount of open water exceeds the amount of vegetative cover. This relationship does not appear to vary seasonally.

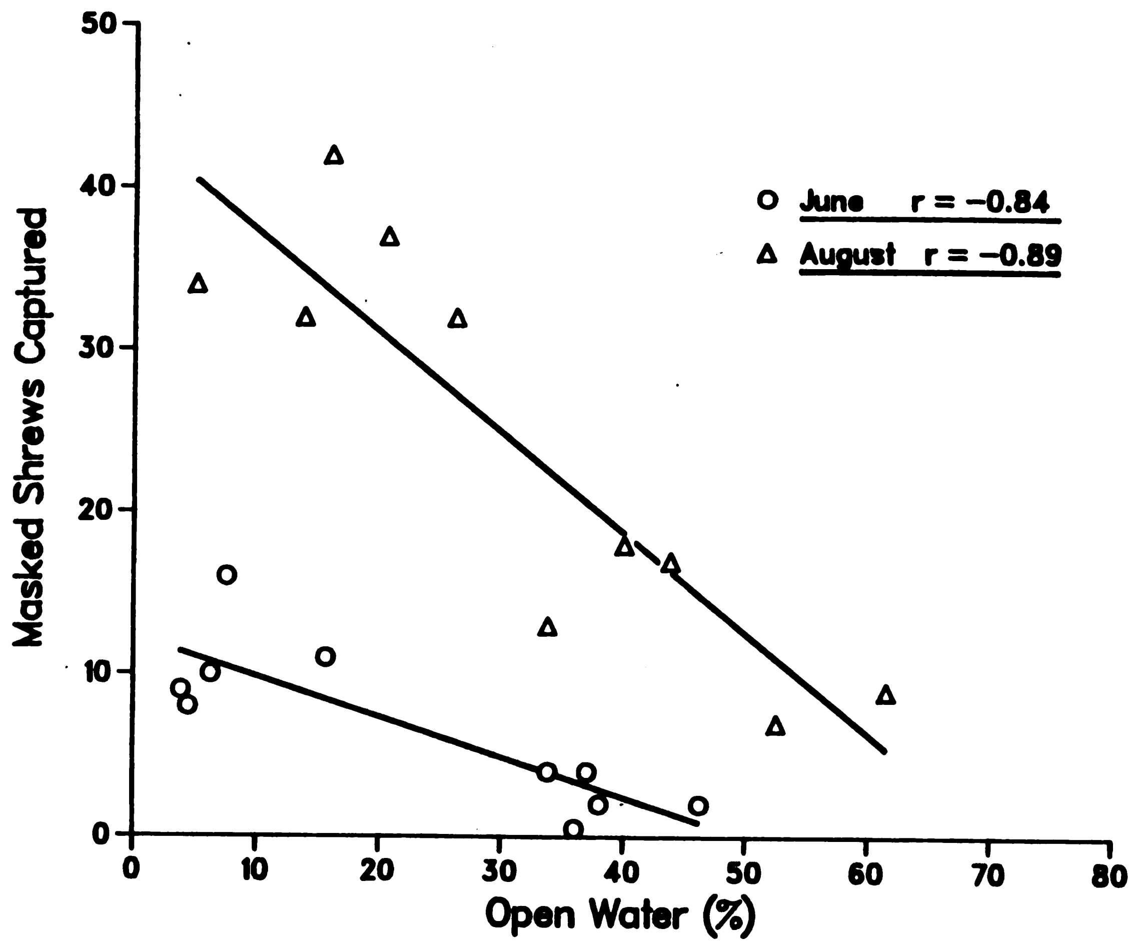

Figure 7. Relationship of open water to masked shrew captures on the wetland in June and August 1979.

DISCUSSION

Small Mammal Community Structure

Small mammal populations on the Houghton Lake wetland are both more abundant and diverse than has been shown by previous studies on the area. Rosman (1978), using Sherman live traps and minnow traps during mid-July and late August, succeeded in capturing only four species: meadow voles in sedge-willow, woodland deer mice (*Peromyscus maniculatus bairdii*) in leatherleaf-low birch, and short-tail and masked shrews in both plant communities. Kasischke (1974), using Sherman live traps during late June and July, successfully trapped shrews, deer mice (*Peromyscus* spp.), Eastern chipmunk (*Tamias striatus*) and shorttail weasel. The present study, using both snap traps and Sherman live traps documented the occurrence of 5 previously unrecorded species: pygmy shrew, water shrew, meadow jumping mouse, star-nosed mole and longtail weasel. Subsequent pitfall- and snap-trapping by Ruhl *et al*. (1982) in leatherleaf-low birch resulted in the capture of four species: meadow vole, masked shrew, meadow jumping mouse and woodland deer mouse.

Soricidae have been trapped in a variety of vegetation types including hardwood and pine uplands, hardwood and coniferous lowlands, bogs, marshes, and fields (Quimby 1943, Getz 1961, Long 1972, Anderson 1977). Their distribution tends to be limited by soil moisture content more so than temperature, vegetation type or amount of available cover;

they seldom occur in very dry areas (Pruitt 1953 and 1959, Getz 1961). As a result, lowland habitats such as bogs, marshes, and riverine areas often constitute preferred habitat (Quimby 1943, Manville 1949, Pruitt 1959, Hall 1981). Masked shrews in particular tend to utilize lowland areas and their preponderance on this study site is consistent with results gathered in similar habitat types (Buckner 1966, Haveman 1973, Master 1978, Ryan 1982).

The presence of pygmy shrews, however, was unexpected. This species is known in Michigan's lower peninsula from a single capture by Burt (1946) in Presque Isle County (Barnhart Lakes, Section 24, T34N, R3E). Thus, the capture of pygmy shrews in Roscommon County (Section 8, T22N, R4W) constitutes the second recorded occurrence of the species in the lower peninsula and provides a range extension of approximately 109 km (68 miles). Subsequent trapping by Ruhl et al. (1982) on this wetland was not successful in capturing pygmy shrews in either snap or pitfall traps. Ryan (1982) successfully pitfall-trapped pygmy shrews at seven new localities in the northern portion of Michigan's lower peninsula. As a result, pygmy shrews are now thought to occur continuously from Presque Isle County to Roscommon county. The trapping ratio of 1 pygmy to 17 masked shrews is not unlike those obtained by other workers (Master 1978), and further demonstrates the sparse population of the former species in the presence of the latter.

Also of notable interest is the capture of a single water shrew. This specimen, a non-breeding female, constitutes a new southern record of occurrence of this insectivore in the lower peninsula, and extends the species geographic range approximately 37 km (23 miles) from the previous most southern locality in Kalkaska County (Manistee River, Section 1, T26N, R5W).

Meadow jumping mice are more numerous on the wetland than this study indicates. Minnow traps set 1-5 m from the discharge pipeline in sedge-willow and leatherleaf-low birch to sample fish, snake and frog populations (Rabe 1980) captured 4 jumping mice, 2 in each plant community (Rabe, unpubl. data). These individuals were subsequently released without being marked. Ruhl et al. (1982) snap-trapped this species at 15, 315 and 515 m down flow from the discharge pipeline in leatherleaf-low birch. This may be an indication that jumping mice are increasing in numbers or altering their distribution on the wetland. Further investigations of population density, distribution, movement patterns and hibernation sites would be helpful in assessing the impact of effluent discharge upon this species.

The remaining species captured during this study typically occur in wetland habitats. None of these species are considered to be numerous on the Houghton Lake wetland at this time. It is possible that deer mice were not captured during this study due to yearly fluctuations in population density or differences in trap placement.

In general, seasonal differences were evident with consistently more captures occurring in August in both plant communities at all distances sampled. This most likely reflects the increase in small mammal numbers resulting from seasonal reproductive efforts.

Fewer small mammals were consistently captured in sedge-willow when compared to leatherleaf-low birch. Pitfall- and snap-trapping by Ruhl *et al*. (1982) was less successful in sedge-willow also. It is believed that the relatively hummocky nature of the leatherleaf-low birch community provides more small mammal habitat for given area than the sedge-willow where the presence of water would quickly limit the dry sites necessary for nesting, resting, and burrowing activities.

Species diversity varied between plant community types. Five of the nine species were trapped in leatherleaf-low birch and not in sedge-willow. While a more diverse small mammal community appears to inhabit leatherleaf-low birch, Shannon diversity values pinpoint the 15-m transect in August as the major contributor to the high values in this plant community. A similar, albeit weaker, tendency is shown at 15 m in sedge-willow also. The increase in small mammal abundance and species diversity at this distance can not be clearly attributed to the presence of wastewater discharge. The occurrence of the pipeline and its support structure, and the habitat disturbance associated with its construction, represent confounding variables that also have potential to influence small mammal population dynamics.

The effects of wastewater discharge on small mammal communities has been studied on a limited basis. On the Drummond Bog in northwestern Wisconsin, no short-term changes in small mammal composition, abundance, or diversity could be attributed to the presence of secondarily-treated wastewater (Kent 1983). Ruhl et al. (1982) trapped the Houghton Lake wetland two years after this study and reported that meadow voles were captured more frequently near the point of effluent discharge while masked shrews were captured less frequently in that area. It is likely that the small mammal community on the Houghton Lake wetland will continue to change in response to the discharge of effluent and plant community alterations.

Impact of Wastewater Discharge on Masked Shrews

Masked shrew captures on the Houghton Lake wetland in 1979 did not show any significant short-term changes in abundance, distribution, sex and age ratios, or reproductive activity due to the addition of treated effluent. While greater numbers of females were trapped in August, the trends were not statistically significant and probably represent behavioral changes. Anderson (1977) also noted an increase in the numbers of females captured and concluded that adult female activity increased as the breeding season ended. Dapson (1968) found that nesting females have a low capture probability. No explanation can be given for the uneven sex ratios in August at the five distances sampled. Sex ratio analyses do not give any indication that sex-related mortality is resulting from wastewater disposal.

Fewer reproductively active masked shrews were captured on all transects in the August sampling period. This decrease was expected because the breeding season is thought to terminate in September (Burt 1957, Anderson 1977).

The higher percentage of breeding animals in sedge-willow in August can be attributed, in part, to the capture of eight reproductively active first-year females. Because these individuals were trapped on all five transects, it is not likely that their activity resulted from the impact of effluent discharge. Burt and Grossenheider (1952) state that some female masked shrews may reach sexual maturity at 4-5 months of age. From two years of trapping in upland hardwoods, Anderson (1977) reported 31% of sub-adult (first-year) females as lactating or pregnant. These females were judged to be 4 to 5.5 months old. Anderson hypothesized that these individuals were inhabiting secondary or peripheral nesting areas, and this may be true for the Houghton Lake wetland as well. Shrew densities, as indicated by trapping data, were consistently low in the sedge-willow community. In addition, trapping would further depress shrew population numbers, and make suitable nesting sites more readily available.

Masked Shrew-Habitat Relationships

Water depth and the percentage of open water were highly correlated in the two plant communities that dominate the Houghton Lake wetland. A comparison of regression line slope values for June and August indicates that the relationship varied seasonally. This may be attributed to the increased abundance of annual plants in both sedge-willow and leatherleaf-low birch in August. However, the higher water levels associated with wastewater discharge are a confounding factor that can't be eliminated at this time.

The correlations between masked shrew captures and water depth showed seasonal differences in the maximum depth tolerated by shrews on the wetland. There is no known explanation for this result. Shrew tolerance might be changing on a seasonal basis in response to a variety of factors including reproductive activity, foraging behavior, or predator-shrew interactions. It is also possible that the strength of this relationship is a function of the strong inter-correlation between water depth and cover-water interspersion.

The interspersion of vegetative cover and open water is believed to have a significant impact on masked shrew abundance. Data indicate that shrew tolerance of open water was consistent in both plant communities in June and August. Masked shrews appear to tolerate a variety of cover-water interspersion patterns. Preferred habitats appear to have relatively few open water areas; shrews would most likely be absent from wetland plant communities where open water covered more than approximately 60% of the area.

While short-term changes in masked shrew abundance could not be related to effluent discharge, long-term changes can be expected in areas where open water dominates the available ground cover for an extended period of time. The areas near the discharge pipeline experiencing prolonged increases in water depths and open water areas, will most likely show a decline in or loss of the masked shrew community in the future. Based on the discharge patterns that occurred from 1978-1982, the area of wetland habitat that is unsuitable for masked shrews is expected to increase as wastewater disposal continues.

FUTURE SAMPLING RECOMMENDATIONS

Population and habitat utilization studies involving small mammals are always complicated by the biases associated with particular sampling methods. Unfortunately, no single type of trap or combination of traps will capture individuals of all species, sexes, and ages with equal probability (Smith et al. 1975). Capture rates also may vary seasonally (Pucek 1969), and with short-term changes of weather (Doucet and Bider 1974), residency status of individuals on the areas trapped (Boonstra and Krebs 1978), and species composition of the small mammal community (Calhoun 1964). It is important, therefore, to consider the biases of different types of traps when designing a sampling program.

Several studies have suggested that pitfall traps are effective for capturing shrews (Chelkowska 1967, Pucek 1969, Andrzejewski and Rajska 1972, Briese and Smith 1974, Master 1978, Ryan 1982). In addition, trap modifications have been developed that increase the trapability of many rodents (Andrzejewski and Wroclawek 1963, Pankakoski 1979). Williams and Braun (1983) hypothesized that species which characteristically travel in burrows (gophers, broad-footed moles) or in runways and along obstacles (long-tailed voles, shrews), and that orient primarily by non-visual senses, are especially susceptible to capture in pitfalls. Comparing the relative effectiveness of Museum Special traps, Sherman non-folding live traps, and plastic pitfall traps, they concluded that greater numbers of small mammals were caught in pitfalls. Given the results of these studies and earlier studies on the Houghton Lake wetland, the use of Sherman live traps on the wetland should be deemphasized. Estimates of both abundance and diversity were more accurate when snap traps were used. In addition, snap traps are relatively inexpensive, durable and easily transported.

The following trapping program was designed for future small mammal population monitoring on the Houghton Lake wetland:

1. Given the low number of captures in sedge-willow and the greater trapping success in late summer, trapping should be concentrated in leatherleaf-low birch and conducted for 4 or more consecutive nights in August.
2. Establish 3 permanent 100 x 30 m trapping grids at 15, 250 and 500 m down-flow from the discharge pipeline with 44 trap stations spaced 10 m apart on each. Center grids within the leatherleaf-low birch community and away from ecotonal areas.
3. Locate one Victor snap trap at each station, and one pitfall trap at every other station. Check traps as soon as possible after sunrise each day.
4. Bait traps with a rolled oats and peanut butter mixture, and renew bait daily.

The program outlined above will result in at least 264 trap-nights at each distance. This should provide adequate sampling for all species occurring at low densities. A minimum sample size of 33 small mammals per trapping grid can be expected based on capture data from this study.

Advantages of this sampling scheme are two-fold. First, it allows for samples to be taken quickly and efficiently. Small mammal density and diversity may be followed over the 20 year duration of seasonal effluent discharge with a single annual trapping session. Secondly, densities per unit area may be compared for distances within a given year, and over time to document changes in the small mammal community.

In addition, the Houghton Lake Wildlife Research Station should require summary reports of all small mammal trapping conducted by agencies or organizations not affiliated with ongoing monitoring programs. This policy would strengthen the annual data base, and increase the accuracy and reliability of monitoring results. Information collected should include: a description of trap type and location, trapping methodology and intensity, and a summary of capture data. Furthermore, specimens preserved for museum collections should be identified and described in a later report.

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APPENDIX I

Distinguishing features and approximate ages in months of the age groups for the genus *Sorex*, from Rudd (1955).

Group 1. 0 to 4 months.

(1-) No tooth wear; sutures not closed; bones of skull almost transparent.

(1) Tip of metacone of third premolar blunted; posterior faces of unicuspids scored; sutures weakly joined.

(1+) Wear on posterior faces of unicuspids reaching tip.

Group 2. 4 to 8.5 months.

(2-) Wear appearing on molars; cutting edge of third premolar worn to non-pigmented enamel; bone opaque; sutures joined; basal 1/3 of lambdoidal suture forming a ridge.

(2) Terminal pigment of metacone of third premolar divided by wear; wear on posterior faces of unicuspids arching over tips; protocones of all molars worn; basal 1/2 of lambdoidal suture ridged.

(2+) Cutting faces of first and second molars showing wear; metastyle of second molar worn to level of the paracone of the third molar.

Group 3. 8.5 to 12.5 months.

(3-) Tips may be worn from posterior unicuspids; ventral faces of first and second molars show a broad band of wear, with the pigment nearly gone from the mesostyle; lambdoidal ridge formed for basal 2/3.

(3) Wear on posterior and anterior faces of unicuspids; protocones of second and third molars worn smooth; lambdoidal ridge heavy for basal 3/4; sagittal crest beginning to form.

(3+) Cusps of third molar worn nearly flat; sagittal crest formed along entire length.

Group 4. 12.5 to 16 months.

(4-) Some unicuspids worn so that the occlusal face of one contacts the worn surface of another; pigment gone from third molar, much reduced on other teeth; crests well formed.

(4) Unicuspids flat on occlusal surface or may be missing; molars show flattened occlusal surfaces.

(4+) Third molars may be worn so that it is separated from second molar.