PERFORMANCE REPORT

As required by

ENDANGERED SPECIES ACT, SECTION 6

TEXAS

Project E-1-2

ENDANGERED AND THREATENED SPECIES CONSERVATION

Job No. 34: Conservation and Management of the Comal River Ecosystem

Principal Investigator: Lee Ann Linam

Larry D. McKinney, Ph.D.
Director
Resource Protection Division

Andrew Sansom
Executive Director
Texas Parks and Wildlife Department

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PERFORMANCE REPORT

STATE: Texas **PROJECT NO.:** E-1

PROJECT TITLE: Endangered and Threatened Species Conservation.

PERIOD COVERED: June, 1990 - August, 1990

JOB NUMBER: 34

JOB TITLE: Conservation and Management of the Comal River ecosystem.

JOB OBJECTIVE: To assess critical habitats for the endangered fountain darter (*Etheostoma fonticola*) and San Marcos salamander (*Eurycea nana*) in the Comal River ecosystem. To assess the impact of the introduced ram's horn snail (*Marisa cornuarietis*) on aquatic macrophytes and on the habitats of these endangered species.

YEAR OBJECTIVES:

1. Determine the abundance, size distribution, and biomass of ram's horn snails in each major habitat type of the Comal River ecosystem.

2. Determine macrophyte food preferences of the ram's horn snail.

3. Determine consumption, growth and survival rates of ram's horn snails when fed different species of aquatic macrophytes.

4. Develop recommendations for control of ram's horn snails in the Comal River ecosystem.

ABSTRACT

Major habitat types were determined for the Comal River ecosystem. Abundance, size distribution and biomass of ram's horn snails were determined in each habitat type. Laboratory experiments were conducted to determine snail macrophyte preferences and consumption, growth and survival rates for snails when fed different species of macrophytes. Three methods of control of ram's horn snails were considered.

ACCOMPLISHMENTS

See attached report.

SIGNIFICANT DEVIATIONS

There were no significant deviations. Future work should utilize exclosures to determine the impact of Marisa cornuarietis on aquatic macrophytes in the San Marcos and Comal River systems.

PREPARED BY: Lee Ann Linam — 12-20-90

Lee Ann Linam — Date

Endangered Species Biologist
Title

APPROVED BY: Larry McKinney — 12-20-90

Larry D. McKinney, Ph.D. — Date

Director, Resource Protection Division
Title

ECOLOGY OF THE INTRODUCED GIANT RAMS-HORN SNAIL, *MARISA CORNUARIETIS*, IN THE COMAL RIVER ECOSYSTEM

T. L. ARSUFFI , B.G. WHITESIDE and M. SKALBERG
DEPARTMENT OF BIOLOGY-AQUATIC STATION
SOUTHWEST TEXAS STATE UNIVERSITY
SAN MARCOS, TEXAS 78666

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BACKGROUND AND INTRODUCTION

Comal Springs, located in New Braunfels, Texas, represents a biologically unique ecosystem as evidenced by its numerous species of plants and animals found nowhere else. For example, two species, the fountain darter and the San Marcos salamander, are recognized by the U.S. Fish and Wildlife Service as threatened with or in danger of extinction. Due to a variety of factors, the Comal is in danger of losing its unique flora and fauna. One major threat is the declining levels of springflow associated with increased use of water in the aquifer for human activities coupled with recent low recharge rates associated with drought. Recently, a potentially important biological threat to the ecosystem has been recognized. Rapid increases in the population size of an introduced species of snail (giant rams-horn, *Marisa cornuarietis*) have been observed. The snail is suspected of causing marked reductions in the aquatic vegetation of Comal Springs and Landa Lake. There is potential for further increase in population size with additional ecological impacts on the ecosystem and the unique species it contains. The main objective of this study is to quantitatively determine the effect of giant rams-horn snails on loss of vegetation in Comal Springs and Landa Lake.

The giant rams-horn snail is a large discoidal snail that is native to northern South America and southern Central America (Baker, 1930). The first occurrence in North America was in Florida (Hunt, 1958). Recently, Neck (1984) reported the discovery of a population of *M. cornuarietis* in June, 1983, in the San Marcos River, Hays Co., Texas.

Marisa cornuarietis was first detected in the Comal River in June, 1984, when four empty shells were collected from the lake in Landa Park. Even with extensive sampling effort, no living specimens were noted. Apparently, snails were introduced about 1983 into the Comal River. The method of introduction is unknown. *M. cornuarietis* is a common aquarium snail and is sold by pet dealers in both San Marcos and New Braunfels; it is likely that unwanted giant rams-horns were released by aquarists. Dumping unwanted specimens is also the likely method of their introduction into southern Florida (Hunt, 1958).

Neck (1984) suggested that M. cornuarietis could have a substantial environmental impact on the San Marcos River. Previous studies have established that M. cornuarietis through predation on both eggs and juveniles and through competitive superiority for food resources is an effective biological control agent against a variety of snail hosts of schistosomiasis (see review in Robins, 1970). M. cornuarietis also is recognized as a voracious herbivore, which is why it became unpopular with aquarists, and has been investigated as a biological control agent for aquatic weeds that clog ponds, canals, and waterways (Seaman and Porterfield, 1964; Blackburn et al., 1971). Herbivory by macroinvertebrates on living plants of macrophytes is very uncommon in freshwater ecosystems (Otto and Svensson, 1981; Wetzel, 1983). To date, no data exists concerning quantitative population trends of the giant rams-horn or whether it is having a deleterious effect on the flora and fauna of the biological communities of the Comal River ecosystem.

However, in the 7 years since its probable introduction into the upper Comal Springs, the population size of M. cornuarietis has increased dramatically. From October 1989 through February 1990, I have observed extremely dense populations of adult snails and large numbers of egg masses in Landa Lake. Areas of the lake, which until recently supported large masses of aquatic macrophytes, have been completely denuded; the bare lake bottom is now crisscrossed with snail tracks. Although no direct evidence exists, M. cornuarietis is believed to be responsible for the disappearance of the vegetation. No apriori data exist to indicate which plant species were affected. At present the dominant macrophytes in the lake are Cabomba caroliniana , Ludwigia repens and Vallisneria americana . In addition to alteration of plant communities, the giant rams-horn snail also might have a drastic effect on a variety of other species including endemic species such as fountain darters and the San Marcos salamander. For example, aquatic vegetation can strongly influence trophic interactions in freshwater communities; mainly by providing cover for invertebrates and small fish thus supplying protection from larger predators (see Janacek 1988 for a review). If snails are significantly cropping vegetation, this could result in a loss of cover and refuge, making fountain darters and invertebrates more susceptible to predation. It also may lead to a reduction in food supply. Thus, giant rams-horn snails could indirectly be the biological agent responsible for leading to the demise of fountain darters as well as other species.

The overall objective of the study was to determine the biological impact of an introduced tropical snail on the aquatic vegetation and the endangered fountain darter, Etheostoma fonticola. Specific objectives were to: 1) determine the major habitat types and estimate the abundance, size distribution and biomass of the giant rams-horn snail, M. cornuarietis ; 2) conduct laboratory experiments to determine snail macrophyte preferences; 3) conduct laboratory experiments to determine consumption, growth and survival rates of snails when fed different species of macrophytes; 4) make recommendations for control of giant rams-horn snails in the Comal River ecosystem.

Objective 1. Determine major habitat types and estimate the abundance, size distribution and biomass of rams-horn snails in Comal Springs and Landa Lake.

SITE DESCRIPTIONS

After several preliminary surveys, eight sampling stations (Figure 1) were established at Comal Springs and Landa Lake. Site 1 is a spring-run that issues from a cave entrance and is located at the northwest boundary of Landa Park. The substrate consists of cobble with a water depth of 13 cm when discharge ranges from 100 - 125 cubic feet per second. Comal 2 is located at the deepest (1.3 - 2.5 m) part of Landa Lake, opposite where the cutter boat is moored. The dominant vegetation is a mixture of V. americana and Cabomba caroliniana. Comal 3 is another spring-run about 73 m north and across California Boulevard from Comal 1. The site is northeast of the walking bridge with a cobble substrate frequently covered with a red alga and patches of the macrophyte, Potamageton illinoensis. Comal 4 is located west of the southern most island in Landa Lake. Water depth ranges from 35 to 65 cm with the dominant vegetation consisting of a mosaic of pure stands of V. americana or L. repens. The four remaining sites are located outside of Landa Park at the northeastern most extremity of Comal Springs. Comal 5 is the area northeast of the walking bridge across from the private park. Water depth ranges from 0.7 to 1.0 m and the substrate is silt and mud. The dominant macrophytes are stands of Sagittaria platyphylla and C. caroliniana. Comal 6 is a small cove located about 30 m northeast of Swan Island. A number of springs discharge at this site at which the substrate is mainly cobble. At other locations the bottom is silt and mud from which C. caroliniana and L. repens grow. Water depth varies from O.2 to 0.5 m. Comal 7 is located 20 m upstream of Comal 6 and has a cobble substrate covered with a mat of filamentous green algae. Water depth varies from 0.2 to 0.8m. Comal 8 is the is the furthest upstream site and is located northwest of the City of New Braunfels Public Works Headquarters. The substrate consists of silt and mud and C. caroliniana is the dominant vegetation. Water depth varies from O.4 to 0.7 m.

METHODS AND MATERIALS

Quantitative benthic samples were taken on 16 and 17 May at each of the eight sites to estimate abundance of M. cornuarietis at each of the designated sampling stations (= habitat types). For each of the spring-runs (sites 1 & 3), three random benthic samples were collected with a Hess bottom fauna sampler. The sampler is a specially constructed cylinder (0.33 m^{-2}) designed for implantation into the streambed and with an attached net to catch dislodged organisms from the sample area. After collection, each sample was preserved for later sorting, enumeration and sizing of snails. Water depth prohibited the use of the Hess sampler for the remaining six sites, instead an Ekman dredge (0.53 m^{-2}) was used. The dredge is a square box with a pair of opposing jaws attached to the lower opening of the box. The box can be lowered from a boat with the jaws held in the open position by a strong pair of springs. Once the dredge has reached the bottom, the springs holding the jaws open can be released and snapped shut by sending a weighted messenger down a rope from the boat. The sample is hauled into the boat and sieved to remove silt and mud from the sample. The sample is preserved for later sorting, enumeration and sizing of snails. At each site, three replicate bottom samples were collected.

RESULTS

The abundance and size of M. cornuarietis at each of the collecting sites are presented in Figure 2. No M. cornuarietis were collected at stations where substrate was mainly cobble and aquatic macrophytes were absent. These included both of the spring-run habitats (sites 1,3) and one upstream (site 7). The greatest concentration of M. cornuarietis occurred in habitats in which substrate composition was mainly silt and mud and macrophytes were in abundance. Even with vegetation present, there was station to station variation in snail abundance; sites 4 and 8 had the fewest number of snails and site 5 the greatest. No obvious differences in size of snails in relation to sampling sites were apparent.

DISCUSSION

The eight sampling stations vary with respect to substrate composition, depth, flow regime and presence and type of aquatic vegetation. A basic habitat requirement of M. cornuarietis is the presence of aquatic vegetation; their preferred food source. Current velocity also seems to limit snail distribution and abundance. Quantitative sampling and direct observation have failed to detect any M. cornuarietis in the upper segments of either of the spring-runs (sites 1 & 3) even though patches of vegetation are present. The bulky, discoidal body shape of giant rams-horn snails is not effective at minimizing resistance to current. For example, in shallow areas (< 1m) with low current velocities, M. cornuarietis is found in the upper canopies of plants. In contrast, in deeper areas in the middle of the channel, M. cornuarietis is seldom observed on plants. Patches of C. caroliniana located in the middle of the channel at site 5 frequently have the lower 10cm of the stem stripped bare of leaves; apparently snails cannot climb higher before being swept off. As long as adequate flows are maintained, the current velocity in the spring-runs will represent a physical barrier that will prevent colonization of M. cornuarietis into these habitats

SAMPLING LIMITATIONS AND SNAIL POPULATION ESTIMATES

Initially, or sampling design was to take triplicate Ekman grab samples in each of the designated six lake habitats. The procedure was to lower the grab to the bottom, send the messenger to close the jaws and contain the sample, and then haul the grab with sample to the surface where it could be sieved free of fine particles and preserved for later sorting. We abandoned this procedure because too many samples had to be discarded once the grab was brought to the surface becauses of leakage through the jaws due to incomplete closure associated with snails and vegetation jamming the grab.

Alternatively, we used a pair of SCUBA divers to position the Ekman grab and ensure complete jaw closure and transfer of the grab to the boat for processing. This was a time consuming process that required two full days to sample the six Landa Lake sites and personnel consisting of two divers and two sample processors in the boat. Snail densities provided in Figure 2 were obtained using this procedure. For several reasons, this also was not a reliable sampling procedure that would provide unbiased estimates of rams-horn size and numbers. One problem is that the grab is placed over and dropped down onto the sample location. Snails are easily knocked off the plants and away from the grab area during placement. This leads to underestimates. Secondly, plants still interfere with the collection and closure process and plant biomass, height and density vary significantly from site to site. Thus, snail densities may be over- or underestimates depending on the degree plants affect sampling efficiency in different habitats.

We have been working on alternative techniques to this problem. Recently, we have been in correspondence with a group of aquatic biologists at the University of California at Berkeley. They have designed a device to sample invertebrates associated with aquatic macrophytes. This device operates opposite to that of the Ekman in that the sample haul begins at the base of the macrophyte bed and collects the invertebrates during passage upward through the water column. We will test this device once the designs have been obtained and one can be built. Alternatively, we recently discovered that a direct visual estimation of snail numbers may be more reliable and less time consuming than mechnical devices. Rams-horn snails can be readily observed in all habitats during the daytime and as such can be enumerated. Of question is how many snails are present and not directly observable in the daytime. In August, we were on Landa Lake electroshocking to assess fish species diversity We went over many sites we had visited the day before during the daytime. To our surprise under the spotlight snail densities seemed much higher in each habitat than during the daytime. This also included small sized individuals which are rarely observed up on plants during the day. Apparently, rams-horn snails undergo diel vertical migrations, possibly to minimize risks of predation during daytime. Thus, night time population censuses might be a useful approach. Which sampling procedure to be employed requires preliminary comparative study.

SIZE OF ADULT SNAILS

One area of Landa Lake, which until recently was reported to support large masses of aquatic vegetation, is now completely denuded; the bare lake bottom is now crisscrossed with snail tracks. This denuded area is a band that extends roughly 500 m southwest of Site

1 and is located along the northwest bank that borders the fault escarpment. Large numbers of dead snails that collect behind rocks or accumulated in depressions can easily be observed from the surface by boat. As indicated earlier, it is rare to find living snails in habitats where vegetation is absent We collected dead (empty shell) snails from these areas to determine size at maturity and compared them to size of dead snails collected from the San Marcos River. Results indicate that diameter of dead adult snails in Landa Lake are 18.2% smaller than those collected from the San Marcos River (Comal: x = 28.9 mm, N = 270; San Marcos: x = 34.2, N = 140. In comparison, Jobin (1970) found that normal adult diameter of M. cornuarietis at 500 days (average life span) ranged from 50-60 mm (≈ x2 size of Comal adults) but when conditions were crowded and less vegetation was available adults grew to only 27 mm after 500 days. These comparisons suggest that snails that existed in this part of Landa Lake may have experienced severe food shortages due to a depletion of aquatic macrophytes.

Objectives 2 & 3. Conduct laboratory experiments to determine snail macrophyte preferences and consumption, growth and survival rates when fed different species of macrophytes.

Differences in abundance of M. cornuarietis at different sites (Figure 2) may also be related to variation in the food quality of the various plant species. It is well known that growth and survivorship rates of invertebrates vary widely in relation to variation in the food quality of the plant species that they feed upon. Nutritional composition (protein, vitamins), toxin concentrations and physical attributes (toughness, fiber content) are three major characteristics of plants that affect food quality and show considerable variation among plant species. The goal of the laboratory experiments described below is to determine how food quality varies among the predominant aquatic macrophytes of Comal Springs and Landa Lake as evidenced by patterns of consumption, growth and survival of M. cornuarietis when fed different plant species.

METHODS AND MATERIALS

Of the submerged and floating macrophytes of Comal Springs and Landa Lake (Table 1), L. repens, C. caroliniana and V. americana were most common. Consequently, these three species were used as foods for the M. cornuaretis feeding experiments. Experiments were conducted using plants and snails collected from Landa Lake which were brought to the laboratory and held in ten-gallon glass aquaria containing wellwater from the Edwards Aquifer. All aquaria were aerated and maintained at 21 ± 2° C.

Plant Preference Experiment

This study was designed to determine which macrophytes were preferred by M . This would help determine which areas of the lake and springs would be most vulnerable to M. cornuarietis predation.

Using only the top 30 cm of each plant, equal weights (grams wet weight) of mature L. repens, C. caroliniana and V. americana were placed in six aquaria. In three aquaria, L. repens, C. caroliniana, and V. americana were randomly placed in separate stands and anchored by plant weights. Five M. cornuarietis, 40-44 mm in diameter were dispersed in each of the three experimental aquaria and allowed to feed for seventy hours. The final three aquaria served as controls, each containing equal amounts of L. repens, C. caroliniana and V. americana.

At the end of the feeding trial all remaining plants were collected, blotted dry and then wet-weighed to the nearest 0.01 g. The pieces of macrophytes that were clipped off by M. cornuarietis and floated to the top of the water were collected and weighed separately to determine the amount of snail-induced plant loss not attributable to consumption. All plants were then dried at 45° C and reweighed. All consumption values reported are on a dry weight basis to remove bias due to differences in water-holding capacities of plants. The average dry weight of each set of replicate treatments was divided by the number of snails per aquarium and the number of days in the feeding interval to obtain grams consumed per snail per day.

Long-term Feeding Experiment

This study was designed to determine the effect of each macrophyte on the growth and survivorship of M. cornuarietis. It was also designed to determine consumption rates for different size classes of snails for each of the three most common macrophytes of Landa Lake. Equal wet-weights, measured to the nearest 0.01 g, of mature C. caroliniana, L. repens, and V. americana were placed in twelve aquaria . There were three replicates for each plant type and control. At Day 0, sixty newly-hatched M. cornuarietis, (shell diameters ranging between 0.24 to 0.85 mm), were dispersed in each aquarium. Feeding intervals ranged from 7 to 14 days. At the end of each interval the remaining plant material was harvested and replaced with freshly collected macrophytes. Aquaria were periodically monitored to ensure snails did not deplete food.

Each time macrophytes were replaced, snails were counted, shell diameter measured, and the water replaced. The macrophytes removed at the end of a feeding interval were separated into two categories; plant material anchored and plant material floating. This allowed us to quantitatively determine two major effects of M. cornuarietis on the vegetation; that of consumption and that of clipping. Consumption was based on the difference between initial plant weight and total plant weight remaining (includes anchored plus floating leaf parts) at the end of a feeding interval. The amount of floating leaf parts is the effect of M. cornuarietis on vegetation loss attributable to "clipping". While feeding, snails often clip the petiole or basal stem of plants before feeding on the cuttings. Snails frequently lose their grip on the cuttings and because leaves and stems are aerenchymous (air-filled), the cuttings float away.

The removed plant material was initially wet-weighed (0.01g) and then dried for 24 hours at 45° C and reweighed to the nearest 0.1 mg to determine dry mass.

Shell size - body mass relations

To establish a method of accurately determining body mass by measuring shell diameter, the following procedure was performed. We collected 105 M. cornuarietis from the Comal River and put them into quick freeze.for at least three days. The snails were then thawed for approximately ten minutes and their bodies extracted using a probe and forceps. The bodies were placed in preweighed and numbered weigh boats and dried at 50° C for 24 hours. A dry weight was taken of both the body and shell separately and the shell diameter measured with calipers to the nearest 0.1mm.

RESULTS

Plant Preference Experiment

In this 70-hour experiment, M. cornuarietis exhibited a higher preference for L. repens than either C. caroliniana or V. americana. but did not reveal a preference between C. caroliniana or V. americana. While feeding, M. cornuarietis clipped a significantly higher amount of L. repens than C. caroliniana; V. americana had no clipped losses (Figure 3).

Long-term Feeding Experiment

The results from the 140-day feeding experiment revealed marked variation in patterns of consumption, growth and survivorship of M. cornuarietis when fed different plant species.

Consumption

There was a positive relationship between snail size and consumption rate when M. cornuarietis was fed L. repens.(Figure 4). The relationship, though, was not always consistent between each feeding interval; occasionally consumption was lower than the previous interval.

In contrast, when M. cornuarietis was fed V. americana, consumption rates remained fairly constant until snails reached 8 mm in shell diameter (Figure 5). Consumption increased markedly at this size and remained relatively constant thereafter.

Over the thirteen intervals, M. cornuarietis feeding on C. caroliniana exhibited only slight increases in consumption rates through time. Interval 11 has an exceptionally high consumption value because M. cornuarietis were fed immature C. caroliniana, which is apparently more palatable than mature C. caroliniana (Figure 6).

Overall, ordering of consumption rates of the three plant species is L. repens > V. americana > C. caroliniana. (Figures 3 - 5). By the end of the experiment, M. cornuarietis had doubled its initial consumption of C. caroliniana. In contrast, M. cornuarietis dramatically increased its consumption of V. americana after 80 days (seventh feeding interval) to x9 its initial consumption. Even though more L. repens was consumed, consumption increased only x4 its initial amount.

The relative contribution of consumption and clipping to vegetation loss for each of the plant species is presented in Figures 7 - 9. Clipping represented a significant loss of plant mass when M. cornuarietis fed on L. repens. The magnitude of the loss became greater as snail size increased. In contrast, loss of vegetation by clipping had a relatively minor impact on V. americana and C. caroliniana.

Growth

M. cornuarietis exhibited rapid growth rates on each species of macrophyte during the early stages of the study (Figure 10). However, through days 25 -75, growth was greater on a diet of L. repens than on V. americana and C. caroliniana. M. cornuarietis in the C. caroliniana and V. americana treatments grew at approximately the same rate until about the 65th day when growth rates of M. cornuarietis on a diet of V. americana increased. By day 85, M. cornuarietis fed V. americana grew 3 mm in 20 days. At this time, M. cornuarietis fed L. repens and M. cornuarietis fed V. americana both measured approximately 9 mm, while M. cornuarietis fed C. caroliniana measured 7.5 mm. The M. cornuarietis fed V. americana continued this rapid growth increase; they were 1.5 mm larger than M. cornuarietis feeding on L. repens and 3.5 mm larger than M. cornuarietis feeding on C. caroliniana after 140 days.

Survivorship

The survival rate of M. cornuarietis when fed L. repens sharply contrasted with rates observed for snails on diets of C. caroliniana and V. americana (Figure 11). Numbers of living snails declined steadily through 140 days on diets of C. caroliniana and V. americana with mortality leveling off in subsequent intervals. Survivorship was high for M. cornuarietis when fed L. repens. At the final feeding interval, survivorship for M. cornuarietis was 97% on L. repens, 65% on C. caroliniana and 50% on V. americana. **Note: This long-term feeding study is still in progress; the data and conclusions are through 2 September 1990.**

Relationship between shell size and body mass

The relationship between shell size to dry body mass is shown in Figure 12. A logarithmic curve fit to the data explained the most variation. Shell size was found to be a very good predictor (R^2) of dry body mass. This relationship was determined so that consumption rates of snails could be estimated on a dry weight basis without the need to sacrifice snails at every feeding interval for the long term lab experiment. This information can also be used to estimate total biomass of field collected snails more efficiently.

DISCUSSION

M. cornuarietis exhibited significant variation in patterns of consumption, growth and survivorship in relation to species of macrophytes used as a food source. When given a choice between the three species of macrophytes, rams-horn snails clearly preferred L. repens over V. americana and C. caroliniana. Based on the results of the food choice experiment, areas of the lake where L. repens dominates the vegetation should be preferred habitats and most susceptible to impact by rams-horn snails. The results from the first three months of the long term feeding study of snail growth, survivorship and consumption on diets of different plant species provide additional evidence to support this conclusion. The results of the long term feeding experiment also indicate three different mechanisms in which M. cornuarietis will have a greater negative impact on L. repens relative to that of V. americana or C. caroliniana. First, after 130 days young M. cornuarietis experienced little mortality when fed L. repens, but suffered nearly 50% mortality on V. americana and C. caroliniana. This means that, provided no other sources of mortality (e.g. predation) occurs, every egg laid among stands of L. repens should survive to sexual maturity and reproduce. In contrast, only one out of two eggs would reach maturity in habitats dominated by V. americana and C. caroliniana. Presumably, through time this would lead to a population effect, with more snails in L. repens habitats than other vegetation types. Second, the results of the preference and long term feeding experiments also indicate that consumption rates are higher on L. repens. This suggests that even if population sizes of snails were the same for each vegetation type, plant loss would be higher for L. repens because individual consumption rates are greater. Finally, in preliminary experiments, we discovered that the effect of M. cornuarietis on loss of vegetation may be much greater than one based on consumption rates and population size alone. This non-consumptive loss is due to the effect of "clipping" in which cuttings float away when snails lose their grip while feeding. We measured the effect of "clipping" in these experiments. The results show that vegetation loss due to clipping is markedly greater for L. repens than V. americana and C. caroliniana. For L. repens, losses due to clipping increases with size and consumption rates of snails and may even exceed losses due to consumption (see Figure 3).

Objective 4. Make recommendations for control of rams-horn snailsin the Comal River ecosystem.

There are three possible ways to control or eliminate rams-horn snails from the Comal River ecosystem. They are: biological control, use of molluscicides and manual harvest. Below we point out some of the advantages and disadvantages of each method.

Biological Control: One possible way to control rams-horn snails is by predation. For example, it is known from studies in other aquatic ecosystems that fish are very effective in regulating snail population size.

At present we do not know if any of the fish species in Landa Lake feed on rams-horn snails. A stomach analysis study would be needed to address this question. The red-eared sunfish, Lepomis microlophus is a well known predator of snails. However, it does not naturally occur in Landa Lake and would have to be introduced. We have no way of predicting what negative impacts this species may have on the ecosystem should it be introduced or even if it would be able to provide any significant control of rams-horn snails. Fish predation would only be effective on smaller snails (< 10 mm) since larger shells would be too big to crush or consume. We have made preliminary observations which suggest that fish may not even be effective predators on small size classes of rams-horn snails because the snails exhibit a daily behavioural pattern which minimizes risk of predation to visual predators. During daylight, small snails are very inconspicuous and rarely observed feeding on plants, whereas by nightfall they migrate up plant stems and can be seen in large numbers feeding on leaves near the tops of plants. By morning, they migrate back down to the base of the plants.

Molluscicides: M. cornuarietis is apparently very sensitive to a variety of molluscicides (Ferguson and Butler 1966). The advantage of using molluscicides is the possibility that rams-horn snails could be completely eradicated from the system. The disadvantage is that without biotoxicity research, there is no way of determining its influence on endangered and endemic species within the macroinvertebrate communities. Their elimination with M. cornuarietis could seriously alter food webs.

Manual Harvest: Use of divers to harvest snails might be an effective short-term method to control (but not eliminate) M. cornuarietis population growth. This method would only be effective for adult snails. The best time of year to maximize the effectiveness of this method of control would January through March. At this time most of the population has reached adulthood. Also, this is the peak in reproductive activity. Snails lay gelatinous egg masses containing from 40 to 200 eggs. The egg masses are very conspicuous since they are usually laid and attached to the uppermost portions of plants. A potentially effective means of suppressing numbers of snails in the next population cohort would be for divers to harvest and destroy these egg masses.

TABLE I. CÓMMON SUBMERGED AND FLOATING MACROPHYTES OF COMAL SPRINGS AND LANDA LAKE

SCIENTIFIC NAME	COMMON NAME
Ceratopteris thalictroides	Floating Fern
Potamogeton illinoensis	Shining pondweed
Sagittaria platyphylla	Delta arrowhead
Vallisneria americana	Eelgrass
Nuphar luteum	Spatterdock
Cabomba caroliniana	Fan wort
Ludwigia repens	Floating primrose-willow
Hydrocotyle verticillata	Water-pennywort
Amblystegium riparium	moss
Juncus sp.	rush

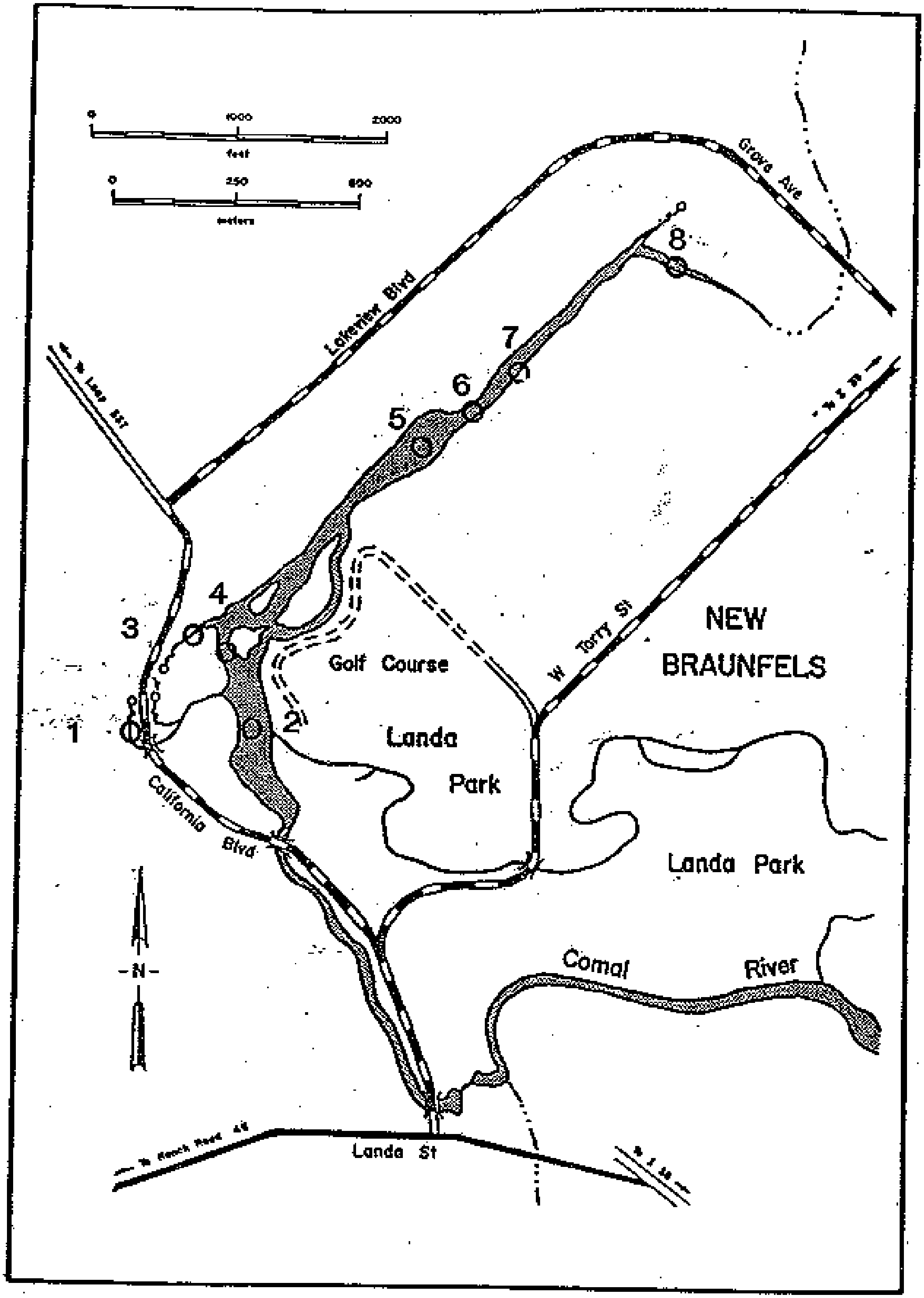

Figure 1. Eight collecting stations for Comal Springs and Landa Lake.

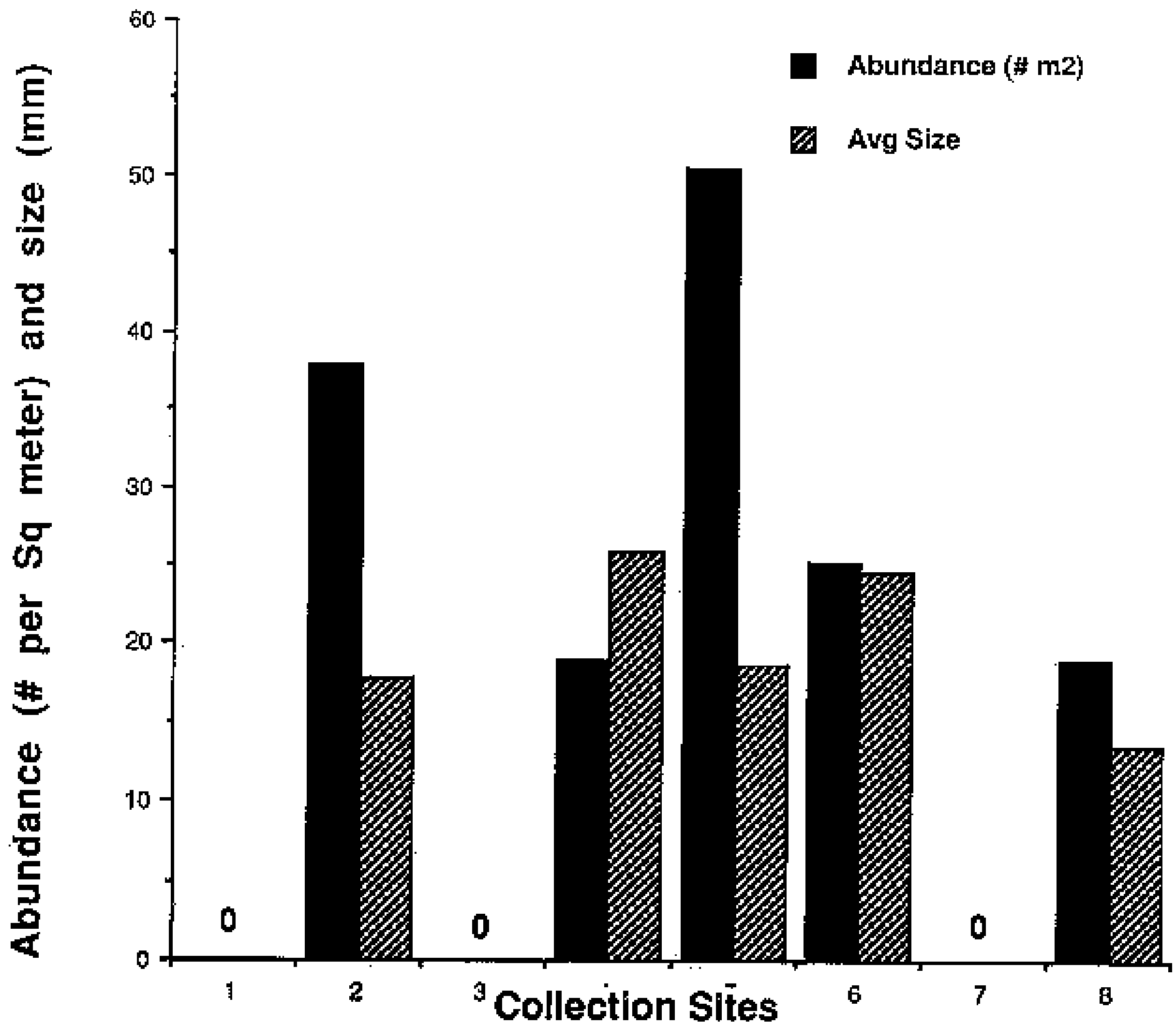

Figure 2. Mean abundance and size of M. cornuarietis at eight collection sites in Comal Springs and Landa Lake.

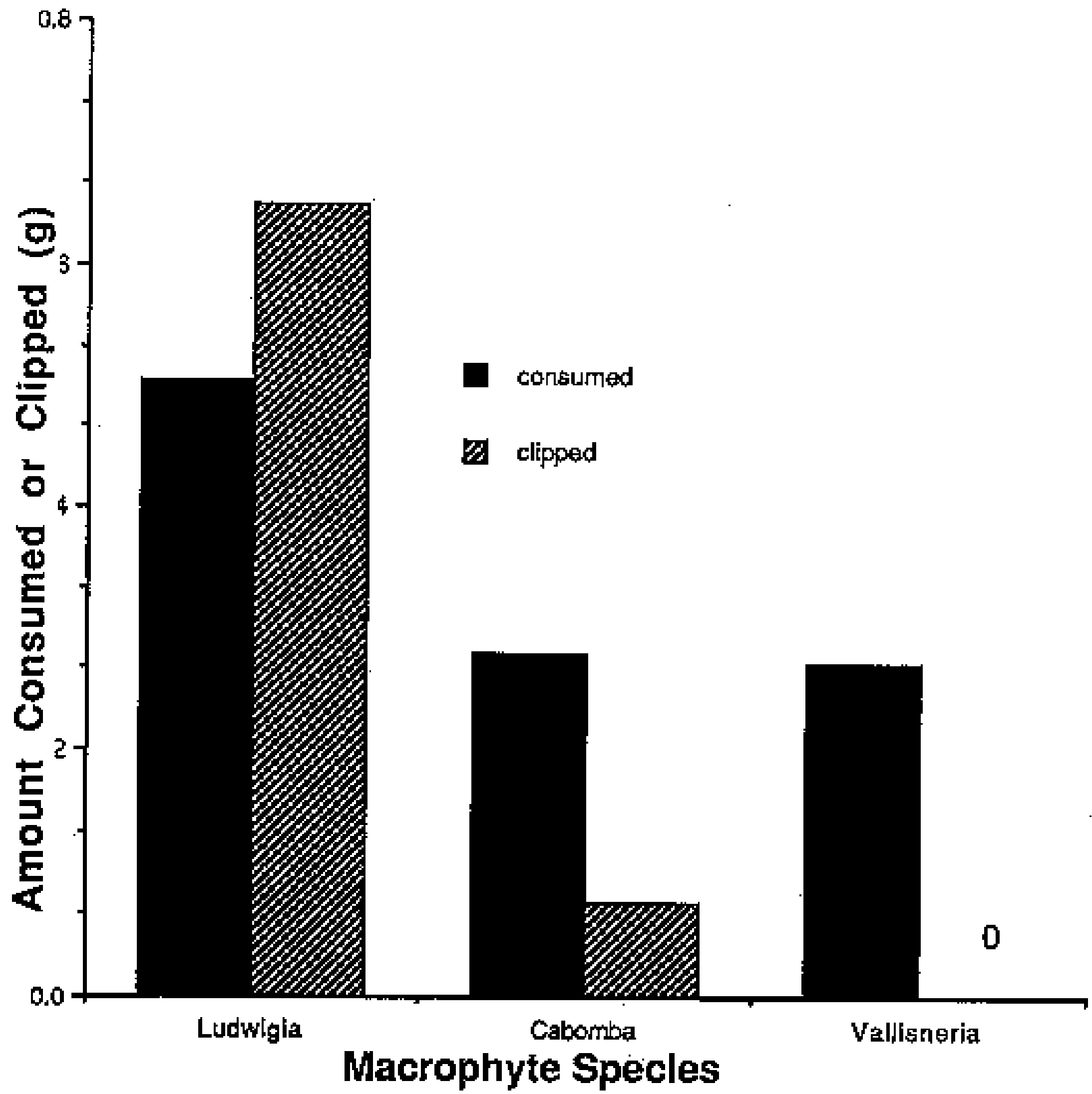

Figure 3. Feeding preferences and clipping losses by M. cornuarietis when offered a choice of different species of aquatic macrophytes. Histograms represent mean values consumed or quantity of floating cuttings (grams, dry mass).

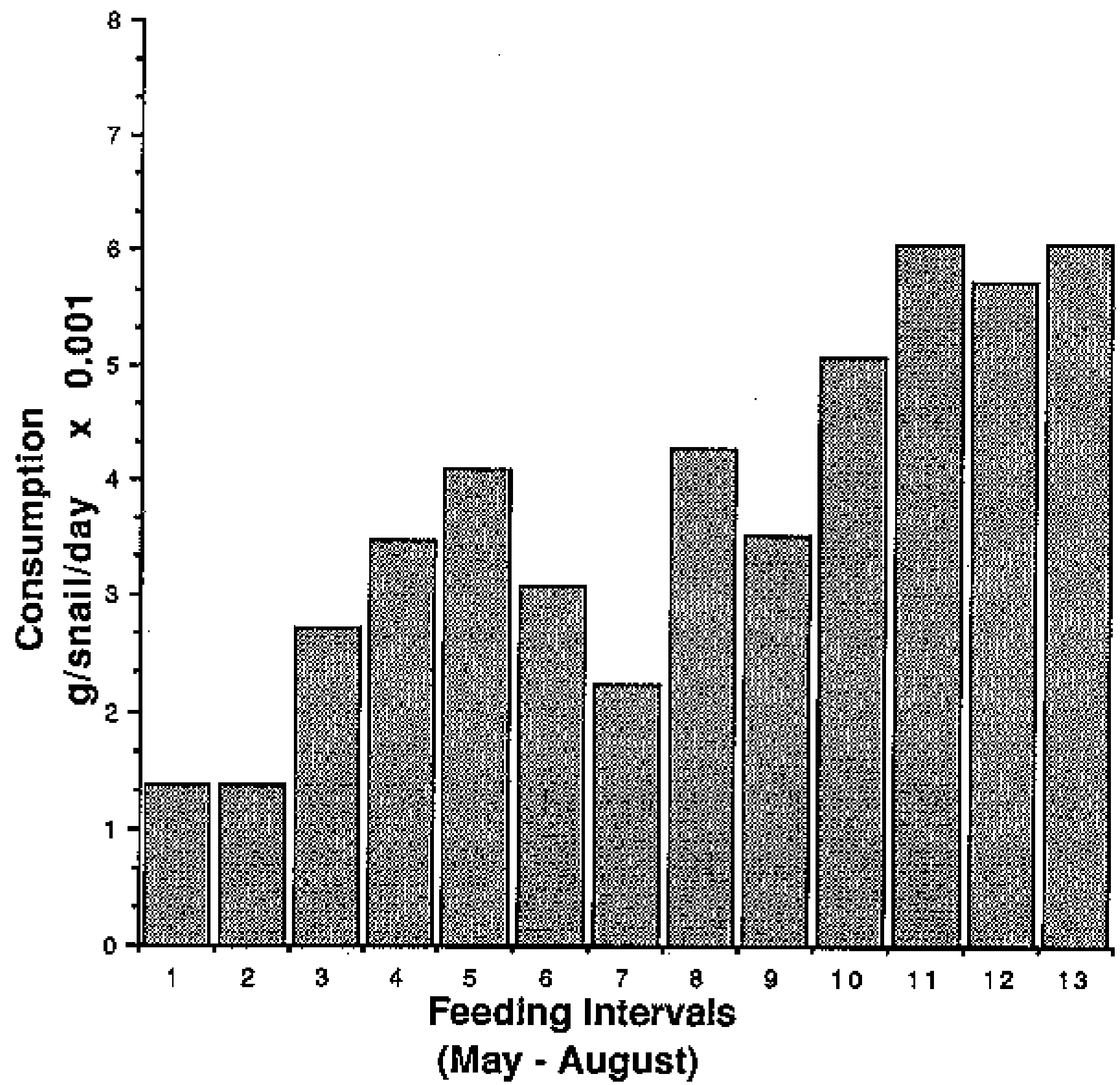

Figure 4. Mean consumption values for M. cornuarietis during each feeding interval on a diet of L. repens.

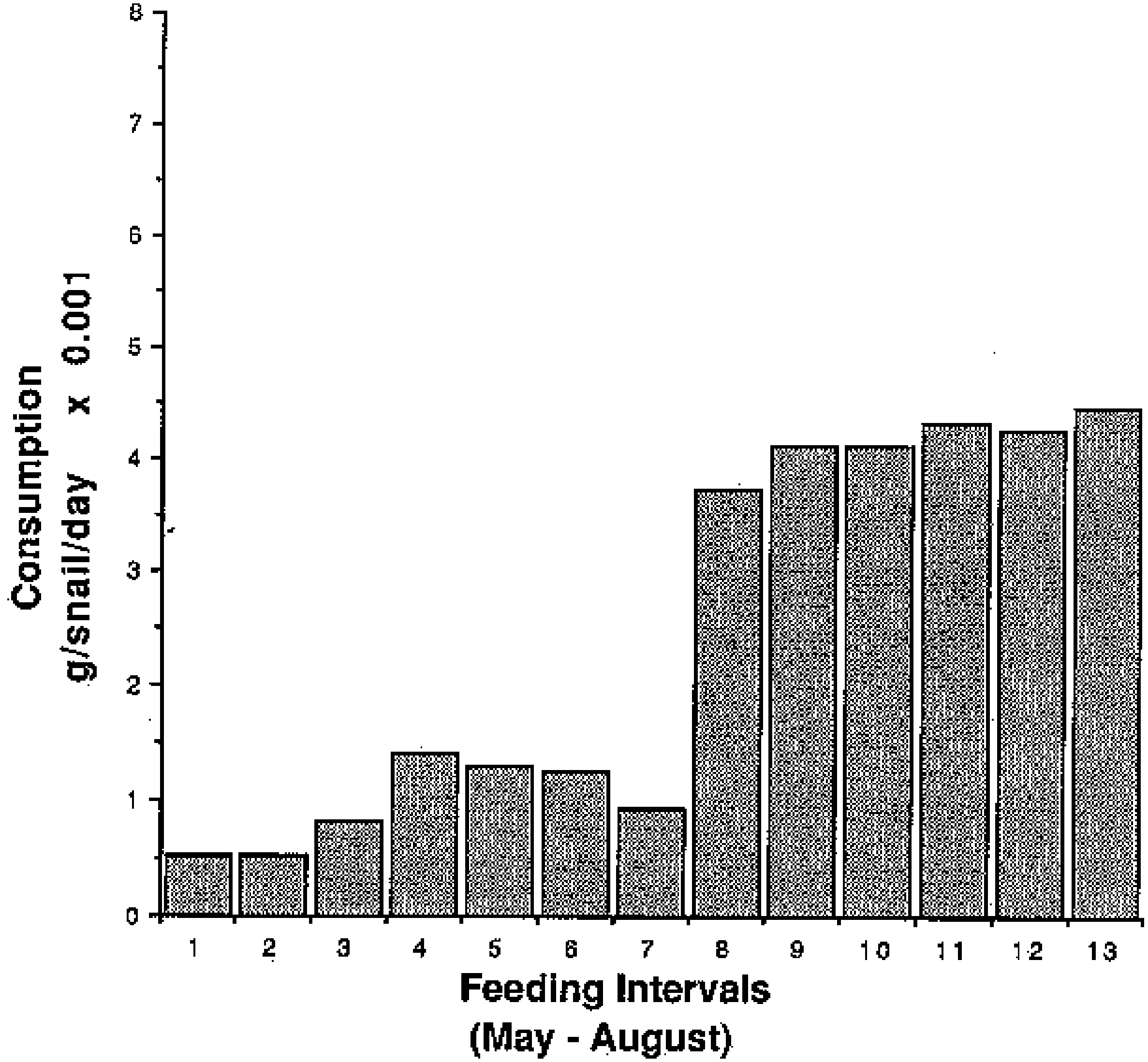

Figure 5. Mean consumption values for M. cornuarietis during each feeding interval on a diet of V. americana.

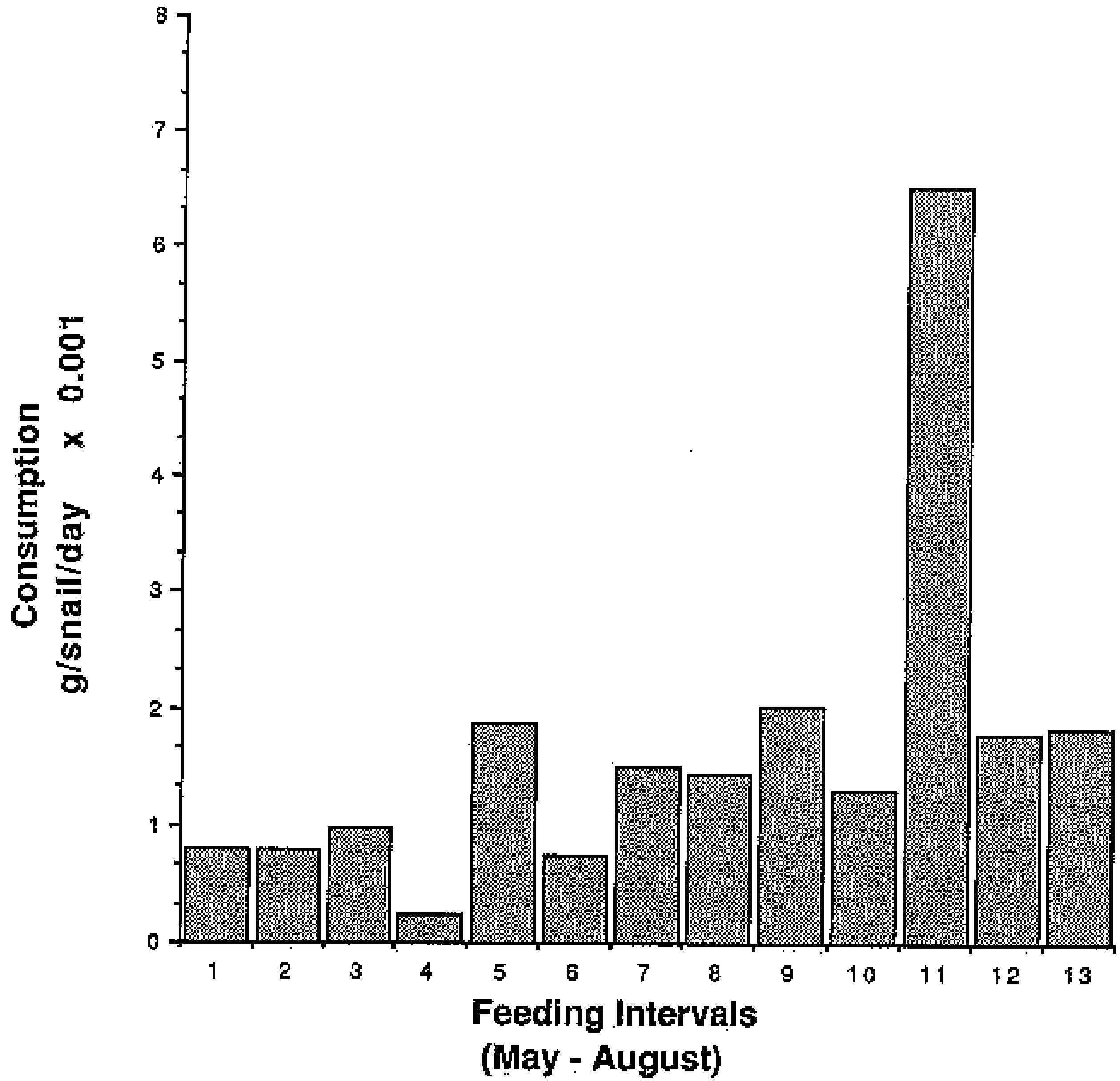

Figure 6. Mean consumption values for M. cornuarietis during each feeding interval on a diet of C. caroliniana.

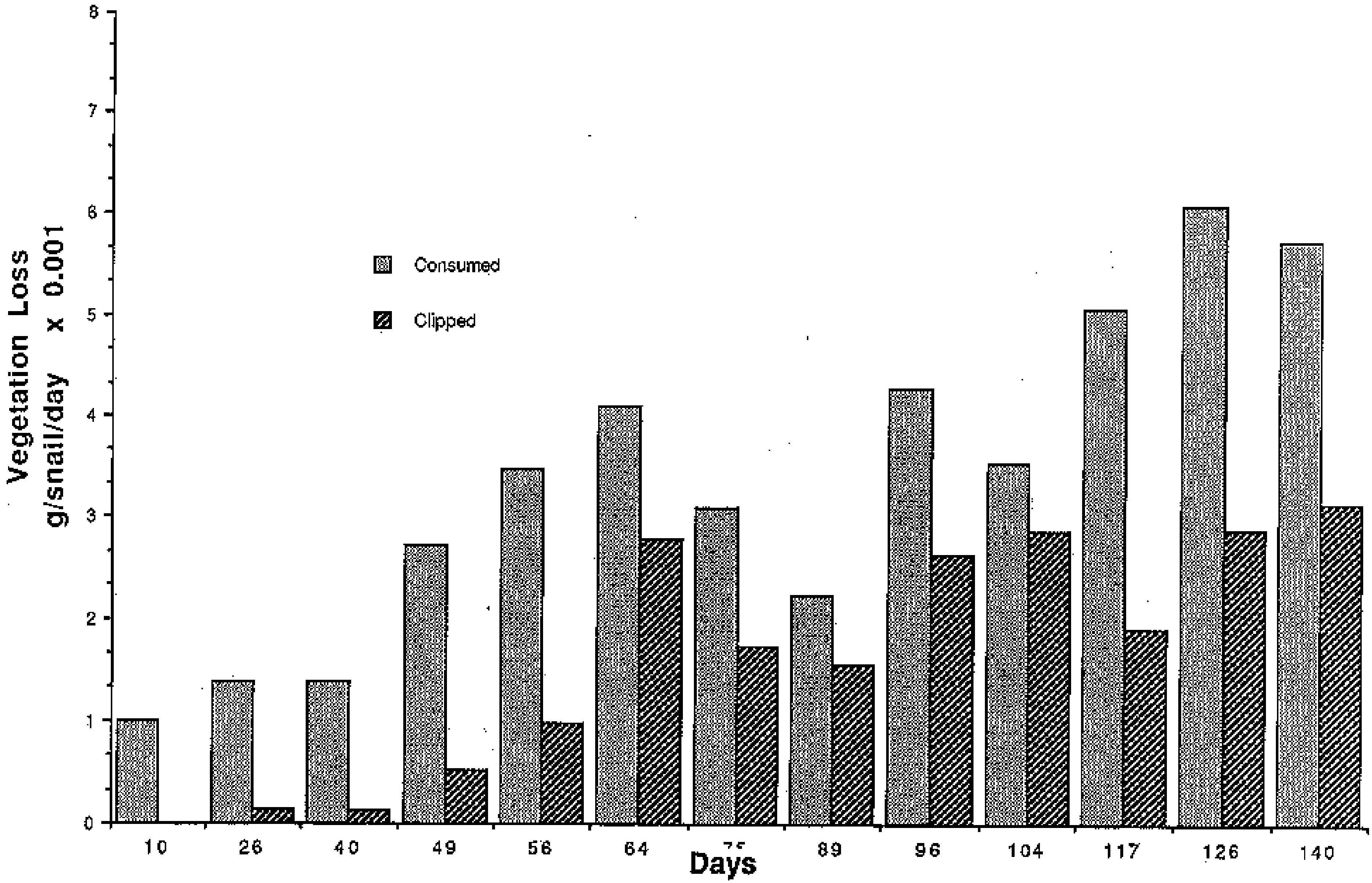

Figure 7. Comparison of mean consumptive versus clipping vegetation losses by M. cornuarietis for each feeding interval during growth on a diet of L. repens.

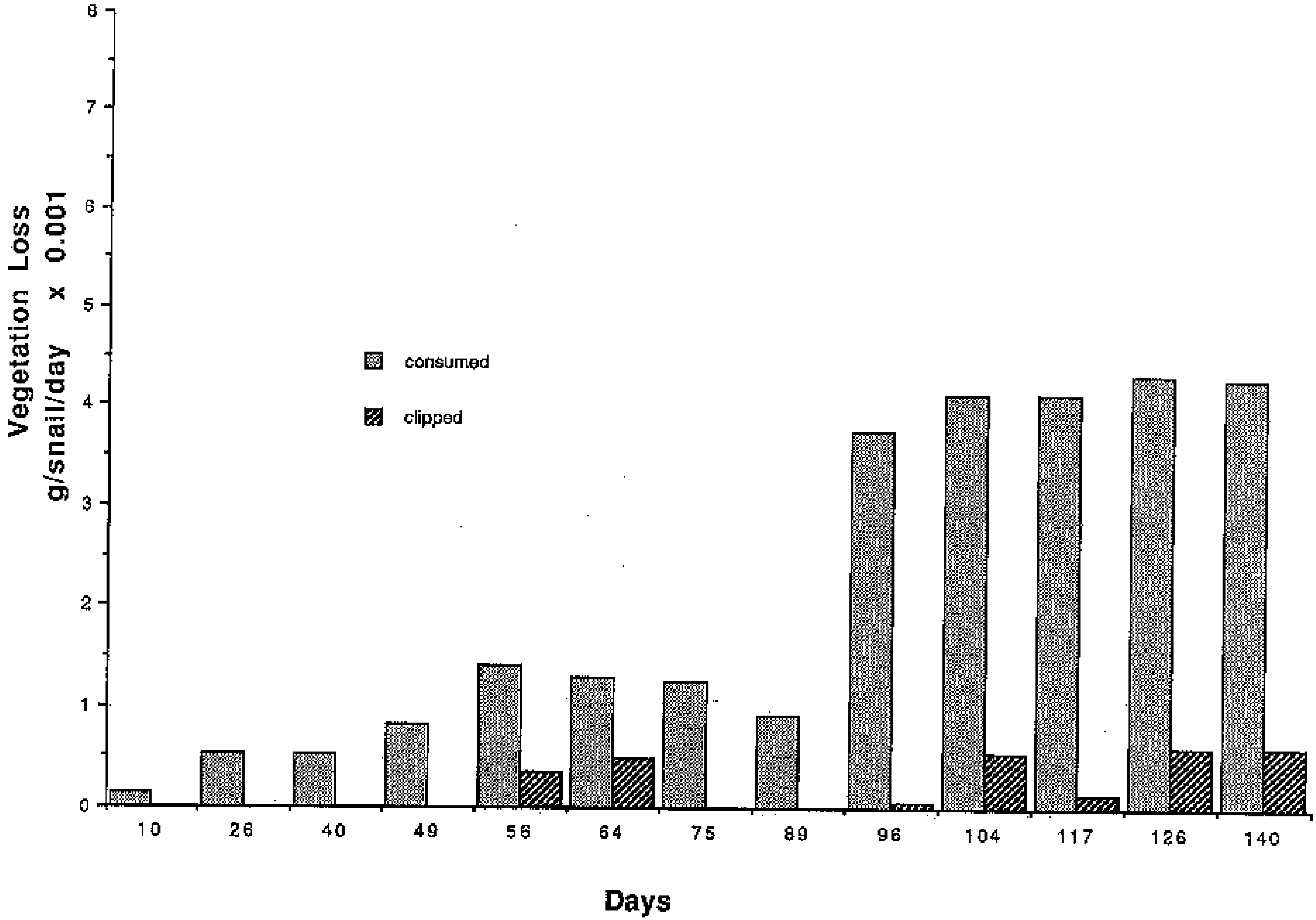

Figure 8. Comparison of mean consumptive versus clipping vegetation losses by M. cornuarietis for each feeding interval during growth on a diet of V. americana.

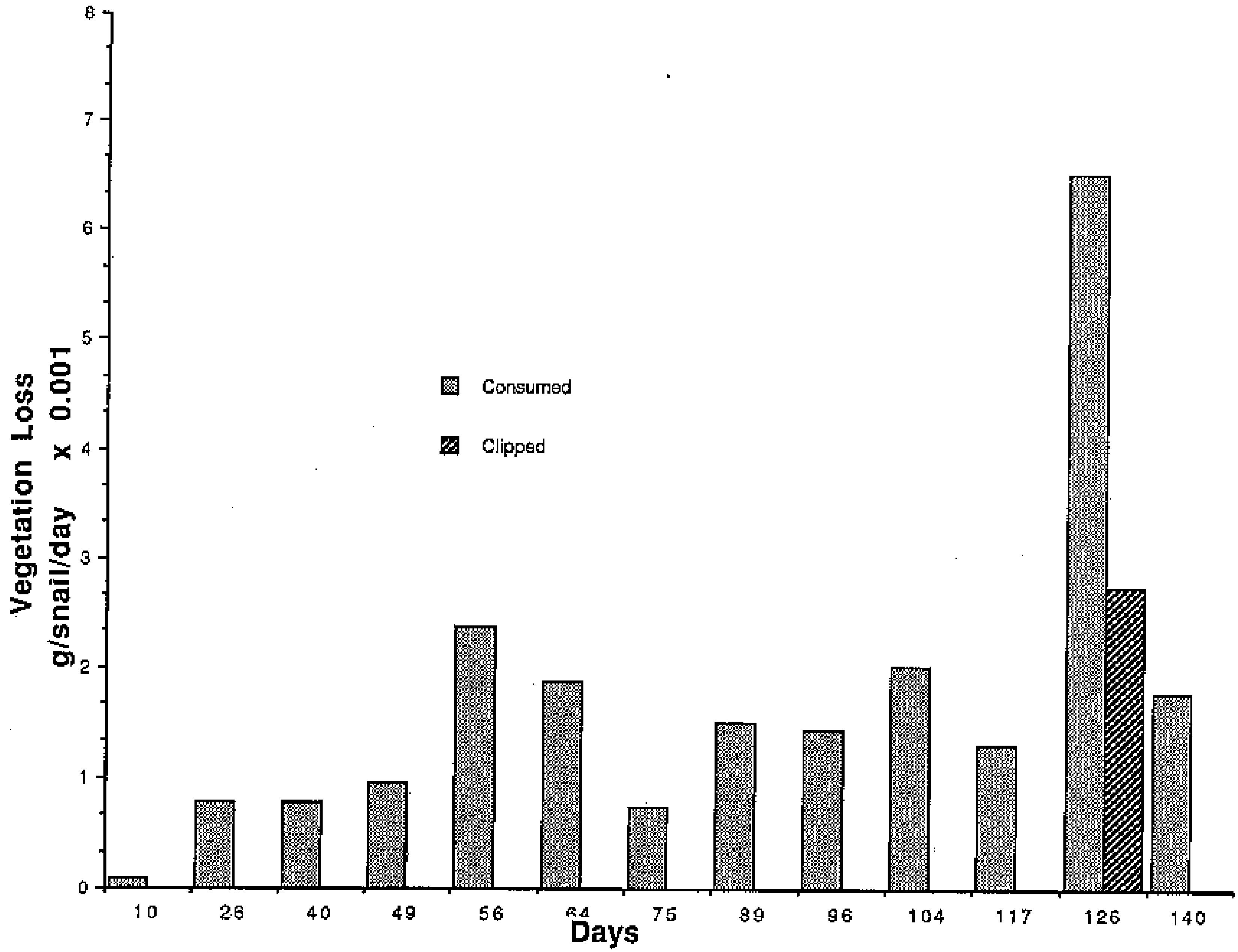

Figure 9. Comparison of mean consumptive versus clipping vegetation losses by M. cornuarietis for each feeding interval during growth on a diet of C. caroliniana.

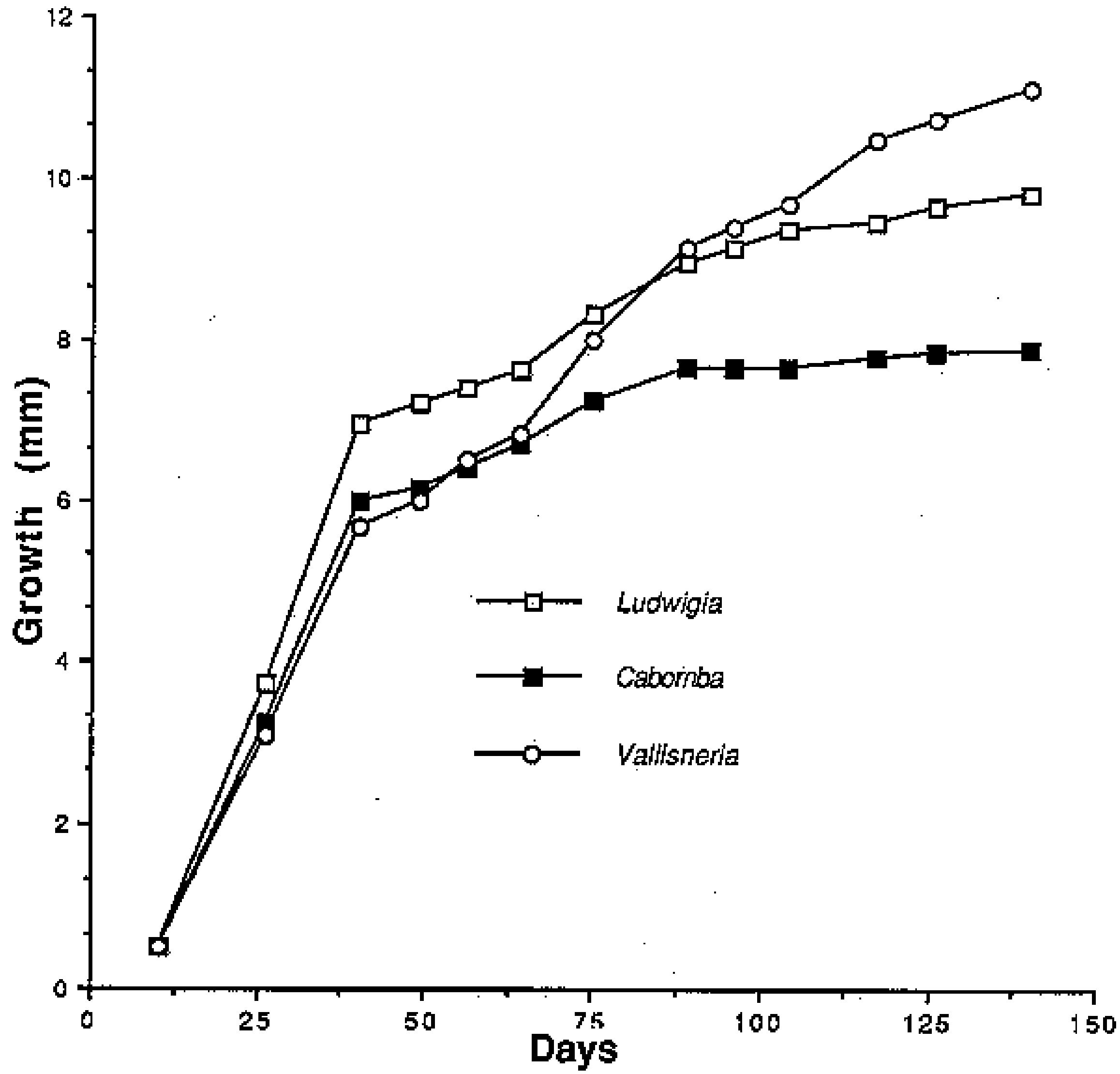

Figure 10. Mean growth of M. cornuarietis on diets of different species of aquatic hyphomycetes.

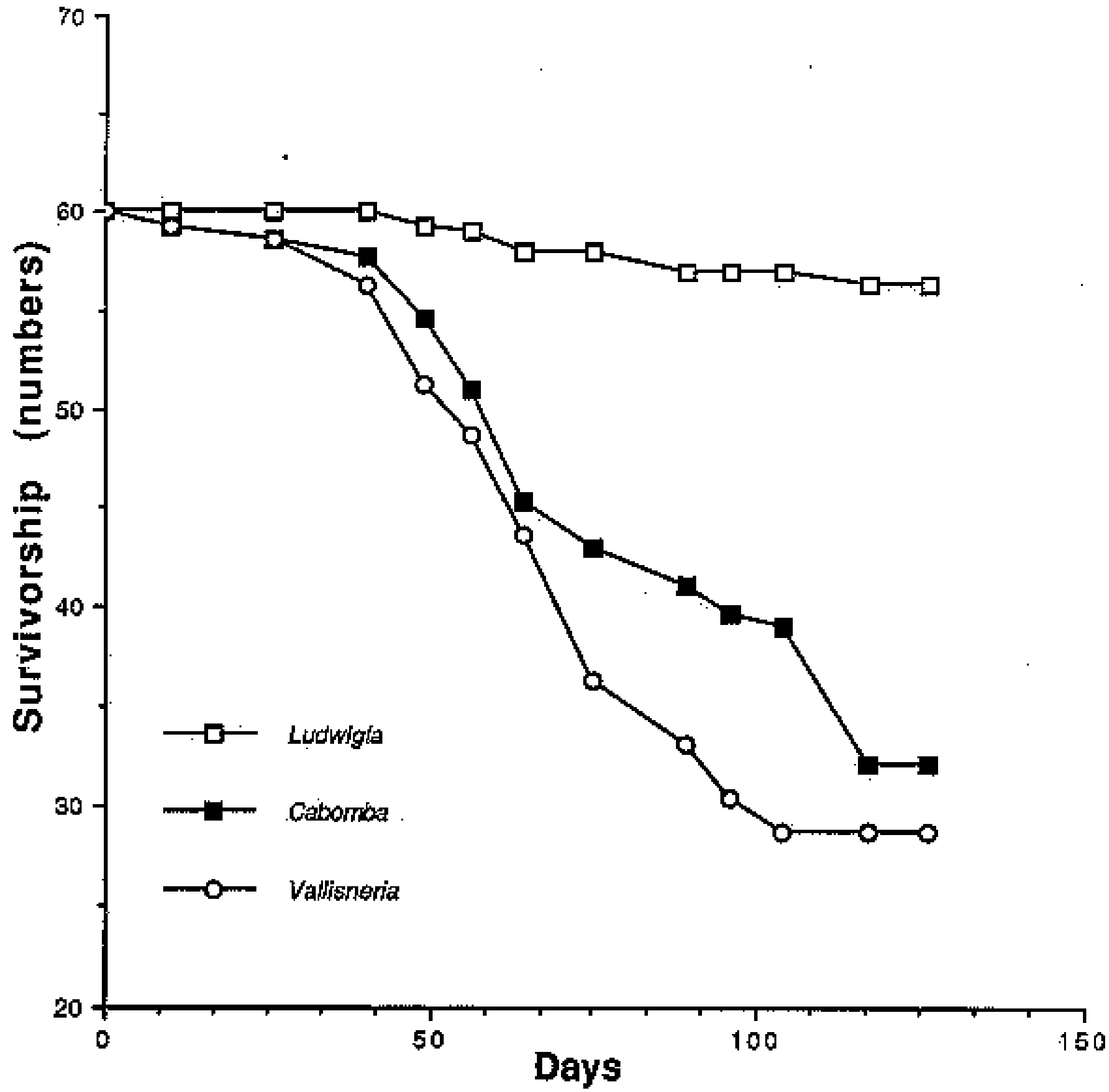

Figure 11. Mean survivorship of M. cornuarietis on diets of different species of aquatic macrophytes.

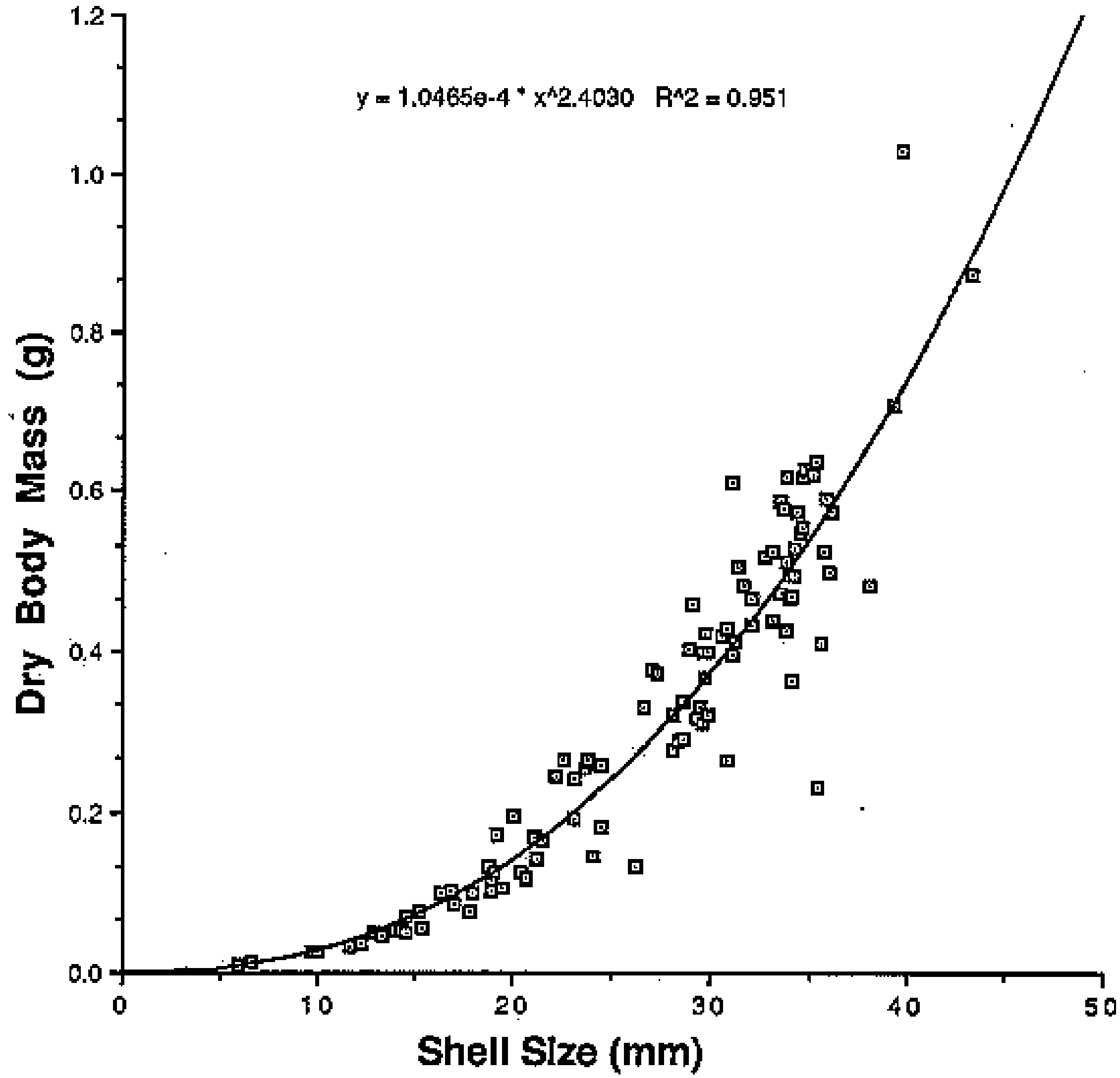

Figure 12. Relationship between shell size (diameter, mm) and dry body mass of M. cornuarietis.