ECOLOGY OF THE EXOTIC GIANT RAMS-HORN SNAIL, *Marisa cornuarietis*, OTHER BIOLOGICAL CHARACTERISTICS, AND A SPECIES/ECOLOGICAL REVIEW OF THE LITERATURE OF THE COMAL SPRINGS ECOSYTEM OF SOUTH CENTRAL TEXAS

T.L. ARSUFFI, B.G. WHITESIDE, M.D. HOWARD AND M.C. BADOUGH
DEPARTMENT OF BIOLOGY-AQUATIC STATION
SOUTHWEST TEXAS STATE UNIVERSITY
SAN MARCOS, TEXAS 78666

1992-1993 Final report to the Edwards Underground Water District and City of New Braunfels

PHASE 1

I. Historical Data

A & B. Species and Ecological Review

1. Fountain Darter (Etheostoma fonticola)

Recognition of the fountain darter began with the inadvertent description of this species as Alvarius fonticola from specimens collected from the San Marcos River just below the confluence of the Blanco River in 1884 (Jordan and Gilbert 1886). The authors noted that the species was abundant in the river at that time. Gilbert (1887), in the intended original description, redescribed the species and noted its occurrence only in the San Marcos River System. Evermann and Kendall (1894) included an illustration of the species by E. Copeland which was designated the lectotype by Jordan and Evermann (1896). Because the "type" referred to by Jordan and Evermann was a lot containing four specimens, Collette and Knapp (1966) selected a lectotype from the U.S. National Museum collections of Etheostoma fonticola originally referenced by Gilbert (1887). The remaining three specimens included in the collection are now paralectotypes (Burr 1978). The fountain darter was officially listed on the Federal Register for endangered species in 1970 (U.S. Fish and Wildlife Service, 1974). It is also listed as endangered by the Texas Parks and Wildlife Department and by the Texas Organization for Endangered Species (1988) and as rare by Miller (1972).

The original range of E. fonticola includes the San Marcos and Comal Rivers in Texas (Jordan and Gibert 1886, Gilbert 1887, Evermann and Kendall 1894, Jordan and Evermann 1896, Ball et al. 1952, Hubbs et al. 1953, Hubbs 1954, Kuehne 1955, Strawn 1955, Hubbs 1957, Hubbs and Strawn 1957b, Schenck and Whiteside 1976a). Fountain darters also have been reported from four other localities, three in Texas and one in Arkansas. The collection from Dickinson Bayou, Harris County, Texas, reported by Evermann and Kendall (1894) appears to be a misidentification (and perhaps a confusion of field locality data) from Evermann's 1891 collections in Texas (Hubbs 1982). Charles T. Menn of the Texas Parks and Wildlife Department apparently mistakenly recorded the presence of E. fonticola in his two most downstream stations in the Nueces River near Corpus Christi, Texas (Texas Parks and Wildlife Department 1965). The validity of these records apparently was questioned in 1965 and the fishes indentified as fat sleepers, Dormitator maculatus, a common estuarine species (C. Hubbs, University of Texas, pers. comm. 1983).

There has been little work done on the fountain darter in the Comal River system. Gordon Linam of Texas Parks and Wildlife Department gave a talk at the 1992 Texas Academy of Sciences (this manuscript has not been released to the public) and stated that fountain darters were found in greatest densities in filamentous algae, Chara and Ludwigia repens. He said that the greater utilization of filamentous algae by fountain darters may be due to a combination of factors. First, filamentous algae appears to provide protective cover for young and most likely for adults as well. He further stated that statistical analysis of densities of fountain darters collected from different depths in filamentous algae indicated that densities were significantly greater ($p<0.05$) at depths of 0.75 to 1.05 meters than in shallower areas; however, no significant differences were detected at depths greater than 0.75 to 1.05 meters.Linam's estimate of the population size of fountain darters in the Comal River system ranged from 114,178 to 254,110 (95% confidence level) with a mean of 168,078. Tom Brandt and B.G. Whiteside (unpublished data) did some collecting of fountain darters in the Comal River system during 1990 through 1991. This was a rough attempt to monitor the status of this species in various sections of Landa Lake. Based on their data there seemed to be a decrease in the population in the first spring run during June and September 1991. There was also a decrease in the amount of aquatic vegetation in this area during June and September 1991. Dr. Donald Morizot of the Univeristy of Texas M.D. Anderson Cancer Center is presently working on the genetic variability of the fountain darter. His data is not available at this time. The U.S. Fish and Wildlife Service has established a contingency/refugia plan for the fountain darter in the event that Comal Springs gets close to drying. The latest version of this plan that we have is attached. The U.S. Fish and Wildlife Service, in conjunction with other state agencies, is presently conducting a study on the instream flow requirements for the Comal River system.

With the exception of a few recent papers, all of the information known about the fountain darter from outside the Comal River system is summarized in the San Marcos River Recovery Plan (1984). The San Marcos Recovery Plan incudes the following studies: Bailey and Gosline (1955); Ball et al. (1952); Burr (1978); Collettee (1962, 1965); Collettee and Banarescu (1977); Collettee and Knapp (1966); Dowden (1968); Evermann and Kendall (1894); Gilbert (1887); Hubbs (1954, 1957, 1959, 1967, 1982); Hubbs and Laritz (1961); Hubbs and Strawn (1957); Jordan and Evermann (1896, 1900); Jordan and Gilbert (1886); Kuehne (1955); Page (1974, 1977); Page and Whitt (1972); Schenck (1975); Schenck and Whiteside (1976a,b,c); Strawn (1955, 1956); Strawn and Hubbs (1956); Texas Parks and Wildlife Department (1965); and U.S. Department of Interior (1973). The recent papers include a survey of the helminth parasites (Berkhouse 1990) and laboratory spawning and rearing (Brandt, et. al. In press).

Evermann and Kendall (1894) reported collecting fountain darters from the Comal River in 1891; this was the first collection record for the Comal River. Kuehne (1955) reported collecting fountain darters in 1951 and in 1952 from the Comal River. Ball et al. (1952) reported collecting fountain darters from the Comal River in conjunction with the application of rotenone to Landa Lake. Hubbs and Strawn (1957a) reported collecting the fountain darter from the Comal River in 1954; this is the last collection record for the fountain darter in the Comal River until its reintroduction. The original population of fountain darters in the Comal River was extirpated in the mid-1950's when the Comal Springs ceased to flow (Hubbs et al. 1991, Schenck 1975, Schenck and Whiteside 1976a, Whiteside and Schenck, 1976). Its extirpation in the Comal River was discovered during the mid-1970's (Schenck 1975, Schenck and Whiteside 1976a). The reintroduction of this species into the Comal River system was approved by the Texas Parks and Wildlife Department and the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service permits; PRT-8-81-C Ammendment and PRT-8-112-C). Its reintroduction into the Comal River system was conducted by B.G. Whiteside, J.R. Schenck and F.E. Potter using fish from the San Marcos River. During 1975 and 1976, they introduced 400 adults into the first large spring and 50 adults into the old river channel (Schenck 1975, Schenck and Whiteside 1976, Whiteside and Schenck, 1976). Evidence of fountain darter reproduction in the Comal River system was found by B.G. Whiteside and J.R. Schenck on 18 June 1976 (San Marcos River Recovery Plan 1984).

2. San Marcos Salamander (*Eurycea nana*)

The San Marcos salamander was described by Bishop (1941) from specimens collected in 1938 from San Marcos springs by C.E. Mohr. *Eurycea nana* is identified as a category 2 threatened species by the U.S. Fish and Wildlife Service (Federal Registry 45:47355-47364; 1980) and by the state of Texas. Members of the genus *Eurycea* are commonly known as "brook" salamanders and are referred to as neotonic, since they retain their gills throughout life and becomes sexually mature in the water without having to metamorphose into a terrestrial stage. Diets of *E. nana* consist largely of crustacean amphipods, midge larvae and pupae, other small insects and snails. The presence of juveniles of all size classes and adults throughout the year suggests that breeding is continous. The salamander apparently prefers coarse substrates with associated vegetation in the form of mats of filamentous algae, moss or angiosperm aquatic plants. Sandy bottoms also are suitable if large rocks are present to hide under. Although they can be maintained in aerated aquaria in the lab, they have not been collected in the field in habitats that lack flowing water.

Eurycea nana are believed to be largely restricted to the uppermost portion of Spring Lake, the headwaters of the San Marcos River, where their numbers were estimated at 17,000 to 20,000 individuals (Tupa and Davis 1976). Janet Nelson, a graduate student at Southwest Texas State University, is in the process of completing a Master's thesis on the San Marcos salamander in Spring Lake which includes recent estimates of distribution and abundance as well as studies of culture techniques for the species in laboratory conditions. Sweet (1978) conducted a morphometric analysis of the species composition of cave and spring salamander populations of the Edward's Plateau and indicated that a population of *Eurycea* discovered at Comal Springs in New Braunfels is likely to be congeneric to *E. nana* of Spring Lake in San Marcos. However, a recent study of subterranean and surface salamanders of the Edwards Plateau region of central Texas using electrophoretic allozyme analysis of proteins indicates that the Comal Springs population of *Eurycea* is not genetically similar to the San Marcos *Eurycea nana* and may possibly be deserving of recognition as a new species (Chippendale, Hillis and Price 1990). Further DNA analysis to confirm the preliminary findings of this study are continuing.

3. Comal Springs riffle beetle (Heterelmis comalensis)

The Comal Springs riffle beetle was originally described by Bosse et al. (1988). Heterelmis comalensis is identified as a Category 2 animal in the Fish and Wildlife Service's Notice of Review (Federal Register 56 (225): 58826,1991). This category "comprises taxa for which information now in possession of the Service indicates that proposing to list as Endangered or Threatened is possibly appropriate, but for which substantive data are not currently available to biologically support a proposed ruling. Further biological research and field study may be needed to ascertain the status of the taxa in this category, and it is likely that some of the taxa will not warrant listing."

The first known specimen was collected from Comal Springs #2 orifice and run on 9 April 1976 by L.S.Bosse. Subsequent collections of the species has been made from Comal Springs #2 and #3 orifices and runs by Dr. C.B. Barr (California State University-Sacramento) on 11 and 19 September 1987 and 2 May 1988. Dr. Barr, during these collecting trips, found no specimens of the species from other spring orifices nor from Hueco Springs and San Marcos Springs. Dr. Harley Brown also has collected specimens of Heterelmis comalensis from Comal Springs in March of 1977 and in April 1988.

Members of the genus Heterelmis are largely neotropical in distribution with species scattered through South and Central America northward into the mountains of the western United States. Heterelmis comalensis is apparrently the only species (of 13) in the genus with such a highly restricted distribution (Brown 1981).

Elmidae are common inhabitants of running waters, yet what little is known of their natural history, ecology and trophic interactions are based on the study of just a few of the more than 100 described species (Tavares and William 1990). Larvae undergo 6-8 instars, requiring anywhere from 6 months to three years to complete a life cycle from egg to adult. Growth and development times are temperature dependent, being faster at higher temperatures. Mature larvae crawl out of the water to construct terrestrial pupal chambers in moist soils, under rocks or in decaying wood. After emergence, adults undergo a short flight period, after which, the adults reenter the water and are incapable of further aerial activity. Reproductive activities occur at this time.

Elmids have been described as small sturdy beetles and are capable of burrowing deep into the bottom substrates (depths to 70cm, Williams and Hynes 1974). Although primarily inhabitants of flowing waters, Brown (1973) showed that adult and larval elmids of the genera Macronychus and Stenelmis have a longevity of several years and can survive under environmental extremes (low dissolved oxygen, high temperature etc.) similar to those occuring in ponds and pools. To the extent that H. comalensis shares adaptive traits with its congeners, such as the ability to burrow and tolerate environmental stress, may explain how H. comalensis was able to survive the drought of the 1950's, particularly 1956, when apparently Comal Springs ceased flowing for up to six months.

4. Peck's cave amphipod (Stygobromus pecki)

Peck's cave amphipod was originally described by Holsinger (1967) and was placed in the genus Stygonectes. After subsequent systematic analysis and taxonomic revision (Holsinger 1977; Karaman 1974) this species now has been placed in the genus Stygobromus. Stygobromus pecki is identified as a Category 2 animal in the Fish and Wildlife Service's Notice of Review (Federal Register 56(225): 58835 1991). This category "comprises taxa for which information now in possession of the Service indicates that proposing to list as Endangered or Threatened is possibly appropriate, but for which substantive data are not currently available to biologically support a proposed rule. Further biological research and field study may be needed to ascertain the status of the taxa in this category, and it is likely that some of the taxa will not warrant listing."

Although collected in the springrun outside the orifices, the primary habitat of Stygobromus pecki is subterranean and in association with the underground waters of the Edward's aquifer. Virtually nothing is known about the life history, trophic relations and other aspects of the biology and ecology of this species of stygobiontic amphipod. However, sufficient information on other species of amphipod has accumulated, together with the unique characteristics of a subterranean existence to warrant speculation and generalization.

As a group, amphipods are recognized as being characteristic of cold, relatively constant temperature habitats and lack a resistant stage in the life cycle capable of resisting dessication. This limits their dispersal into other habitats by passive dispersal. Their abilities for active dispersal are also limited and they cannot migrate upstream against strong currents. This restricts spread of amphipods throughout river drainage networks. Most amphipods avoid bright light and are mainly associated with bottom materials such as rocks, interstitial crevices, detritus etc. Since Stygoparnus comalensis lives a subterranean existence, their primary source of food most likely consists of dead organic matter produced by plants and animals that live aboveground and transported to the aquifer via recharge streams.

Most amphipods have annual life cycles, completing growth, development and maturation inside of a year. However, some troglobitic species are reported to require up to six years to mature. With few exceptions, female amphipods produce a single brood. Compared to warm-water relatives, amphipods of cold, spring type habitats exhibit longer life cycles, reduced fecundity and absence of seaonality in life cycles (overlapping generations). These characteristics probably apply to Stygoparnus comalensis.

Amphipods generally are good indicators of water quality because they require high concentrations of oxygen. When vertebrate and invertebrate predators are absent and food resources abundant, amphipods can reach high densities numbering thousands of individuals per square meter. Under these conditions, they are important components of ecosystems and play a critical role in detrital food chains as well being an important food resource to higher trophic levels.

Holsinger (1986) observed that the genus Stygobromus is a composite of several previously described genera that have been synonymized under a single name, but in fact, may not constitute a natural grouping. Holsinger (1986) suggests that this genus is need of revision and should be divided into smaller taxonomic units (genera, subgenera) to more clearly sreflect patterns of morphological divergence.

5. Comal Springs dryopid beetle (Stygoparnus comalensis)

The Comal Springs dryopid beetle was first described by Barr and Spangler (1992). The first known specimens were first collected from Comal Springs in 1987 by Dr. Harley Brown, Professor Emeritus (University of Oklahoma) however the holotype was based on collections made 2 May 1988 by C.B. Barr (California State University-Sacramento). Other specimens have since been collected by Dr. W.D. Shepard (California state University-Sacremento) on 6 June 1988. Dr. Paul Spangler (National Museum of Natural History) has collected at Comal Springs during May 1991 and did not encounter specimens of Stygoparnus comalensis. Intensive collecting at Comal Springs at each of the three major springhead orifices during the present study also resulted in no specimens of this species.

Stygoparnus comalensis represents the first and only known stygobiontic (eyeless, underground/cave-water-inhabiting) species of Dryopidae in the world. Although the species was collected aboveground in the springrun just downstream from the spring orifice, its primary habitat is clearly subterranean based upon the eyeless condition and light pigmentation of the adults. The areal extent of its underground distribution is not clear. The fact that it was collected from only a single spring orifice in close proximity to two others (Comal 1&3) indicates the possibility its distribution is limited to an underground cavern in the vicinity of where flows from Comal 2 emerge.

Little is known about the feeding ecology or demographic characteristics of Stygoparnus comalensis in particular and members of the Dryopidae in general to discuss their importance as ecosystem components.

Sygoparnus comalensis is identified as a Category 2 animal in the Fish and Wildlife Service's Notice of Review. This category "comprises taxa for which information now in possession of the Service indicates that proposing to list as Endangered or Threaatened is possibly appropriate, but for which substantive data are not currently available to to biologically support a proposed rule. Further biological research and field study may be needed to ascertain the status of the taxa in this category, and it is likely that some of the taxa will not warrant listing."

Little is known about many features of the life history of species in the family Dryopidae. However, two known biological characteristics for most species in the family are significant in that certain habitat modifications could eliminate the population of Stygoparnus comalensis from its presently restricted distribution locality associated with the Comal Spring Orifice # 2. The first feature regards the strict reliance of adult beetles on atmospheric oxygen for respiration. Adult Elmidae and Dryopidae beetles capture a bubble of air (plastron) on their undersides, which is held in place when submerged underwater by a dense layer of specialized hairs. The bubble behaves as a "physical gill" with oxygen for respiration diffusing from the water into bubble and carbon dioxide diffusing out. For the trapped air bubble to function effectively as a gill requires the water to be rich in oxygen. Consequently, changes in water quality that lower oxygen levels may be detrimental to this species. This feature also needs to be considered in the evaluation and design of any type of spring augmentation plan.

The second biological feature of note concerns the distribution and habitats of adult and larval beetles. Larval forms of Stygoparnus comalensis are thought to be terrestrial and presumed to be associated with soil, roots and debri lining the ceiling of the subterranean orifices (Barr and Spangler 1992). Thus, habitat alterations that affect or separate either the larval or adult habitats could have profound negative consequences for the species.

Although relatively few specimens of Stygoparnus comalensis and Stygobromus pecki have been collected, these data do not necessarily mean that the distribution of each species is restricted to Comal Springs or that the population size of either species is rare. These species are stygobiontic and are adapted to conditions, food resources and interactions with other species characteristic of a subterranean world without light. I am unaware of studies or methods available to explore the extent of this habitat or determine the distribution and abundance of its species. The only insight we obtain on this unique community is through openings to the surface world in the form of springs or wells. Also, It is not surprising that few individuals of the stygobiontic species were discovered since the quantitative and qualitative sampling methods are largely designed to collect the benthic fauna of surface-running waters and stygobiontic individuals might be suspected to suffer high mortality because they lack the ability to exploit the resources of lighted surface waters and escape predators. Barr (1992) suggested that S. comalensis might have a highly restricted distribution since it was only collected from one of the three spring orifices which lie in close proximity to each other. To improve estimates of relative population size and distribution of the stygobiontic species, I recommend that drift nets be positioned as close as possible to spring orifices and held in position over a 24 hour period. This may prove to be a more effective sampling technique than benthic samples, which limit the surface area which can be covered because of sorting time constraints. Drift net sampling allows large volumes of water emerging from the aquifer to pass through the net, which may contain floating or swimming amphipods or dryopid beetles.

6. Giant rams-horn snail (Marisa cornuarietis)

The giant rams-horn snail, *Marisa cornuarietis* family Pilidae (=Ampullariidae; Linnaeus, 1758), is a large discoidal prosobranch gastropod that is native to northern South American and southern Central America (Baker 1930). Its first occurrence in North America was in Florida (Hunt 1958). In June 1983, Neck (1984) reported a population of *M. cornuarietis* in the San Marcos River (Hays Co., Texas), individuals were detected in the nearby Comal River a year later (Horne et al. 1991). The giant rams-horn snail was a common aquarium snail sold by pet dealers in both San Marcos and New Braunfels; it is likely that unwanted specimens were released by aquarists in Texas as well as in Florida (Hunt 1984).

Species in the tropical family Pilidae (e.g.*Marisa Pomacea)* show a preference for macrophytes as food resources (Andrews 1965), and *Marisa* has been investigated as a biological control for aquatic weeds (Seamann and Porterfield 1964; Blackburn et al. 1971). For example, Seamann and Porterfiels (1964) found that 150 adult snails (30-60mm) required less than a week to conpletely consume masses (1360 g wet wt) of several species of aquatic macrophytes. The radular morphology of *Marisa* is of the taenioglossate pattern with long canine lateral teeth which can effectively pierce and tear plant leaf and stem tissue. The powerful jaws clip, grasp, and hold stems and leaves while the radula shreds them. A voracious herbivore, *Marisa* has been implicated in the 1989-1990 massive decline in aquatic plants in Landa Lake (Comal River; Horne et al. 1991) and the recent, marked reduction in aquatic vegetation in Comal Springs (T. Arsuffi, personal observations). Plants in many areas of Landa Lake have been denuded of leaves or even grazed to the bottom. Feeding snails frequently clip the petiole or basal stem of plants before feeding on the cuttings and often lose their grip, allowing the aerenchymous cuttings to float away in the current to form large floating masses. Mowing of plants in Landa Lake by park employees was once necessary to allow recreational use of parts of the lake. This has stopped since the snails have so effectively grazed the macrophyte communities.

Densities of *Marisa cornuarietis* in some areas of the San Marcos and Comal Rivers are now as high as 100 m^2, with an estimated population of 2-12 million snails in the 14 acre Comal Springs-Landa Lake area (Arsuffi, unpubl.). While North American snails are relatively small and serve as an important food for other aquatic organisms, *Marisa* is large (5-6 cm diameter) and appears to have few, if any, predators in Texas. Little is known about this species, even in its native habitat, so it is difficult to evaluate the ecological significance of the ram's horn snail to river systems in the USA. *Marisa cornuarietis* was placed on the list of "Harmful or potentially harmful exotic shellfish" by the Texas Parks and Wildlife Department in March 1990.

Herbivory on flourishing, rooted plants by macroinvertebrates is exceedingly uncommon in freshwater ecosystems of North America (Otto and Svensson, 1981; Wetzel, 1983) where most snails feed by scraping the attached algae from the surface of leaves rather than consuming the living plant (Bronmark, 1989). The introduction of the rams-horn snail into ecosystems where no significant herbivores previously existed, provides a completely new component to trophic structure of these ecosystems. Densities of *Marisa cornuarietis* in some areas of the San Marcos and Comal Rivers are now as high as 100 m^2 with an estimated population of 2-12 million snails in the 14 acre Comal Springs-Landa Lake area (Arsuffi, unpubl.). While North American snails are relatively small, and serve as an important food for other aquatic organisms, *Marisa* is large (5-6 cm diameter) and appears to have few, if any predators in Texas. Little is known about this species, even in it's native habitat, so that it is difficult to evaluate the ecological significance of the ram's horn snail to river systems in the USA. *M. cornuarietis* was placed on the list of "Harmful or potentially harmful exotic shellfish" by the Texas Parks and Wildlife Department as of March, 1990.

Literature Cited

Andrews, E.B. 1965. The functional anatomy of the gut of the prosobranch gastropod Pomacea canaliculata (D'Orb.) and some other pilids. **Proceedings of the Zoological Society of London** 145:19-36.

Bailey, R.M. and W.A. Gosline. 1955. Variation and systematic significance of vertebral counts in the American fishes of the family Pericdae. **Miscellaneous publications of the Museum of Zoology, University of Michigan** No. 93. 44 pp.

Baker, H.B. 1930. The mollusca collected by the University of Michigan Williamson expedition in Venezuela. **Occasional papers of the Museum of Zoology, University of Michigan** 210:1-94.

Ball, J., W. Brown, and R. Kuehne. 1952. Landa Park is rennovated. **Texas Game and Fish** 10(5):8-9,32.

Barr, C.B. and P.J. Spangler. 1992. A new genus and species of stygobiontic dryopid beetle Stygoparnus comalensis (Coleoptera: Dryopidae) from Comal Springs, Texas. **Proceedings of the Biological Society of Washington** 105:40-54.

Berkhouse, C. 1990. M.S. Thesis, Southwest Texas State University, San Marcos, Tx.

Bishop, S.C. 1941. Notes on salamanders. Comstock Publ. Co., Ithaca, New York. XIV+555 pp.

Blackburn, D., T.M. Taylor, and D.L. Sutton. 1971. Temperature tolerance and necessary stocking rates of Marisa cornuarietis L. for aquatic weed control. **Proceedings from European Weed Control Research Council International: Symp. Aquatic Weeds** 3:79-85.

Bosse, L.S., D.W. Tuff and H.P. Brown. 1988. A new species of Heterelmis from Texas (Coleoptera: Elmidae). **The Southwestern Naturalist** 33:199-203.

Brandt, T.M., K.G. Graves, C.S. Berkhouse, T.P. Simon and B.G. Whiteside. In press. Laboratory spawning and rearing of the endangered fountain darter. **Progressive Fish Culturist.**

Bronmark, C. 1989. Interactios between epiphytes and freshwater snails: a review. **Journal of Molluscan Studies** 55:299-311.

Brown, H.P. 1973. Survival records for elmid beetles, with notes on laboratory rearing of various dryopids (Coleoptera). **Entomological News** 84:278-284.

Brown,H.P. 1981. A distributional survey of the world genera of aquatic dryopoid beetles (Coleoptera: Dryopidae, Elmidae, and Psephenidae sens. lat.) **Pan-Pacific Entomology** 57:133-148.

Burr, B.M. 1978. Systematics of the percid fishes of the subgenus Microperca, genus Etheostoma. **Bulletin of the Alabama Museum of Natural History** 4:1-53.

Collette, B.B. and P. Banarescu. 1977. Systematics and zoogeography of the fishes of the family Percidae. **Journal of Fisheries Research Board Canada** 34:1450-1463.

Collette,B.B. and L.W. Knapp 1966. Catalog of type specimens of the darters (Pisces, Percidae, Etheostomatini). **Proceedings of the U.S. National Museum** 119:1-88.

Collette, B.B. 1965. Systematic significance of breeding tubercules in fishes of the family Percidae. **Proceedings of the U.S. National Museum** 117:567-614.

Collette, B.B. 1962. The swamp darters of the subgenus Hololepis (Pisces, Percidae). **Tulane Stud. Zoology** 9:115-211.

Dowden, D.L. 1968. Population dynamics of the San Marcos Salamander, Eurycea nana. Unpubl. M.A. Thesis, Southwest Texas State University, San Marcos, Texas. 44 pp.

Evermann, B.W. and W.C. Kendall. 1894. Fishes of Texas and the Rio Grande basin, considered chiefly with reference to their geographic distribution. **Bulletin of the U.S. Fish Committee** for 1892: p. 57-126.

Gilbert, C.H. 1887. Descriptions of new and little known etheostomatiods. **Proceedings of U.S. National Museum** 10:47-64.

Holsinger, J.R. 1967. Systematics, speciation and distribution of the subterranean amphiopd genus Stygonectes (Gammaridae). **U.S. National Museum Bulletin** 259:1-176.

Horne, F.R., T.L. Arsuffi and R.W. Neck. 1992. Recent introduction and potential botanical impact of the giant rams-horn snail, Marisa cornuarietis (Pilidae), in the Comal Springs ecosystem of Central Texas. **Southwestern Naturalist** 37(2):194-214.

Hubbs, C., R.J. Edwards, and G.P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. **The Texas Journal of Science** 43(4):supplement 56 pp.

Hubbs, C. 1982. Occurrence of exotic fishes in Texas waters. Pearce-Sellards Series No. 36, Texas Memorial Museum, 19 pp.

Hubbs, C. 1967. Geographic variations in survival of hybrids between etheostomatine fishes. **Bulletin of the Texas Memorial Museum,** No. 13. 72 pp.

Hubbs, C. and C.M. Laritz. 1961. Occurrence of a natural intergeneric etheostomatine fish hybrid. **Copeia** 196:231-232.

Hubbs,C. 1959. Laboratory hybrid combinations among etheostomatine fishes. **Texas Journal of Science** 11:49-56.

Hubbs, C. and K. Strawn. 1957a. Relative variability of hybrids between the darters Etheostoma spectabile and Percina caprodes. **Evolution** 11:1-10.

Hubbs, C. and K. Strawn. 1957b. The effects of light and temperature on the fecundity of the greenthroat darter, Etheostoma lepidum. **Ecology** 389:596-602.

Hubbs, C. 1957. Distributional patterns of Texas fresh-water fishes. **Southwestern Naturalist** 2:89-104.

Hubbs,C. 1954. Corrected distributional records for Texas freshwater fishes. **Texas Journal of Science** 6:277-291.

Hubbs,C., R.A. Kuehne and J.C. Ball. 1953. The fishes of the upper Guadalupe River, Texas. **Texas Journal of Science** 5:216-244.

Hunt, B.P. 1958. Introduction of Marisa cornuarietis into Florida. **Nautilus** 72:53-54.

Jordan, D.S. and B.W. Evermann. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. **Bulletin of U.S. National Museum** 47:1-1240.

Jordan, D.S. and C.H. Gilbert. 1886. List of fishes collected in Arkansas, Indian Territory and Texas, in September 1884, with notes and descriptions. **Proceedings U.S. National Museum** 9:1-25.

Kuehne,R. A. 1955. Stream surveys of the Guadalupe and San Antonio Rivers. Texas Game and Fish Committee, IF Rep. Ser., No. 1. 56 pp.

Merritt, R.W. and K.W. Cummins (eds.) 1984. An introduction to the aquatic insects of North America, 2nd edition. Kendall/Hunt, Iowa. 722 pp.

Neck, R.W. 1984. Occurrence of the striped ram's horn snail, Marisa coruarietis, in central Texas (Ampullariidae). **Nautilus** 98(3):119-120.

Otto,C. and B.S. Svensson. 1981. How do macrophytes growing in or close to water reduce their consumption by aquatic herbivores. **Hydrobiologia** 78:107-112.

Page, L.M. 1977. The lateralis system of darters (Etheostomatini). **Copeia** 1977(?):472-475.

Page, L.M. 1974. The subgenera of Percina (Percidae: Etheostomatini). **Copeia** 1974(1):66-86.

Page,L.M and G.S. Whitt. 1972. Lactate dehydrogenase isoenzymes, malate dehydrogenase isoenzymes and tetrazolium oxidase mobilities of darters (Etheostomatini). **Comparative Biochemistry and Physiology** 44B:611-623.

Pennak, R.W. 1989. Fresh-water invertebrates of the United States, 3rd, edition. John Wiley & Sons, Inc., New York. 628 pp.

San Marcos River Recovery Plan. 1984. U.S. Fish and Wildlife Service. Albuquerque, New Mexico.

Schenck, J.R. and B.G. Whiteside. 1976a. Distribution, habitat preference and population size estimate of Etheostoma fonticola (Osteichthyes: Percidae). **Copeia** 1976:697-703.

Schenck, J.R. and B.G. Whiteside. 1976b. Food habits and feeding behavior of the fountain darter, Etheostoma fonticola (Osteichthyes: Percidae). **Southwestern Naturalist** 21:487-492.

Schenck, J.R. and B.G. Whiteside. 1976c. Reproduction, fecundity, sexual dimorphism and sex ratio of Etheostoma fonticola (Osteichthyes: Percidae). **American Midland Naturalist** 98:365-375.

Schenck, J.R. 1975. Ecology of the fountain darter, Etheostoma fonticola (Osteichthyes: Percidae). Unpubl. M.S. Thesis, Southwest Texas State University, San Marcos, Texas. 100 pp.

Seamann, D.E. and W.A. Porterfield. 1964. Control of aquatic weeds by the snail, Marisa cornuarietis. **Weeds** 12:87-92.

Strawn, K. and C. Hubbs. 1956. Observations on stripping small fishes for experimental purposes. **Copeia** 1956:114-116.

Strawn, K. 1955. A method of breeding and raising three Texas darters. Part I. **Aquarium Journal** 26:408-412.

Tavares, A.F. and D.D. Williams. 1990. Life histories, diet, and niche, overlap of three sympatric species of Elmidae (Coleoptera) in a temperate stream. **Canadian Entomologist** 122:563-577.

Texas Parks and Wildlife Department. 1965.

Thorp, J.H. and A.P. Covich (eds.). 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, Inc., San Diego. 874 pp.

Wetzel, R.G. 1983. Limnology, 2nd Edition. Saunders College Publishing, Philidelphia, Pennsylvania.

Williams, D.D. and H.B.N. Hynes. 1973. The occurrence of benthos deep in the substratum of a stream. **Freshwater Biology** 4:233-246.

II. Annotated Bibliography

Akerlund, G. 1969. Oxygen consumption of the ampullariid snail Marisa cornuarietis in relation to body weight and temperature. Oikos 20: 529-533.

The oxygen consumption of about 100 specimens of Marisa cornuarietis, a possible biological control snail against hosts for the Bilharzia parasite, was studied in relation to body weight and temperature. The temperatures were 20, 25 and 350C. The average respiratory rate increased with increasing temperatures for adult snails, while juveniles showed a parallel trend but at a higher rate. During starvation their metabolism decreased. Normallly their respiratory rate is relatively high indicating voracious feeding habits which may contribute to the ability of M. cornuarietis to reduce the populations of other species.

Anonymous. Espey, Huston and Associates, Inc. 1975. Investigation of flow reqirements from Comal and San Marcos springs to maintain associated aquatic ecosystems, Guadalupe River Basin. Engineering and Environmental Consultants, Austin, Tx. 141 pp.

A major survey of the San Marcos and Comal Rivers was performed by Espey, Huston and Associates to determine the minimum spring flow required that would insure the continued existence of the Comal and San Marcos rivers. The study provides physical descriptions, water chemistry, and flora and fauna species lists for both rivers. From this survey data critical habitats/reaches of the river were identified and indicator species were identified for each river. Flow requirements were set forth for habitat preservation and water quality.

Anonymous. Guyton, W.F. and Associates. 1979. Geohydrology of Comal, San Marcos, and Hueco Springs. Texas Department of Water Resources. Report234.

The geohydrology fo the three natural discharge points for the Edwards Aquifer is reviewed from the geologic formations of the Edwards aquifer to the effect of pumpage from the aquifer. The Edwards Aquifer is recharged primarily by seepage of water from streams crossing its outcrop. Before there were any withdrawls, all recharge was discharged through six major spring outlets. Estimates of water stored in the Edwards ranges between 15 and 45 million

acre feet. The average daily flow for the three springs has decreased progressively since the late 1800's when withdrawals first began. The water from all three springs is constant in mineral quality and no evidence of major pollution has been found at any of the three groups of springs to date. Future studies should include evaluation of all practical means of conjunctive use of ground water and surface water, to obtain the optimum development of both.

Arsuffi, T.L. and B.G. Whiteside. 1991. Distribution and abundance of the endangered fountain darter, Etheostoma fonticola in the Comal and San Marcos aquatic ecosystems and the ecology and biological impact of the exotic giant rams-horn snail, Marisa cornuarietis. Endangered Species Proposal. Biology Department, Southwest Texas State University, San Marcos, Tx.

Ball, J., W. Brown, and R. Kuehne. 1952. Landa Park is renovated. Texas Game and Fish 10(5):8-9,32.

Barnhart, R.W. 1975. An application of numerical taxonomy to the genus Eurycea (Urodela: Plethodontidae) as found on the Edwards Plateau, Texas. 46 pp. M.S. Thesis, Southwest Texas State University, San Marcos, Tx.

Selected internal and external body measurements and counts are examined in three previously described species of epigeal salamanders (Genus Eurycea) inhabiting springs in Central Texas. Statistical and compartive evidence supports the argument that these three species of salamanders are indistinguishable to such an extent that the specific epithets nana and pterophila should be suppressed in favor of the species name Eurycea neotenes.

Barr, C. and P. Spangler. 1992. A new genus and species of stygobiontic dryopid beetle, Stygoparnus comalensis (Coleoptera: Dryopidae), from Comal Springs, Texas. Proceedings of the Biological Society of Washington 105(1):40-54.

A stygobiontic new genus and species, Stygoparnus comalensis, from Comal Springs, Texas, is described and compared with the dryopid genus Helichus. Distinctive characters of the adult and larva are llustrated with pen and ink drawings and scanning electron micrographs. his new taxon is the first member of the family Dryopidae reported from subterranean waters.

Bayer, C.W. 1975. The dragonfly nymphs (Odonata: Anisoptera) of the Guadalupe River basin, Texas. 117 pp. M.S. Thesis, Southwest Texas State University, San Marcos, Tx.

The author attempts to determine the ecological distribution of the nymphs of the Odonata suborder Anisoptera in the Guadalupe River basin. A key to the nymphs of Anisoptera is included.

Blackburn, R.D. and T.M. Taylor. 1971. Temperature tolerance and necesary stocking rates of Marisa cornuarietis L. for aquatic weed control. Proc. Eur. Weed Res. Council, Third International Symp. on Aquatic Weed. pp. 70-86.

The marisa snail (Marisa cornuarietis L.) is native to the Magdalena and Orinoco Rivers of South America. It was introduced into the waters of the United States near Coral Gables, Florida, in1957. Marisa is also of recent introduction into Puerto Rico where it is now being used as a biological control agent for the snail Austrolarbis glabratus.

Marisa will eat a variety of submersed aquatic plants. The tendency of the snail to eat newly germinated rice has caused a reluctance to release the snail in rice growing regions of the world. Research has shown that Marisa will eat young rice plants only if no other food source is available.

During the last six years, studies have been conducted on the effectiveness of Marisa as a biological control for aquatic weeds. Studies were conducted on the stocking rates necessary to control selected weed species and the effect of various temperatures on their survival.

Blair, W.F. 1950. Biotic provinces of Texas. Texas J. of Sci 2:93-117.

An ecological description of the state of Texas based upon its differing soil and vegetation types. Each of the different vegetative sections is called a biotic province and wildlife species are associated with each province dependent on the different vegetative habitats.

Bosse, L.S. 1979l. A survey of the adult dryopids (Coleoptera) in the San Marcos and Comal Rivers in central Texas. M.S. Thesis, Southwest Texas State University, San Marcos, Tx.

Adult dryopoids were sampled from the San Marcos and Comal River, central Texas, on a biweekly basis for a period of one year at eight stations, and results presented. The two populations of beetles were compared with respect to temporal distribution, niche preference, factors affecting population density, feeding habits, and basic morphology of all life forms of P. texanus.

Bosse, L.S., D.W. Tuff, and H.D. Brown. 1988. A new species of Heterelmis from Texas (Coleoptera: Elmidae). Southwestern Naturalist 33:199-203.

Heterelmis comalensis (new species) is described from Comal Springs, one of the headwaters of the Comal River, in New Braunfels, Texas. It is apparently endemic, hind wings brachypterous, and smaller in size than any other species known form the United States (1.7 to 2.1 mm in length, 0.8to 0.91 mm in breadth). It is closest to Heterelmis glabra (Horn) from which it differs in body contour and in size, H. glabra being 1.9 to 2.35 mm long and 1.0 to 1.17 mm wide.

Bowles, D.E. and T.L. Arsuffi. In Press. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, U.S.A.: a consideration of their importance, threats to their existence, and efforts for their conservation. Aquatic conservation.

1. This paper discusses the karst aquatic ecosystems of the Edwards Plateau, Texas, including a synopsis of those systems that are threatened or endangered due to anthropogenic disturbances. Thousands of springs issue from the aquifers on the Edwards Plateau, including the largest springs in the state.

2. The endemic and unique aquatic biota of the Edwards Plateau are presented, including taxa faced with extinction. Tentatively, 91 species and/or subspecies are identified as being endemic to aquatic ecosystems of the Edwards Plateau.

3. Threats to aquatic ecosystems are overpumping of aquifers associated with an expanding human population in the region, agricultural practices, urbanization and development, pollution, recreational activities,

introductions of exotic species, and changes in regional and global climactic patterns.

Brown, W.H. 1953. Introduced fish species of the Guadalupe River basin. Texas Journal of Science 5(2):245-251.

The author address the controversy among fisheries workers in Texas over the status of several fishes occurring in the Guadalupe River Basin of Texas, especially in the headwaters of the San Antonio, Comal, and San Marcos Rivers. Issues concerning the status of the following species with regards to being endemic or introduced was discussed. Family Cyprinidae: Dionda episcopa couchi Girard, Mexican roundnose minnow; Family Poecilidae: Mollienesia latipinna LeSueur, Sailfin molly; Family Characidae: Astyanax fasciatus mexicanus (de Filippi), Rio Grande tetra; Family Cichlidae: Herichthys c. cyanoguttatus Baird and Girard, Rio Grande perch; and Family Centrarchidae: Ambloplites r. rupestris (Rafinesque), Northern rock bass. Studies were conducted to determine if the fishes in question were native to these waters. Only earliest collection records were considered as being pertinent to the investigation. All five species of fishes have been collected by the author in the Guadalupe River Basin since 1947.

Brune, G. 1975. Major and historical springs of Texas. Texas Water Development Board Report 189. 95 pp.

Texas originally had 281 major and historically significant springs, other than saline springs. Of these, four were originally very large springs (over 100 cubic feet per second flow); however, only two, Comal and San Marcos Springs, remain in that class today. Sixty-three springs, many with important historical backgrounds, have completely dried. Of the 281 springs studied, 139 issued from two underground reservoirs, the Edwards (Balcones Fault Zone) and the Edwards-Trinity (Plateau) aquifers. Detailed information is given separately for each spring, including the location, geologic setting, historical background and discharge.

Brune, G. 1981. Springs of Texas. Vol. 1. Branch-Smith, Inc. Fort Worth, Tx. 566 pp.

This publication "...is an effort to show what is happening to springs and why, and to depict what is left of the fast-fading natural, beautiful

environment in which man and his fellow animals and plants evolved, before it is destroyed by pollution and over population." One hundred and eighty-three counties are covered by the study, and all springs within them mapped.

Carrola, H.L. 1978. A comparative study of two populations of Psephenus texanus (Coleoptera: Psephenidae) in the San Marcos and Comal Rivers. M.S. Thesis, Southwest Texas State University, San Marcos, Tx.

This study was conducted in order to determine the number of dryopid species which inhabited the upper Comal and San Marcos rivers. Twelve species were collected during the 14 months of sampling riffle areas. Distribution and abundance of species is given and a key was constructed to twelve species of dryopids found in the San Marcos and Comal rivers.

Cedeno-Leon, A. and J.D. Thomas. 1982. Competition between Biomphalaria glabrata and Marisa cornuarietis: feeding niches. British Ecological Society pp. 707-721.

To evaluate the potential of Marisa cornuarietis as an agent for the biological control of Biomphalaria glabrata various components of their feeding niches were measured when the two species were kept separately and together in competitive situations. M. cornuarietis was found to be a better competitor than B. glabrata, although juveniles of both species were better able to adapt to novel food items than their adult conspecifics. B. glabrata is more adversely affected by interspecific competition than is M. cornuarietis.

Chippendale, P.T., D.M. Hillis and A.H. Price. 1990. Molecular studies of Edwards Plateau neotenic salamanders, Eurycea and Typhlomolge. Performance Report. Endangered Species Act-Section 6. Project E-1-2, Job No. 3.4. Texas Parks and Wildlife Department.

No Abstract. The report deals with a study to examine the genetic and taxonomic relationships of noetenic salamanders species of the Edwards Plateau. The authors suggest the data indicates that the salamanders collected from Comal Springs show greater genetic similarities to the widespread and common Eurycea neotenes than to E. nana collected from San Marcos Springs.

Demian, E.S. and R.G. Lutfy. 1965. Predatory activity of Marisa cornuarietis against Bulinus truncatus, the transmitter of urinary schistosomiasis. A. Tropical. Medicine and Parasitology. 59: 331-336.

Laboratory experiments suggest that M. cornuarietis preys upon B. truncatus, a snail vector of Schistosoma haematobium. The predation is three-fold: adult M. cornuarietis were observed deliberately to attack and devour adult B. truncatus of various sizes; adult and young M. cornuarietis devoured newly hatched B. truncatus and newly hatched and young M. cornuarietis destroyed the egg masses of B. truncatus and consumed the eggs.

Demian, E.S. and R.G. Lutfy. 1966. Factors affecting the predation of Marisa cornuarietis on Bulinus truncatus, Biomphalaria alexandrina and Lymnaea caillaudi. Oikos 17: 212-230.

The rate at which adult M. cornuarietis prey on adult and juvenile B. truncatus and L. caillaudi increases with temperature up to about 30 degrees C, then decreases slightly again. The rate of predation is proportional to the ratio of predators to prey, and is far less affected by population densities. M. cornuarietis seems to ingest the entire organism if it is small (shell diameter < 5 mm), and with larger specimens, they attack only the soft parts. The predation of M. cornuarietis occurs accidentally while grazing on aquatic plants, but also deliberately. It seems probable that M. cornuarietis of all ages are capable of reducing B. truncatus, B. alexandrina and L. caillaudi populations.

Dowden, D.L. 1968. Population dynamics of the San Marcos Salamander, Eurycea nana. 44 pp. M.A. Thesis. Southwest Texas State University, San Marcos, Tx.

A one year study was undertaken to dtermine the life history, and population range, size and dynamics of Eurycea nana. An evaluation of its habitat was also conducted.

Edwards Aquifer Research and Data Center. 1988. Proceedings: San Marcos and Comal Springs Symposium. December 2-3, Southwest Texas State University, San Marcos, Tx.

Presentations concerned with anthropogenic impacts on the Edwards aquifer and San Marcos River are compiled. Symposium objectives were as follows: "To begin formulation of an orderly assessment of the several values and costs of maintaining and protecting natural flows at San Marcos and Comal Springs - to assess effects locally and downstream of changes on streamflows, water rights, fish and wildlife, and ecology within spring sites; to identify the expertise required to make these assessments; to begin an active and detailed public information program to make certain all interests are properly represented in the assessment process and that policy decisions are reached appropriately."

Edwards, R.J., G. Longley, R. Moss, J. Ward, R. Matthews, and B. Stewart. 1989. A classification of Texas aquatic communities with special consideration toward the conservation of endangered and threatened taxa. Texas Journal of Science 41(3):231-240.

A classification of Texas aquatc habtats was developed. Seven biotic provinces and 11 primary aquatic habitat types are recognized. The distribution of endangered and threatened vertebrates of Texas among habitats and provinces was considered. We found that habitats associated with spring systems (aquifers, springs, and spring-runs) contained a majority of the endangered fauna in the central and western part of the state, whereas large rives and streams contained the greatest number of endangered taxa in the eastern part of the state. Only through wise conservation of a wide variety of water resources throughout the state will the state's aquatic resources be maintained at their current levels of abundance.

Edwards, R.J., et al. 1985. The San Marcos Recovery Plan for San Marcos and Comal rivers endangered and threatened species. San Marcos Recovery Team. DRAFT. United States Fish and Wildlife Service.

The San Marcos River Recovery Plan discusses the physiography, hydrology and history of the San Marcos and Comal Rivers. The goal of the recovery plan is to secure the survival and eventual recovery of four species found in the San Marcos and/or Comal River. Conservation efforts, background, distribution and habitat requirements are described for these four species (Etheostoma fonticola, Gambusia georgei, Eurycea nana, Zizania texana). The plan concludes by stating/describing the major steps to be taken to insure the survival of these protected species.

Ferguson, F.F. and J.M. Butler, Jr. 1966. Ecology of Marisa and its potential as an agent for the elimination of aquatic weeds in Puerto Rico. Proceedings of Southern Weed Conference pp. 468-476.

Marisa cornuarietis was observed to be successful as an agent for biological control of Australorbis glabratus, the snail intermediate host of schistosomiasis mansoni. Under laboratory conditions M. cornuarietis will also control the African snail vector of schistosomiasis Biomphalaria mansoni, , but as yet does not appear to be effective against Oncomelania, the Japanese vector of this disease. There are good indications that also M. cornuarietis may be useful as a biological control agent for Fasciola hepatica, the cattle liver fluke.

Hale, M.C. 1964. The ecology and distribution of the introduced snail, Marisa cornuarietis, (Ampullaridae) in south Florida. 115 pp. M.S. Thesis. University of Miami, Coral Gables, Florida.

This thesis covers the following topics: use of Marisa as a biological control organism; range of size, color and sexual dimorphism; distribution and abundance; habitat characteristics; response to dissolved materials; food habits; and reproduction and growth.

Haridi, A.A.M., S.H. El Safi and W.R. Jobin. 1985. Survival, growth and reproduction of the imported ampullarid snail Marisa cornuarietis in Central Sudan. J. Trop. Med Hyg. 88: 135-144.

In field studies, M. cornuarietis was found to reach 4 cm in diameter after one year. Population densities ranged from 60 - 175 snails per meter of shoreline and survival after one year was 0.03. This indicates that M. cornuarietis could establish strong populations in central Sudan.

Hershler, R. and G. Longley. 1986. Phreatic hydrobiids (Gastropoda: Prosobranchia) from the Edwards (Balcones Fault Zone) aquifer region, south-central Texas. Malacologia 27:127-172.

This paper provides a systematic analysis of phreatic hydrobiids from 23 localities in south-central Texas, including 14 artesian wells and four springs in the Edwards (Balcones Fault Zone) Aquifer. Hauffenia micra (Pilsbry and Ferriss) and Horatia nugax (Pilsbry and Ferriss) are redescribed as members of a new genus, and two additional new genera, seven new species and one new subspecies are also described (Table 2). Detailed morphological descriptions, provided for all taxa, emphasize characters of the shell, operculum, pallial cavity, digestive system, and reproductive system of both sexes. Two of the genera are monotypic littoridinines having affinities with with phreatic or epigean littoridinines from Mexico. The affinities of the third new genus, a hydrobiine which includes seven well-differentiated species, remain unclear. While all of the species are found in the Edwards (Balcones Fault Zone) Aquifer, at least four of the species are found in other aquifers of south-central Texas as well. With the description of seven new hydrobiid species, the rich and still poorly sampled troglobitic biota of the Edwards (Balcones Fault Zone) Aquifer now totals 39 troglobitic animal species, including four vertebrates.

Hofkin, B.V., G.A. Stryker, D.K. Koech and E.S. Loker. 1991. Consumption of Biomphlaria glabrata egg massses and juveniles by the ampullariid snails Pila ovata, Lanistes carinutus and Marisa cornuarietis. Acta Tropica. 49: 37-44.

Lanistes carinatus and Pila ovata from Kenya and Marisa cornuarietis from the Dominican Republic were examined for their ability to consume egg masses and juveniles of Biomphalaria glabrata under laboratory conditons. Adults of all three species consumed all egg masses presented to them over a five day period of observation. Juvenile P. ovata consumed significantly more egg masses than juveniles of M. cornuarietis or L. carinatus. Egg masses attached to floating refugia were not attacked, apparently reflecting the difficulty experiencd by ampullariids in reaching free-floating objects. B. glabrata egg masses and juveniles were consumed even though lettuce was continually present in experimental aquaria.

Holsinger, J.R. 1967. Systematics, speciation, and distribution of the subterranean amphipod genus Stygonectes (Gammaridae). United States National Museum Bulletin No. 259. 176 pp.

No abstract. Significance: first description of the species Stygonectes pecki (now Stygobromus pecki) from Comal Springs in New Braunfels, Texas.

Horne, F.R., T.L. Arsuffi, and R.W. Neck. 1992. Recent introduction and potential botanical impact of the giant rams-horn snail, Marisa cornuarietis (Pilidae), in the Comal Springs ecosystem of Central Texas. Southwestern Naturalist 37(2):194-214.

This paper documents the recent introduction and identifies the potential botanical impact of the giant rams-horn snail, Marisa cornuarietis, in the Comal springs ecosystem. Radular morphology and feeding activity of Marisa is discussed. Marisa is herbivorous, consuming macrophyte tissue, and is associated with recent reductions in plant biomass in the lake.

Hunt, B. 1958. Introduction of Marisa into Florida. Nautilus 72: 53-55.

On February 1, 1957, three specimens of Marisa cornuarietis were collected in the Coral Gables canal in Florida. By July, hundreds of snails were present at the discovery site. One year later, M. cornuarietis was found in abundance along 5 miles of the canal . Experimentation revealed M. cornuarietis can tolerate environmental conditions usually considered adverse, i.e. low dissolved oxygen and periods of starvation. The population expansion was expected to continue into all south Florida canals.

Jobin, W.R. and A. Laracuente. 1984. Snail Marisa cornuarietis in tropical hydroelectric reservoirs. Journal of Environomental Engineering 110(2): 356-368.

For three years, populations of Marisa cornuarietis, the ampullarid snail used in bilharzia control, were monitored in 28 hydroelectric and multi-purpose reserviors in Puerto Rico to establish the habitat requirements for this ampullarid snail if it is introduced into hydorelectric reservoirs in other countries. The major factors determining habitat suitability were water temperature, the area of submerged shore which supported vegetation, and the rate or recession of the reservoir level. The ampullarid had established itself in 22 of 28 reservoirs.

Jobin, W.R. 1970. Population dynamics of aquatic snails in three farm ponds of Puerto Rico. Am. J. Trop. Med. Hyg. 19: 1038-1048.

Three ponds containing , the snail host of schistosomiasis, and other aquatic snails were studied in Puerto Rico for over a year to determine birth, death, and growth rates of the snails. A sampling system involving an Emery dredge was used to estimate the total number of snails in the ponds as well as the amount of vegetation. In addition, water temperatures and pond size were recorded at each biweekly sampling. Results showed that B. galbrata lived less than 200 days in the field, about a third of their laboratory lifespan. In contrast, Marisa cornuarietis had a life span of over 500 days in the field, providing a partial explanation for its domination of one of the ponds to the exclusion of B. glabrata.

Konu, Ozlen. 1992. Foraging strategy of the giant rams-horn snail, Marisa cornuarietis. 49 pp. M.S. Thesis. Texas Tech University, Lubbock, Texas.

This study evaluates factors that affect food preference of M. cornuarietis for two macrophytes, Vallisneria americana and Ludwigia repens. The phytochemical differences between the two macrophytes were analyzed via paried t-tests. M. cornuarietis exhibits a distinct preference for L. repens, possibly because it contains a higher concentration of holocellulose and has higher digestibility than V. americana. Plant phenolics and ash content do not contribute to preference.

This study also analyzes the foraging strategy of M. cornuarietis. Individual linear programming models were established based on two variables: the consumption of L. repens and V. americana. As a population, M. cornuarietis does not maximize energy or minimize time, but forages in an intermediate fashion.

Linam, G.W., K.B. Mayes, and K.S. Saunders. Draft. Habitat preference and population size estimate of fountain darters, Etheostoma fonticola, in the Comal River, Texas. Texas Parks and Wildlife Department, San Marcos, Tx.

Fountain daters (Etheostoma fonticola) were sampled in the Comal River, Texas, to determine their habitat preference and population size. Grids were established along transects to characterize the vegetation community and depth regimes. Darters were sampled within these grids. Fountain darters were found in greatest densities in filamentous algae at depths of 0.75 to 1.05 m. The population estimate ranged from 114,178 to 254,110 (95% confidence level) with a mean of 168,078 individuals.

Longley, Glenn. 1981. The Edwards Aquifer: Earth's most diverse groundwater ecosystem? Int. J. Speleology. 11: 123-128.

Recent studies on the Edwards Aquifer, a karstic formed cavernous system in Texas, indicate an extremely diverse community of aquatic troglobites. Sampling of wells and springs is providing new insight into the dynamics of this fascinating system, which is possibly the most diverse subterranean aquatic ecosystem known in the world today.

Madsen, H. 1992. Food selection by freshwater snails in the Gezira irrigation canals, Sudan. Hydrobiologia 228: 203-217.

Stomach content analysis was carried out on samples of the freshwater snail species Biomphalaria pfeifferi, Bulinus truncatus, Bulinus forskalii, Lymnaea natalensis, Melanoides tuberculata, Cleopatra bulimoides and Lanistes carinatus from different irrigation canals in Sudan. Samples of Marisa cornuarietis and Heliosoma duryi were also analyzed. The results indicate a great similarity of food choice for these species, especially among the pulmonate species. All species feed on fine detritus, epiphytic algae and decaying macrophytes. No fresh fragments of aquatic macrophytes were found and animal remains were found only a few occasions. However, the stomach contents of the ampullarid species were characterized by large fragments of dead macrophyte tissue, while the composition of the finer particles showed a great resemblance to that of the pulmonate species. Detritus constitutes the major component of the stomach content of all these snail species.

Neck, R.M. 1991. Occurrence of the striped rams-horn snail, Marisa cornuarietis, In central Texas, (Ampullariidae). Nautilus 98:119-120.

This paper documents the occurrence of Marisa cornuarietis in the San Marcos River and possible environmental impacts are discussed.

Odgen, A.E., A.J. Spinelli and J. Horton. 1985. Hydrologic and hydrochemical data for the Edwards Aquifer in Hays and Comal Counties, October 1983 to June 1985. Edwards Aquifer Research and Data Center. Report No. 2-85.

Data represents the result of many different independent studies as well as individual samples brught in by bconcerned citizens. The following types of data are included: 1) Collections and analysis of water samples from Hueco,

Comal, and San Marcos Springs for comparative purposes and time-series analysis, 2)Sampling of sites on the Upper San Marcos River and its tributary, Sessom Creek, to determine the effect of storm water runoff on water quality, 3) Sampling water in Ezells Cave, Rattlesnake Cave and Sink Springs, 4) Random sampling of water wells in the Edwards Aquifer in Hays County, and 5) Frequent sampling of water wells during aquifer tests to determine changes in water chemistry versus pumping time. The purpose of this report is to present data without interpretation.

Ogden, A., A.J. Spinelli and J. Horton. 1985. Hydrologic and hydrochemical data for the Edwards Aquifer in Hays and Comal Counties, October 1981 to September 1983. Edwards Aquifer Research and Data Center. Report No. RI-85.

Data represents the result of many different independent studies as well as individual samples brught in by bconcerned citizens. The following types of data are included: 1) Collections and analysis of water samples from Hueco, Comal, and San Marcos Springs for comparative purposes and time-series analysis, 2)Sampling of sites on the Upper San Marcos River and its tributary, Sessom Creek, to determine the effect of storm water runoff on water quality, 3) Sampling water in Ezells Cave, Rattlesnake Cave and Sink Springs, 4) Random sampling of water wells in the Edwards Aquifer in Hays County, and 5) Frequent sampling of water wells during aquifer tests to determine changes in water chemistry versus pumping time. The purpose of this report is to present data without interpretation.

Ottmers, D. 1987. Intensive survey of the Comal River Segment 1811. Report IS 87-08. Texas Water Commission, Austin, Texas.

An intensive water quality survey was conducted on the Comal River (Segment 1811) July 8-9, 1986 by the Texas Water Commission. The Comal River flows through the center of the City of New Braunfels, in central Texas. The river is spring fed, clear, swift and is a major tourist attraction for the city. Parks provide adequate access to the river and swimming, snorkeling and tubing are enjoyed by thousands fo area residents and visitors.

Field measurements of dissolved oxygen, pH, temperature, and conductivity were made at four main stem stations and five tributary stations.

Inflow from the tributaries was measured and water samples were collected for laboratory analyses. A time-of-travel study was also conducted.

No water quality problems were observed during the study. Carbonaceous and nitrogenous oxygen demand was low as were levels of suspended solids. The spring water naturally contains nitrates; however, other nutrient material were not detected and algal production was low. Dissolved oxygen levels were moderately low, however only one early morning measurement was less than the 5 mg/L criterion. Aquatic macrophytes grow abundantly in the clear water and their metabolism may contribute to increasing the range of dissolved oxygen during a diel period.

Otto, C. and B.S. Svensson. 1981. How do macrophytes growing in or close to water reduce their consumption by aquatic herbivores? Hydrobiologia 78: 107-112.

Larvae of Potomophylax cingulatus (Trichoptera) which are polyphagous herbi- and detritivores, were used as test organisms to investigate the palatability of aquatic and terrestrial macrophytes. In 7 out of 9 plant pairs the consumption rate was low on the species growing in or close to water. The consumption rate was negatively correlated with the nitrogen content of the plant. It is argued that the majority of the aquatic plants produce secondary plant substances, which reduce the attacks by aquatic herbivores. A restricted distribution, the long time of exposure to herbivores, as well as the relatively large probablity of being discovered at the border of an inhabitable area, are factors suggested to have influenced the development of chemical defence mechanisms in aquatic macrophytes.

Peters, M.S. 1977. The Mayfly nymphs (Insecta: Ephemeroptera) of the Guadalupe River Basin. 84 pp. M.S. Thesis. Southwest Texas State University, San Marcos, Tx.

The authors goal was to provide baseline data on the mayfly fauna of the Guadalupe River Basin of Texas Biotic and abiotic components of the entire basin were analyzed to provide data for correlation of ecological distributions of organisms with the habitat. Illustrations and a key are provided to facilitate future identification. From this study, priorities may be established for furhter work on the taxonomy and distributions of mayflies of the region.

Rich, E.R., and W. Rouse. 1970. Mass producing a tropical snail for biological control. Proceedings of the Southern Weed Society 23: 288-298.

The purpose of this study was to develop economical mass rearing techniques. Growth data, food preferences, optimal growing conditions and reproductive potentials for Marisa cornuarietis were studied. Similar work on Biomphlaria glabrata (=Australorbis glabratus) and on Lymnea has shown the feasibility of rearing snails in the laboratory. Snails can then be introduced to various aquatic systems as a check of aquatic weeds.

Rothermel, S. and A.E. Ogden. 1987. Hydrochemical investigation of the Comal and Hueco spring systems, Comal County, Texas. Edwards Aquifer Research and Data Center. Report No. RI-87.

To better understand the nature of recharge and flow to the springs a hydrochemical investigation of the Comal and Hueco spring systems was executed between April 1982 and July 1983. This study involved the analysis of fracture and joint orientation, dye-tracing and sampling of spring water chemistry. A large portion of the investigation involved the weekly sampling and analysis of water chemistry of four outlets of Comal Springs and two of Hueco Springs.

Robins, C.R. 1971. Ecology of the introduced snail, Marisa cornuarietis (Ampullariidae) in Dade County, Florida. The Biologist 53(3):136-152.

The author discusses the distribution, abundance and ecology of the giant rams horn snail, M. cornuarietis, discovered in parts of the Dade County canal system in 1957. Biotic and abiotic factors affecting the distribution and abundance of M. cornuarietis were identified and discussed.

Schenck, J.R. 1975. Ecology of the Fountain darter, Etheostoma fonticola (Osteichthyes: Percidae). 100 pp. M.S. Thesis. Southwest Texas State University, San Marcos, Tx.

Study objectives were: to evaluate the population status of Etheostoma fonticola in both the San Marcos and Comal rivers; to determine the distribution, spawing times, fecundity, sex ratio, food habits, feeding activity, and parasites of E. fonticola; to describe morphological characters of the species; and to correlate habitat preference of the species with various biological and physicochemical factors.

Schenck, J.R. and B.G. Whiteside. 1976a. Distribution, habitat preference and population size of Etheostoma fonticola (Osteichthyes: Percidae). Copeia 11976(4):697-703.

Etheostoma fonticola is an endangered species of fish living only in the San Marcos and Comal rivers, Texas, and the Dexter National Fish Hatchery, New Mexico. This species was reintroduced into the Comal River after extensive sampling revealed its absence, and introduced into the Dexter fish hatchery for protection and propagation. E. fonticola was collected only in vegetated habitats. The habitats preferred by most of the fish had vegetation that grew close to the substrate; specifically, Rhyzoclonium sp. A conservative rough estimate of the number of E. fonticola living in the San Marcos River watershed was 103,000.

Schenck, J.R. and B.G. Whiteside. 1976b. Food habits and feeding behavior of the Fountain darter, Etheostoma fonticola (Osteichthyes: Percidae). Southwestern Naturalist 21(4):487-492.

Food habits and feeding behavior of the endangered fountain darter, Etheostoma fonticola was studied in the San Marcos River, Texas. This species was found to be selective in how and what it eats. The food habits varied with seasons and size of fish and the species fed primarily during daylight.

Schenck, J.R. and B.G. Whiteside. 1976c. Reproduction, fecundity, sexual dimorphism and sex ratio of Etheostoma fonticola (Osteichthyes: Percidae). American Midland Naturalist 98(2):365-375.

Etheostoma fonticola is an endangered species of fish which spawns year-round in the relatively constant temperature headwaters of the San Marcos River and Spring Lake (impounded origin of the river), Hays Co., Texas. However, the species appears to have two spawning peaks, one in August and the other in late winter to early spring. Proposed explanations for this observed spawning periodicity are a slight increase in water temperature and /or a decreased flow. Ripe ovaries of preserved E. fonticola contain three distinct classes of ova based on their size and appearance. The number of mature ova (Size Group I) is positely correlated with total length of the fish while the mean diameter of mature ova is not positively correlated. Etheostoma fonticola provides no parental care to the ova and has very low fecundity (mean fecundity

was 19). Sexual dimorphism is evident in the shape and size of the gential papillae and the pelvic fins and in the intensity of body coloration. The sex ratio of E. fonticola is 1.39:100 (M:F).

Seaman, D.E. and W.A. Porterfield. 1964. Control of aquatic weeds by the snail Marisa cornuarietis. Weeds 12: 87-92.

Experiments were conducted in 200-gal concrete tanks. Adult Marisa cornuarietis were collected from a canal near Miami, Florida, where a colony had recently become established. The snails controlled Ceratophyllum demersum, Najas guadalupensis, and Potamogeton illinoiensis completely and Pistia stratiotes and Alternanthera philoxcroides partially. Eichhornia crassipes was not completely eaten but its growth and flowering were greatly retarded. M. cornarietis preferred submersed weeds to floating or emersed weeds, but the floating weed Salvinia rotundia was eaten nearly as readily as submersed weeds. Little damage was done by M. cornuarietis to 4-and 5- week old rice plants, but younger rice was eliminated when M. cornuarietis had no other food available.

Stryker, G.A., D.K. Koech and E.S. Loker. 1991. Growth of Biomphalaria glabrata populations in the presence of the ampullariid snails Pila ovata, Lanistes carinatus and Marisa cornuarietis. Acta Tropica. 49: 137-147.

Adults of three ampullariid species were examined for their ability to affect the population growth of Biomphalaria glabrata under laboratory conditions in which food was supplied over an eleven week interval. The presence of either 3 or 9 Lanistes carinatus or 3 Marisa cornuarietis per 40 liter aquarium did not reduce the population size of B. glabrata below levels attained in control aquaria lacking ampullariids. The presence of 9 M. cornuarietis adults significantly reduced B. glabrata populations by week 10 of the experiment. Presence of 3 or 9 Pila ovata per aquarium significantly reduced B. glabrata numbers below control levels starting at week 4 of the experiment. The results of this laboratory study suggest that further investigation of the role of ampullariids as biological control agents for pulmonate snails in sub-Saharan Afrika should focus on P. ovata.

Sweet, S.S. 1978. The evolutionary development of the Texas Eurycea (Amphibia:Plethodontidae). 450 pp. Ph.D. dissertation. University of California, Berkeley, California.

Tupa, D.D. and W.K. Davis. 1976. Population dynamics of the San Marcos salamander, Eurycea nana Bishop. Texas Journal of Science. 32:179-195.

Results of a study of the population ecology and demography of a paedogenetic species of salamander, Eurycea nana Bishop, endemic to the San Marcos River, San Marcos, Texas, are presented. The physical, chemical and biotic aspects of the natural habitat are reported and evaluated. Information is given regarding the food habits, the reproductive conditions, the population density and range, and the existence of predators of the species.

Young,W.C., B.G. Whiteside, G. Longley and N.Carter. 1973. The Guadalupe-San Antonio-Nueces River Basins. Phase I: Review of existing biological data. 400 pp. Final Report to Texas Water Development Board. Aquatic Station, Southwest Texas State University, San Marcos, Texas.

This study thoroughly describes the Guadalupe, San Antonio and Nueces River Basins. Beginning with topography, this study then lists fish species, covers their distributional patterns, lists the aquatic invertebrates, other aquatic vertebrates, waterfowl and aquatic macrophytes found in all three river basins.

III. A - C. Data Evaluation and Interpretation and Needs Assessment

There does not appear to be significant threats associated with predation, disease or other biological components of the habitats to populations of the Comal Springs water beetle, Peck's Cave amphipod or the Comal Springs dryopid beetle. However, little is known on the biology, community structure or food web interactions for any of the species. Scientific collecting does not appear to be frequent or intensive enough to pose much of a problem. All species are small and inconspicuous and would not attract interest as components of aquarium communities. Further, the Parks and Recreation Department of the City of New Braunfels does not allow public access (wading) to the spring orifices and runs and requires permission from the city to collect on city property. San Pedro and San Antonio springs when flowing are subject to recreational impacts. Hueco and Sink springs are relatively protected since they are on private property. Fern Bank Springs, even though on private property, may be sensitive to recreational impact. The springs are small and run a short distance before falling into the Blanco River. Alot of campers use the area and frequently visit the springs.

Present and potential threats to habitat

The most significant threats to endemic invertebrates at Comal Springs are related to elimination or modification of habitat as a result of anthropogenic disturbances. The most immediate threat is declining levels and the ever increasing liklihood of cessation of springflow due to overdrafting of groundwater associated with human activities. A number of other springs (San Antonio, San Pedro) at elevations higher than Comal Springs, once issued from major natural discharge points of the Edward's Aquifer now cease to flow or do so intermittently. The Edward's Aquifer and the springs that issue from the aquifer are the sole source of water for the 1.5 million people of the region. the Texas Legislature recently passed legislation (Senate Bill 1477) to regulate pumping from the aquifer. A key feature of this bill is that total annual usage permitted to be pumped is 450,000 acre feet (this amount is equal to current average withdrawals) over the next 15 years and then 400,000 acre feet from then on. While this bill is a step in the right direction, it still might not be able to gaurantee spring flows during even a mild drought. For example, minimum recharge to the aquifer has been as little as 43.7 thousand acre feet in 1956. Even now, pumping for agricultural and lawn watering can cause the aquifer to drop more than foot a day measured in well J-17 in San Antonio. Even with aquifer levels at historic highs, it would require little time without rain for the aquifer to drop to 619 feet and for Comal Springs to begin to go dry. Although Bill 1477 calls for a critical period management plan to be in effect when aquifer levels are low, the adequacy of the plan cannot be evaluated at this time since it has not been formulated. Projected water usage associated with human population growth predicted for the region indicates demands on the aquifer will increase.. Expectations are that by the year 2000, continuous flow from Comal Springs is unlikely. Late spring and summer are seasons with the greatest probability for cessation of springflow. During these periods, recharge from rainfall is low and withdrawal for irrigation by agriculture and landscape watering is high. When levels of the Edward's Aquifer drop below about 619 feet mean sea level (J-17 reference well, San Antonio), Comal Springs will cease flowing. During the summer of 1990, the aquifer level dropped below the lip of the orifices of Comal Springs 1 &2 and the spring runs dried up. Too little is known to determine levels of threat posed by spring flow cessation on the subterranean species. However, H. comalensis as adults should be able to survive periods of no spring flow by burrowing down into the coarse cobble substrate. The period of time this may work as a survival strategy will depend on the depth of the substrate in relation to the duration of no spring flows.

Declining springflows also may impact species through indirect effects. With declining flows, water depths decrease and the turnover time for Landa Lake is increased which means the water has a longer residence time. This allows for greater solar insolation and consequently warmer water temperatures. There is an inverse relationship between water temperature and its ability to hold oxygen; as temperature rises oxygen concentration decreases. In contrast, invertebrates exhibit a positive relationship between temperature and rate of metabolism; as temperature rises oxygen consumption increases. Thus declining flows could cause physiological stress to invertebrates in that as water temperature increases oxygen concentration decreases at a time when invertebrate metabolic demands for oxygen are increasing.

A second threat to the habitat is the potential for pollution since Comal Springs and its associated terrestrial watershed are located in the urban environment of New Braunfels, Texas. At present, this does not appear to be a major problem based on recent water quality analyses conducted by the Edwards Aquifer Research and Data Center. However, the possibility for increased flooding, erosion and silt deposition with increased urbanization and population growth within the vicinities of the springs should be monitored. Also, as springflow declines, the effects of point and non-point source pollution increase proportionately since the dilution factor is decreasing.

Exotic species also may pose a threat to the habitat. Recently, the exotic giant rams-horn snail, Marisa cornuarietis rapidly increased in number and is markedly altering habitats and communities by consuming vast quantities of vegetation in Landa Lake below the largest spring orifices. At present, since all three endemic invertebrate species are primarily limited to the spring runs and orifices, the giant rams-horn snail poses no threat. It has yet to show evidence of migrating upstream against a fast current. However, as spring flows decline with depletion of the aquifer, invasion by this exotic into biological communities associated with the spring orifices and runs seems likely.

Based on previous reports and the results of this study all of the target species have their distribution and abundance limited to Comal Springs. However, Stygoparnus comalensis has recently ben discovered at Fern Bank Springs (Cheryl Barr, California State University, personal communication).

The Comal Springs riffle beetle (Heterelmis comalensis), Peck's Cave amphipod (Stygobromus pecki) and the Comal Springs dryopid beetle (Stygoparnus comalensis) all depend on the biological communities of which they are a part. Although little is known about the structure, function and key interactions that occur in these communities, it is clear that there is a strong reliance on springflow to maintain the biological intregrity of these communities. As such, the conservation and protection of species is best achieved by ensuring adequate springflows.

Since the species appear to have a rather limited distribution and are restricted to the spring orifices and spring runs, I recommend that future development and construction in the surrounding watershed adjacent to and upstream from the spring orifices be curtailed to minimize the impacts of anthropogenic disturbances (sedimentation, chemical spills, pesticide runoff, other pollutants) to the species.

Future research needs should include a continuation of monitoring population dynamics of giant ramshorn snails and their effects on community structure of Comal Springs. In addition, a monitoring program for these snails in the San Marcos Springs should be inititiated since little is known about their ecology in this aquatic ecosystem. Other biological studies that need addressed as they relate to endangered and threatened species are identified in the U.S. Fish and Wildlife Service - San Marcos and Comal Springs Recovery Plan which is presently undergoing revision. Recently, the U.S. Fish and Wildlife Service has initiated a two year study to determine minimum flow requirements for listed species at Comal Springs.

PHASE II

INTRODUCTION

Comal Springs, located in New Braunfels, Texas, represents a biologically unique ecosystem as evidenced by its numerous endemic species of plants and animals. 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.

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).

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.

SITE DESCRIPTIONS

After several preliminary surveys, eight sampling stations (Fig. 1) were established in May 1990 throughout Landa Lake and Comal Springs which vary with respect to substrate composition, depth, flow regime and type of macrophyte present. 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. Site 2 is located at the deepest part of Landa Lake (1.3 - 2.5 meters), opposite where the cutter boat was moored. The dominant vegetation is a mixture of V. americana and C. caroliniana. Site 3 is another spring-run about 73 m north of Site 1 and across from California Blvd. This site is northeast of the walking bridge with a cobble substrate frequently covered with a red alga and patches of the macrophyte, Potamogeton illinoensis. Comal 4 is located west of the southern most island (across from the gazebo) in Landa Lake. Water depth ranges from 0.5 to 2 meters with dominant vegetation consisting of a mosaic of pure stands of V. americana or L. repens. By January 1991, the stands of L. repens at this site had been decimated, and slowly began to grow back in June 1991. In January 1991, a few small stands of a "red" color morphology of L. repens were first noted about 30 meters north of transect 4. This "red ludwigia" has since spread and become well established. We added an additional sampling location here, site 4a. Water depth ranges from .75 to 1 meter and the substrate is mostly cobble. The four remaining sites are located upstream, in a private residential area, 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 meters and the substrate is silt and mud. The dominant macrophytes at this site are stands of Sagittaria platyphylla and C. carolinana. Site 6 is a small cove located about 30 meters northeast of Swan Island. A number of small springs discharge at this site and the substrate is mainly cobble. At other locations, the bottom is silt and mud from which C. carolinana and L. repens grow. Water depth varies from 0.2 to 0.5 meters. Site 7 is located 20 meters upstream of Site 6 and has a cobble substrate covered with a mat of filamentous green algae. Water depth varies from 0.2 to 0.8 meters. Site 8 is the furthest upstream site and is located northwest of the City of New Braunfels Public Works Headquaters. The substrate consists of silt and mud and C. carolinana was the dominant vegetation. Since February of 1992 thick beds of L. repens (green) have become dominant at Site 8. Water depth varies from 0.4 to 0.7 meters.

PHASE II: BIOLOGICAL AND ECOLOGICAL RESEARCH

I. Characterize the biologic communities in which the endangered, threatened, and endemic species of the Comal Springs aquatic ecosystem exist, by analyzing the macroinvertebrate communities associated with these habitats.

Rationale: Macroinvertebrate composition can be used as a key biological criteria in assessing the quality of freshwater ecosystems. It provides baseline descriptive information on the physical, chemical and biological characteristics against which future impacts could be assessed. The U.S. Environmental Protection Agency, Texas Parks and Wildlife Department and the Texas Water Commission use data on macroinvertebrate composition and their feeding relationships to provide insights into water quality and, in some circumstances, the minimum flow requirements needed to maintain the biological integrity of the springs. This information would be critical to determine spring flow required should pumping regulations be instituted or augmentation plans implemented. A study of macroinvertebrates would also be of use in identification of potential food items of fountain darters and salamanders as well as potential competitors and predators.

METHODS

We conducted two annual macroinvertebrate surveys of Comal Springs and Landa Lake. In May 1990, triplicate Ekman dredge samples (0.053 square meters) were taken from each of the eight designated transects except sites 1 and 3. The latter sites are located in spring runs and were sampled with a Hess sampler (0.085 square meters). Mud and silt picked up in the grab samples was sieved through pans stacked in order of decreasing mesh size. Macroinvertebrates collected on the pans were picked off and preserved in 80% ethanol. Triplicate Hess collections made in each spring run were done by agitating the substrate inside the area of the sampler for 1 minute. Invertebrates collected in the mesh cup at the end of the net, were washed into a jar of 80% ethanol. The survey conducted in June 1991 involved taking triplicate Ekman dredge samples, but only sampling the transects in Landa Lake (2, and 4-8). The same procedure followed the previous year for collecting macroinvertebrates was repeated in the June 1991 sampling. For both surveys, samples were taken to the laboratory for enumeration and identification to the lowest taxon possible using keys in Merritt and Cummins (1984) and Thorp and Covich (1991).

RESULTS

Twenty-one taxa in ten orders of macroinvertebrates were collected at the various sites spring runs (Tables 1 and 2). Taxonomically among Lanka Lake sites the most diverse group were the gastropods consisting of seven species distributed amon three families. In contrast, insects (Coleoptera: Psephenidae) and crustaceans (Amphipoda) dominated the fauna of the spring runs. Spatial and temporal variation in benthic invertebrate densities was observed with densities highest at site 2 and 7 and lowest at site 6. In both the 1990 and 1991 samples, gastropods were the most abundant taxon at sites 2,4,5,6,7,and 8, with the family Pleuroceridae making up > 90% of all individuals.

DISCUSSION

Although quantitative Ekman dredge samples were taken, numbers were not recorded for the 1990 macroinvertebrate samples. We did not report the numerical data because the dredge was not functioning properly with the jaws being jammed open by snails and vegetation. For the next sampling period we used scuba divers to ensure the dredge closed properly.

The taxonomic composition of aquatic insects dominsting the fauna in transects one and three is typical of spring runs. in contrast, an abundance of gastropods, as was found at sites 2,4-8, is common in lentic areas with high oxygen levels and dense macrophyte stands. The two dominant snails numerically, Thiara granifera and Thiara tuberculata, are not naive species but instead are exotics whose historical distribution is from Africa and Asia. Our sampling data provides baseline benthic data, but further sampling is needed to provide a baseline description on which water quality and flow assessments could be made.

MANAGEMENT SIGNIFICANCE

Until the introduction of M. cornuarietis, the lack of significant grazing resulted in very large standing crops of aquatic vegetation. With the introduction of M. cornuarietis, another trophic level has been added to this ecosystem. Rather than simply grazing the periphyton from the surface of the plant leaves like resident snail populations, M. cornuarietis consumes the plant itself. Dense populations of this snail could therefore modify the factors previously structuring these plant communities: changing from a community primarily structured by the relative competitive abilities of plant species to one that is structured by predation. We also anticipate a shift in the animal (fishes and invetebrates) communities from direct effects of M. cornuarietis (egg mass predation while feeding on plants) and two types of indirect effects resulting from shifts in food resource categories: 1) decreased leaf surface area reduces food resources of invertebrate functional feeding groups that rely on attached microbial assemblages and 2) increased fine particulate organic matter production through feeding and fecal activities increases food resources of collector-gathering and -filtering invertebrates. Changes in plant cover and abundance also decreases refugia therefore increases predation risk.

II. Determine the impact of the giant rams-horn snail (Marisa cornuarietis) on the Comal Springs aquatic ecosystem.

Rationale: Exotic organisms can displace native species through predation and reduction in biodiversity via habitat degradation, therefore by knowing which habitats are most susceptible to impact, we can identify M. cornuarietis's potential threats to the endangered, threatened, and endemic species in the Comal River.

A. Descriptive field studies have been conducted within the different macrohabitats to determine 1) snail population demographics, i.e., distribution, abundance, and size class compostition, and 2) other snail life history characteristics (behavior, reproductive ecology).

Rationale: This information will identify critical sites susceptible to invasion and defoliation and provide baseline information against which future changes in population size and distribution can be assessed.

METHODS

Distribution, abundance, size class composition and reproductive ecology

Initially, in May 1990, estimates of the abundance, size distribution and biomass of the M. cornuarietis were conducted at six of the designated transects using an Ekman dredge (see Interim Report 1991-1992 for sampling design). We have since employed an alternative method of determining snail density by using a nondestructive visual technique that was proposed in Interim Report 1991-1992. On a quarterly basis, since June1991, population estimates of M. cornuarietis have been made at three random locations along a transect at each site (except sites1 and 3 which are located in spring runs). We conducted visual estimates at night using a 0.1 square meter PVC quadrat held below the water surface and illuminated the area with a Q-beam spotlight. After enumeration of snails and egg masses within the quadrat area, the snails were collected with a dip net or hand-picked, and shell diameter was recorded. Snails were then partitioned into one of four size classes (0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm). Depth and current velocity (Marsh and McBirney model 210 portable current meter) were also determined. In addition to nighttime estimates, we conducted a preliminary mark-release-recapture estimate (15 October 1992) of M. cornuarietis abundance in a 100-square meter area of V.

americana with a depth of 1.5 meters. Five hundred adult snails (25 to 40 millimeters in diameter) were marked with a non-toxic paint pen and released into the marked area (100 square meters) at 1500 hours. Two recaptures were conducted (twenty-four and seventy-two hours later) during which volunteers (SWT 4416 General Ecology lab students) visually scanned the plot and recorded the number of marked and unmarked snails. Estimates of population size were then calculated using the Petersen Index (Cox 1990).

RESULTS

Distribution and Abundance

Marisa cornuarietis densities were highest in stands of macrophytes consisting of V. americana and L. repens, from summer 1991 through spring 1992 (Figure 2). Since the summer of 1992, abundance has been increasing in S. platyphylla and decreasing in the L. repens (red morphological type). Lowest abundance occurred in stands of C. carolinana at all times of the year. Mark-release-recapture estimates of M. cornuarietis density in V. americana range from 30 to 40 per square meter, a density 76 % lower than the mean density determined from the nighttime visual observation population estimates.

There is a inverse relationship between abundance of M. cornuarietis and depth over all sampling intervals (Figure 3). Snail abundance peaks at 1.22 meters depth (90 snails/square meter), but decreases by more than 50% when depth approaches 2 meters.

Examination of sites 2, 4 and 5 which varied in current velocity between the Fall and Winter 1991 (relative to low and high aquifer levels, respectively) shows that snail abundance is negatively correlated to flow (Figure 4). There was more than a 50% reduction in abundance of M. cornuarietis at transect 4 when current velocity doubled.

Overall, snail abundance was calculated assuming the entire surface area of the lake bottom was covered with macrophytes. Thus, a peak estimate of 7.5 million giant rams-horn snails in the14 acre lake area occurred in the fall 1991(Table 3). This was followed by a 65% reduction in snail abundance during the winter 1991, with subsequent population estimates for the Landa Lake system remaining at about 3 million.

Size Class Composition & Reproductive Ecology

A definite seasonal pattern is evident in size class distribution of M. cornuarietis (Figure 5). All size classes are present in the summer and fall of the year, with the larger size classes (2-3 & 3-4) making up the greatest percent composition. During the winter, only the largest two size classes were found in population samples. The very smallest size class (0-1) are most abundant only in the spring of the year. Egg mass density, however, peaked in summer 1991 in V. americana, with a mean of 26 masses per square meter (Figure 6). Since M. cornuarietis produces a mean of 50 eggs per egg mass, this represents a potential recruitment into a new cohort of about 1300 snails per square meter in the V. americana. Subsequent estimates have not resulted in egg mass densities that high or suggest any trends that are indicative of any seasonal reproductive cycle.

DISCUSSION

Descripitive field studies indicate that the distribution and abundance of M. cornuarietis is concentrated in the macrophytes, V. americana, L. repens (red morphology only) and S. platyphylla. Areas of the lake that are shallow and have relatively slow current velocity also support greater densities of the snail. From this we conclude that areas of Landa Lake having the above physical conditions and macrophytes are most susceptible to invasion and defoliation. As noted in the site descriptions, L. repens (green morphology) was completely eliminated from site 4 and surrounding areas by January of 1991, and red ludwigia became established in its place. Marisa cornuarietis soon colonized the red ludwigia resulting in high snail abundance in this macrophyte in the summer and fall 1991 (Figure 2). A peak in rams-horn abundance occurred in the Spring 1992 in L. repens (red) due to the presence of large numbers of juveniles (0-1 and 1-2 centimeter size class, Figure 5). Very lush growth of L. repens (green) has been established in the upper most reaches of the river (near transect 8), but has not yet been colonized by M. cornuarietis, as indicated by population censuses of the area and egg mass data (Figure 6). In contrast, M. cornuarietis has a patchy distribution in the V. americana due to variations in depth and current velocity. Areas that are shallow and have slower flow have a greater abundance of rams-horn snails. The combination field demographics and laboratory experiments on growth and fecundity suggest that areas of Landa Lake containing V. americana could support rapid population growth of rams-horn snails. In addtion, field enclosure studies show that if M. cornuarietis populations reach or exceed 4x the average population density (400 snails per square meter) in V. americana, significant reductions in plant biomass occurs.

The overall reduction in snail abundance (Table 3) during the winter of 1991 was probably caused by heavy flooding. Increased discharge and current velocity probably caused some M. cornuarietis to be washed into deeper parts of the river, where not many survived. This would account for the relatively low numbers observed during the winter census and led to the reduced recruitment in spring which has kept subseqent overall estimates low (about 3.5 million snails per 14 acres).

Reproductive ecology assessed by seasonal size class composition and seasonal egg mass density show somewhat conflicting patterns. According to size class distributions of M. cornuarietis, spring is the time of greatest reproductive effort. However, egg mass data suggests that summer is the reproductive peak. There are several life history characteristics which could account for this discrepancy. First, newly laid egg masses take about one month (24-27 days) to hatch. In addition, laboratory studies on growth of M. cornuarietis feeding on V. americana and L. repens show that newly hatched snails (1-1.5 millimeters in diameter) take at least three months to reach a size of 10 millimeters and eight months to reach 15 millimeters. This means that between four and nine months elapse from the time egg masses are laid and when they reach a size that is generally detectable in the population censuses. Thus, eggs laid in the summer months (July through August) produce juveniles that would only be counted in the spring population censuses

Also, inadequacies in the method used to count egg masses could provide density estimates that are low/inaccurate. Working in enclosures of V. americana (ref. Section II B., Interim Report 1992-1993) we noticed that egg masses are laid near the base of plants as well as near tops. The particular leaf morphology of different plants could obscure the view of egg masses (as in L. repens). Marisa cornuarietis usually lays egg masses either on the stems of L. repens and C. caroliniana or the undersurface of leaves, and thus masses are more difficult to count accurately in these macrophyte beds. Suggestions for more accurate estimation procedure is provided in the section, Management Synthesis.

There are several explanations why the mark-release-recapture estimates (Peterson Index) produced lower estimates of M. cornuarietis in the V.

americana than did nighttime visual population censuses. First, inexperienced data collectors may have overlooked/missed some unmarked rams-horn snails or inadvertently knocked them off the plants. Secondly, the marked individuals may have been hard to detect, due to defective markings, and the time of day the recapture was conducted. To use mark-release-recapture in the future, we recommend that individuals be marked with fluorescent paint and conduct the recapture at night. This is because M. cornuarietis exhibits a diel vertical migration pattern (discussed in Interim Report 1992-1993 II B(2)), climbing to the tops of plants at sunset and remaining there throughout the night, consequently more accurate visual counts can be made at night.

MANAGEMENT SIGNIFICANCE AND RECOMMENDATIONS

It is clear from our population estimates, that M. cornuarietis is a significant biological feature of the Comal Spring/Landa Lake ecosystem. As such, it represents a potentially serious threat to the biological structure and integrity of other species within the system, especially when population levels reach critical thresholds where herbivory by giant rams-horn snails causes the vegetation to disappear. We have identified two abiotic features of the environment which appear to have an effect on population size: water depth and current speed. Areas of Landa Lake that are relatively deep or with moderate current velocity do not appear to be habitats that favor the buildup of M. cornuarietis populations. Depth and current velocities are highly variable seasonally and annually depending on aquifer levels, which in turn, are dependent on rainfall, recharge, discharge and pumping demands. For this reason, we recommend that population estimates of snails be continued to monitor snail density changes. This may be especially important at times when the aquifer levels are dropping rapidly (spring and summer, 1-2 feet per day). As water depths and current velocities in Landa Lake decline, the conditions are favorable for a widespread population explosion of giant rams-horn snails.

METHODS

Behavioral characteristics

In February 1992, we set up a field study to document a suspected diel vertical migration (DVM) pattern (see Interim Report 1991-1992). We used two different procedures to determine if M. cornuarietis exhibited a vertical movement up from the substrate to the tops of plants and back down again, over a twenty-four hour period.

The first was a direct and quantitative study to demonstrate the distance, direction, and time of day snails moved. Three replicate sites (1 meter deep) in V. americana were designated and 100 marked snails (nail polish), were released per site. After they were marked and returned to the designated sites, a three hour acclimation period was allowed before we began to monitor their movements. Diver's were equipped with snorkel and weight belt to maintain their position under water at the sites. At 0200 hours on 14 February, we began monitoring the vertical movement of marked snails at two hour intervals, before and after sunrise and sunset, and at four hour intervals during the day and night. At each time interval, we recorded distance above the substrate of each marked snail within 4 square meters of each site. In addition, the number and shell diameter of unmarked M. cornuarietis within the site was recorded.

The second procedure was an indirect method of detecting a diel movement by M. cornuarietis. The technique of nondestructive visual counts, over a twenty-four hour period was used to monitor snail behavior in experimental field enclosures, constructed for a feeding study (ref. preliminary enclosure experiment, Interim Report July 1992, II B.). The basis for this study was, if diel vertical migration was occurring, we should see fewer snails in each enclosure during the daytime than at night. At three hour time intervals before and after sunrise and two hour intervals before sunset, we counted the number of visible M. cornuarietis on leaves of V. americana within enclosures (each contained 100 snails per 0.45 square meter enclosure). This study also allowed us to verify the accuracy of using nighttime, nondestructive visual counts to census giant rams-horn snail populations.

RESULTS

M. cornuarietis exhibits a definite diel vertical migration behavior, climbing to the tops of V. americana after sunset, remaining during the night, then descending to the substrate at sunrise (Figure 7). During the daylight hours, most snails remained at or near the substrate. Small unmarked, M. cornuarietis (less than 20 millimeters shell diameter) seemed to undergo a greater vertical displacement than did larger snails (personal observation). Counts in enclosures (2, 5, and 10, x4 density) over a twenty-four hour period show a similar pattern of migration up from the substrate after sunset (Figure 8).

The greatest number of rams-horn snails were visible on the leaves of V. americana in enclosures after sunset and through the night than during the day. There was about a five-fold increase in the numbers of snails counted at night than during the daty (Figure 9). Comparing the mean estimate of 52 snails (n=3) in enclosures, each containing 100, shows a 52% accuracy in the visual estimation method.

DISCUSSION

Marisa cornuarietis undergoes a diel vertical migration in V. americana in which snails climb to the tops of the plants after sunset, remain there through the night, and descend to the substrate at sunrise (Figure 7). This behavior may represent a behavioral adaptation that reduces predation by visual and tactile predators. Snails avoid visual predators, such as fish, which forage during the daylight hours by seeking refuge at or near the substrate during the day where it is difficult for predators to detect them. This appears especially important for the juvenile size classes of snails (.5 to 2.5 centimeters) because of their smaller size and thinner shell are more suseptible to predation. Tactile predators such as crayfish, mainly active during the nighttime, are avoided by M. cornuarietis via climbing the blades of V. americana to remain out of reach. However, in the field, rams-horn snails up to 35 millimeters in diameter were observed to have been eaten by crayfish (ref. Section II B., Interim Report 1992-1993). Crayfish are able to eat adult M. cornuarietis by using their mandibles to chip away the shell from the aperature (opening). Crayfish are generally thought to be omnivorous, but according to Brown (1991) crayfish select snails instead of macrophytes if given a choice. From this we conclude that crayfish in Landa Lake could function as a significant predator of the giant rams-horn snail. We suggest that laboratory studies be conducted to determine crayfish preference for M. cornuarietis over other snails common to Comal Springs. It is possible that M. cornuarietis has been in the Comal Springs ecosystem for a sufficient period of time for crayfish to now have learned to recognize these snails as prey.

Nighttime visual counts of M. cornuarietis in enclosures showed as much as 60% accuracy in the estimation procedure. With this we can feel fairly certain that estimations made on a per meter square are representative of the population, although may be somewhat underestimated. We have since modified the method used to count snails (see Management Synthesis, Section II B., Interim Report 1992-1993).

MANAGEMENT SIGNIFICANCE

One reason why exotic species are thought to be able to have rapid population explosions in new habitats is that they have escaped their predators. Little is known of the predator-prey interactions of M. cornuarietis in its native habitats of northern South America and southern Central America. However, in Landa Lake, fish and crayfish are two potential predators of M. cornuarietis. One management strategy to control giant rams-horn snails is to run assays to determine the predation potential.....

B. Conduct manipulative field experiments to determine the effect of the snails on the flora and fauna of the spring system. Objectives were to (1) determine the population size of M. cornuarietis that would significantly reduce the standing crop biomass of V. americana; (2) determine the impact on associated macroinvertebrates, and (3) determine the effects of intraspecific competition on M. cornuarietis's survival and reproductive rates.

Rationale: By determining the population size of M. cornuarietis that would significantly reduce stands of V. americana, we would have an indication of when snail populations would impact the flora and fauna of the spring system. Knowledge of the effects of intraspecific competition will help us understand how food limitation affects snail population dynamics. Dense snail populations could also cause a shift in the animal communities (fish and invertebrates) through egg mass predation while feeding on plants as well as reduction of food resources. Changes in plant cover and abundance also decreases refugia thereby increasing predation risk.

METHODS AND MATERIALS

We chose to set up the enclosure experiment in a stand of V. americana because the site was easily accessible and relatively homogenous with respect to depth and current velocity. The enclosures consisted of a PVC frame (2.5cm in diameter), covered with 25 millimeter squared plastic mesh. They were 1.5 meters tall, each with a base that enclosed 0.45 square meters, and each had four legs (20 centimeters in length) which were pushed into the substrate to anchor the enclosure in place. The enclosures extended about 50 centimeters above the water level and the top was left uncovered to prevent shading. To access the interior of the enclosure during the study, a door was cut into the upper half of the enclosure on the downstream side.

On 8 August 1992, we placed nine experimental and three control enclosures about two meters apart in a dense stand of V. americana at a depth of 1 - 1.5 meters. All rams-horn snails were removed from each enclosure, counted and sized to establish population densities for the experimental area. All egg masses also were removed and counted. A 21 square centimeter area of V. americana within each enclosure was clipped and immediately bagged. These samples were later placed in a drying oven for 48 hours and weighed to obtain an estimate of the dry weight standing crop biomass in each enclosure. The associated macroinvertebrates in each enclosure were removed from the roots and leaves of the V. americana samples and preserved in 80% EtOH. They were identified in the laboratory and enumerated to obtain qualitative and quantitative data of macroinvertebrates for each enclosure. To determine the snail densities to be used in the experiment, we averaged previous population estimates of snails observed in V. americana (described in section IIA). Three replicate enclosures were set up with 50 snails (>25mm) in each to represent overall mean population density in V. americana, since mean population on a square meter basis represents about 100 snails (range 67-533 snails/m^2), three replicates of 100 (x2 overall mean population), and three replicates of 200 snails (x4 overall mean population). To minimize shading and current velocity reduction, all surfaces of the experimental and control cages were brushed once a week to remove accumulated vegetation and periphyton. At the end of the experiment (90 days), we collected all remaining aboveground biomass within each enclosure to obtain final dry weights. At this time, we also assessed macroinvertebrate composition and abundance within each enclosure to determine the impact of M. cornuarietis on their populations.

At biweekly intervals, to determine reproductive dynamics, enclosures were inspected for egg mass production. For each enclosure, egg masses were counted, the number of eggs per mass determined and then egg masses were removed.

At monthly intervals, all snails were hand-picked from each enclosure, and both live and dead snails (empty shells) were counted to determine survivorship. The dead snails, and any unaccounted snails, were replaced with snails collected from outside the enclosure to maintain treatment densities.

RESULTS

After 90 days, experimental results showed that density had no effect on snail mortality during the first two months (Figure 10). However, after three months, a trend was developing that indicates a positive relationship between density and mortality. In the final sample, mortality was 12% higher in the x4 enclosures and 7% higher in the x2 than in the x1 enclosures. Also, the number of mortalities had dramatically increased across all treatments during the third month relative to the previous two months of the study. In contrast, an inverse relationship between fecundity and density was observed (Figure 11). As the numbers of snails per enclosure increased, the number of egg masses produced decreased. Comparing the initial and final weights of V. americana within the enclosures revealed an inverse relationship between snail density and plant biomass (Table 4). The x4 density enclosure showed a mean loss of 60% plant biomass as compared to an increase of 1% in the x1 enclosures. In fact, the controls, which did not contain any ramshorn snails, showed an 22% increase in plant biomass over the three month period (Figure 12). The effects of M. cornuarietis on associated macroinvertebrates was detected only in the x4 density enclosures. As plant biomass decreased in enclosures, macroinvertebrate density also decreased, but the taxonomic composition, primarily gastropods, did not change significantly.

DISCUSSION

The field experiment in which enclosures containing V. americana at different densities shows that stands of V. americana can support a x4 snail density over a period of three months. However, the dramatic decrease in plant biomass in the x4 density enclosures indicates that the snails would have soon eliminated their food supply. This, together with results from a long-term feeding laboratory experiment (section II,C) that shows M. cornuarietis is capable of high consumption, survival, growth and reproductive rates when fed a diet of V. americana, suggests that a uniform density (400 per square meter) of rams-horn snails could denude Landa Lake of all standing crop biomass within a six month period. However, as densities reach this level, the negative intraspecific effects of increasing snail densities could cause populations to crash. For example, the data collected by Horne et al. (1992) in April 1990, suggest that adult snail populations had undergone an apparent crash with dead subadult shells abundant; extensive sampling produced few living specimens. The absence of large snails indicates that food shortage could have caused the population to decline. Decreasing fecundity with increasing densities would result in smaller populations of M. cornuarietis. Predation could also be a factor in maintaining smaller populations. The dramatic increase in mortality during the third month of the experiment was due to an invasion of crayfish into the enclosures. During our third snail count in November, we discovered piles of empty snail shells that were chipped and eaten away around the aperture. This type of shell damage is indicative of crayfish predation (Brown 1991). At present, Landa Lake is a mosaic of high and low snail population densities that vary in relation to macrophyte composition, and flow and depth regime. High flows and depths make it more difficult for M. cornuarietis to access plant food and some macrophytes are less nutritious, therefore habitats with these characteristics have a smaller abundance of snails. With the projected future decrease in the spring system's discharge and depth, snail densities will increase because more areas of Landa Lake will be accessible to M. cornuarietis. Increased snail densities will increase plant biomass loss. As observed in the x4 density enclosures, plant biomass reduction resulted in a reduction in associated macroinvertebrate populations. M. cornuarietis, by significantly cropping vegetation, reduces cover and refuge, thereby increases susceptibility to predation, as well as reducing potential food sources. As a result, endangered or endemic species, such as the fountain darter, could be lost from the ecosystem.

Future research is needed to determine these same effects of M. cornuarietis on stands of Cabomba caroliniana and Ludwigia repens as well as some of the other subdominant macrophytes (Sagittaria platyphylla, Potomogeton pectinatus and a morphological variant of Ludwigia repens). These macrophytes have increased over the past two years as a result of the decrease of large stands of Ludwigia repens. Year-long studies are needed to monitor seasonal fluctuations in mortality (and snail predation), and fecundity. Also, M. cornuarietis growth patterns could be studied during a longer field experiment. More indepth descriptive studies on the flora and fauna of the springs system are much needed; current information is incomplete.

MANAGEMENT SIGNIFICANCE

By varying densities of M. cornuarietis in stands of V. americana, we were able to estimate the population density at which M. cornuarietis could begin to negatively impact populations of native flora and fauna. This knowledge, along with the knowledge obtained from our other studies, will allow us to begin to set up an efficient plan to control populations of rams-horn snails.

C. Conduct laboratory feeding experiments. Objectives were to determine M. cornuarietis consumption, growth, survival and reproductive rates when fed different species of macrophytes.
Rationale: Determination of which macrophytes snails prefer to consume when compared with habitat preferences of endangered species, will identify which vegetation types will first be threatened by rams-horn snails. Data on consumption rates when used in conjunction with field survey information on abundance, distribution and size class, can be used to provide estimates of annual plant biomass consumption by snails. If measurements of standing crop biomass of the aquatic vegetation are available, the percent plant biomasss consumed by snails can be calculated. The consumption data also can be used to make projections of snail impact in the future should populations continue to increase.

METHODS AND MATERIALS

Ludwigia repens, C. caroliniana and V. americana are the three dominant species of macrophytes in Landa Lake and were therefore used as foods for M. cornuarietis in the long-term feeding experiment. The experiment was conducted using plants and snails collected from Landa Lake which were brought to the laboratory and held in 10-gallon glass aquaria containing wellwater from the Edwards Aquifer. All aquaria were aerated and maintained at 21 ± 2 ° C. Equal wet weights, measured to the nearest 0.01g of mature C. caroliniana, L. repens and V. americana were placed separately in 12 aquaria. There were three replicates for each plant type and control (no snails). At Day 0, 60 newly-hatched M. cornuarietis: (shell diamters ranging betweeen 0.24 to0.85mm), were dispersed in each of nine aquaria. Feeding intervals ranged from 14-18 days. At the end of each interval the remaining plant material was harvested and replaced with freshly collected and preweighed 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 and then dried for 24 hours at 45°C and reweighed to the nearest 0.1mg to determine dry mass.

The experiment was terminated after 700 days. Ram-shorn snails had reached reached reproductive maturity in the V. americana treatment in Februrary 1991 (Figure 21) and we collected data on fecundity for about a year before ending the study.

RESULTS

The results from the 700-day feeding experiment revealed marked variation in patterns of consumption, growth, and reproduction of M. cornuarietis when fed different plants.

Consumption

There was a positive relationship between snail size and consumption rate when M . cornuarietis was fed L. repens. Consumption rate gradually increased from the first day and then markedly increased when snails reached about 18 mm in shell diameter (Figure 13).

In contrast, when M. cornuarietis was fed V. americana, consumption rates remained fairly low until snails reached 8mm in shell diameter (Figure 14). Consumption increased rapidly after this point with significant jumps in consumption at 11mm, 20mm and 24mm in shell diameter.

Over the 700 day period, M. cornuarietis feeding on C. caroliniana increased in consumption rate through time. Intervals 11 and 14 have exceptionally high consumption values because M. cornuarietis were fed immature C. caroliniana, which is apparently more palatable than mature C. caroliniana (Figure 15). Consumption rate began to increase at a higher rate after 330 days, when M. cornuarietis had reached 9mm in shell diameter.

Peak consumption rate for the three plant species for the first 380 days was 80% greater for L. repens (10mg/snail) and 75% greater for V. americana (8 mg/snail) than C. caroliniana (2 mg/snail); after this point, the ordering shifted to V. americana (33 mg/snail) being 64% greater and 60% greater for L. repens (30 mg/snail) than C. caroliniana (12 mg/snail) (Figures 13-15). The shift from L. repens to V. americana occurred when M. cornuarietis feeding on V. americana reached about 20mm in shell diameter.

The relative contribution of consumption and clipping to vegetation loss for each of the plant species is presented in Figures 16-18. Clipping represented a significant loss of plant material when M. cornuarietis fed on L. repens. The magnitude of loss due to clipping represented about 50% of the amount plant material consumed. In contrast, loss of vegetation by clipping had a relatively minor impact on V. americana and C. caroliniana.

Growth

Marisa cornuarietis exhibited rapid growth rates on each species of macrophyte during the early stages of the study (Figure 19). However, through days 25 to 75, growth was greater on a diet of L. repens than on V. americana or C. caroliniana. Marisa cornuarietis in the C. caroliniana and V. americana treatments grew at about the same rate until the 65th day when growth rates of M. cornuarietis on a diet of V. americana increased. By day 85, M. cornuarietis fed V. americana had grown 3mm in 20 days. After 700 days, M. cornuarietis on a diet of V. americana were 20% larger than M. cornuarietis feeding upon L. repens and 50% larger than M. cornuarietis feeding upon C. caroliniana.

Survivorship

Initially, 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 20). Numbers of living snails declined steadily through 130 days on diets of C. caroliniana and V. americana with mortality leveling off in subsequent intervals. However, survivorship for snails fed L. repens began to decrease dramatically 300 days into the experiment and continued to decrease until termination of the experiment. At this point, survivorship for M. cornuarietis feeding upon L. repens was 36% lower than M. cornuarietis feeding on either V. americana or C. caroliniana.

Fecundity

Snails feeding on C. caroliniana exhibited a slow growth rate and never reached reproductive maturity during the 700 day experiment. However, M. cornuarietis feeding on V. americana and L. repens reached reproductive maturity and began producing egg masses once they were 16-18mm in diameter (Figure 21 and 22). Fecundity was highest for snails feeding on V. americana. They produced about ten times as many egg masses as M. cornuarietis feeding on L. repens and remained prolific until the experiment was terminated.

DISCUSSION

Marisa cornuarietis exhibited significant variation in patterns of consumption, growth, reproduction 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 (Interim Report 1991-1992). 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 long-term feeding study of snail consumption, growth, survivorship and reproduction provide additional evidence to support this conclusion, and also suggest that stands of V. americana may also be susceptible to impact by M. cornuarietis. Small size classes (0-1cm and 1-2cm) of M. cornuarietis are most successful on L. repens. After 150 days, young M. cornuarietis (<15 millimeters diameter) experienced little mortality when fed L. repens, but suffered nearly 50% mortality on V. americana or C. caroliniana. But just prior to reaching reproductive maturity (20 mm), the mortality of M. cornuarietis feeding on L. repens increased by 50%. After an initial crash of the smallest size class (0-1cm), the larger size classes (1-2,2-3,3-4cm) of M. cornuarietis feeding on V. americana became the most successful. This means that, provided no other source of mortality (e.g. predation) occurs and both macrophytes are accessible, every egg laid among stands of L. repens and/or V. americana should survive to sexual maturity and reproduce. These data indicate that stands of L. repens and V. americana are most susceptible to impact by rams-horn snails because the food quality of these plant species is sufficiently high to allow rapid population growth.

MANAGEMENT SIGNIFICANCE

According to Linam (Texas Parks and Wildlife Report 1992), one of Etheostoma fonticola's preferred habitats is L. repens. This macrophyte is abundant in the upper reaches of the Comal River and presently is not accessible to M. cornuarietis because of prohibitive current velocity. However, if discharge continues to decrease, M. cornuarietis could migrate upstream and reduce much of the presently undisturbed stands of L. repens. Also, it is suspected that the elimination of the entire standing crop of L. repens further downstream by January 1991 was caused by M. cornuarietis.

Through habitat degradation, M. cornuarietis could significantly reduce populations of E. fonticola and other associated fauna.

MANAGEMENT SYNTHESIS

There are three possible ways to control rams-horn snails in the Comal Springs and Landa Lake aquatic ecosystem. They are biological control, use of molluscicides and manual harvest. Of the three, manual harvest would have the least negative impact on the ecosystem.

We propose that divers be used to harvest snails as an effective method to control (but not eliminate) M. cornuarietis population growth. This method would only be effective for adult snails (>20mm). The best time of year to maximize the effectiveness of this method of control would be January through March. At this time, most of the population has reached adulthood. Also, this is the peak in reproductive activity. Rams-horn snails lay gelatinous egg masses containing from 30 to 100 eggs. The egg masses are very conspicuous since they are fairly large (>4cm) and white in color. A further means of suppressing numbers of snails in the net population cohort would be for divers to harvest and destroy these egg masses. We propose that rams-horn snails and their egg masses be harvested from an experimental section (50 x 50 m) of V. americana that contains relatively high densities of snails (100-150 per square meter). Removed snails and egg masses would be enumerated and sized. Snails and egg masses would continue to be removed from the experimental section during the months of February and March. After this period no more snails would be harvested from the experimental sections. Instead, a post-removal monitoring program would be instituted. The monitoring would include documentation of plant recovery patterns and rates of snail recruitment through immigration and reproduction. Snail recruitment would be monitored by implementing a mark-release recapture program in which snails discovered in the experimental section after the mass removal phase of the project would be individually marked (Freilich, 1989). This procedure would be repeated at subsequent bimonthly sampling intervals. This would provide information on rates of immigration, emigration, growth, survivorship, mortality and longevity. This would be used to determine the feasibility of using manual harvest of giant rams-horn snails on a larger scale to reduce thier impact on the ecosystem.

PHASE II

Literature Cited

Blackburn, D., T.M. Taylor, and D.L. Sutton. 1971. Temperature tolerance and necessary stocking rates of Marisa cornuarietis L. for aquatic weed control. **Proceedings from European Weed Control Research Council International: Symposium of Aquatic Weeds** 3:79-85.

Brown, K.M. 1991. Mollusca: Gastropoda. Pages 285-314 in: J.H. Thorpe and A.P. Covich, eds. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, California.

Cox, G.W. 1990. Laboratory Manual of General Ecology. Wm. C. Brown Publishers, Dubuque, Iowa.

Freilich, J.E. 1989. A method for tagging individual benthic macroinvertebrates. **Journal North American Benthological Society** 8:351-354.

Horne, F.R., T.L. Arsuffi and R.W. Neck. 1992. Recent introduction and potential botanical impact of the giant rams-horn snail, Marisa cornuarietis (Pilidae), in the Comal Springs Ecosystem of Central Texas. **Southwestern Naturalist** 37(2):194-214.

Janacek, J.A. 1988. Fishes interactions with aquatic macrophytes with special reference to the upper Mississippi River system. U.S. Fish and Wildlife Service, occasional publication. 57 pp.

Linam, G.W., K.B. Mayes and K.S. Saunders. DRAFT. Habitat preference and population estimate of fountain darters, Etheostoma fonticola, in the Comal River, Texas. Texas Parks and Wildlife Dept., San Marcos, Tx.

Merritt, R.W. and K.W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co.

Neck, R.W. 1984. Occurrence of the striped rams-horn snail, Marisa cornuarietis in central Texas (Ampullariidae). **Nautilus** 98:119-120.

Otto C. and B.S. Svensson. 1981. How do macrophytes growing in or close to water reduce their consumption by aquatic herbivores. **Hydrobiologia** 78:107-112.

Seaman, D.E. and W.A. Porterfield. 1964. Control of aquatic weeds by the snail, Marisa cornuarietis. **Weeds** 12:87-92.

Wetzel, R.G. 1983. Limnology, 2nd Ed. Saunders College Publishing, Philadelphia, Pennsylvania.

TABLE 1. Macroinvertebrate composition, distribution and abundance in various habitats of Comal Springs and Landa Lake. Each value represents results of Ekman dredge (sites 2,4,5,6,7,8) and Hess (sites 1&3) samples taken in May 1990 over eight transects in Landa Lake.

Transect One

Class: Amphipoda

Order: Diptera
- Chironomidae

Order: Coleoptera
- Psephenidae
  - *Psephenus*

Transect Two

Order: Diptera
- Chironomidae

Order: Odonata
- Coenagrionidae
  - *Argia*

Class: Oligochaeta

Class: Gastropoda
- Pleuroceridae
  - *Thiara granifera*
  - *Thiara tuberculata*
  - *Elimia comalensis*
- Planorbidae
  - *Gyraulus parvus*
- Hydrobiidae
  - *Cincinattia comalensis*

Transect Three

Class: Amphipoda

Order: Coleoptera
- Elmidae

Order: Ephemeroptera
- Baetidae
  - *Baetis*
- Tricorythidae
  - *Tricorythodes*

Transect Four

Order: Diptera
- Chironomidae

Class: Oligochaeta

Class: Hirudinea

Transect Five

Order: Diptera
- Chironomidae

Class: Oligochaeta

Class: Amphipoda

Transect Six

Order: Ephemeroptera
- Ephemeridae
  - *Hexagenia*
- Tricorythidae
  - *Tricorythodes*

Class: Gastropoda
Pleuroceridae
Thiara granifera
Thiara tuberculata
Elimia comalensis
Planorbidae
Gyraulus parvus
Helisoma anceps

Class: Gastropoda
Pleuroceridae
Thiara granifera
Thiara tuberculata
Elimia comalensis
Planorbidae
Helisoma anceps

Class: Amphipoda

Class: Gastropoda
Pleuroceridae
Thiara granifera
Thiara tuberculata
Elimia comalensis
Planorbidae
Gyraulus parvus
Helisoma anceps
Hydrobiidae
Cincinattia comalensis
Physidae
Physa virgata

Transect Seven

Order: Diptera
Chironomidae

Class: Amphipoda

Class: Gastropoda

Transect Eight

Order: Diptera
Chironomidae

Order: Coleoptera
Psephenidae
Psephenus

Order: Odonata
Coenagrionidae
Argia

Order: Ephemeroptera
Caenidae
Caenis

TABLE 2. Macroinvertebrate composition, distribution and abundance in various habitats of Comal Springs and Landa Lake. Each value represents results of Ekman dredge (sites 2,4,5,6,7,8) samples taken in June 1991 over six transects in Landa Lake.

Macroinvertebrates	Transects					
Class Insecta	2	4	5	6	7	8
Order: Diptera						
Chironomidae	2	3	0	0	11	6
Order: Trichoptera	0	1	0	0	0	1
Helicopsychidae						
Helicopsyche						
Order: Coleoptera						
Psephenidae						
Psephenus	0	0	0	0	12	0
Elmidae	0	0	1	0	2	0
Order: Odonata						
Coenagrionidae						
Argia	0	0	0	0	1	0
Order: Ephemeroptera						
Ephemeridae						
Hexagenia	0	0	0	5	0	0
Tricorythidae						
Tricorythodes	0	0	0	0	9	23
Class: Oligochaeta	12	5	15	0	0	0
Class: Amphipoda	4	0	11	8	96	42
Class: Gastropoda						
Pleuroceridae						
Thiara granifera	1274	82	92	0	510	31
Thiara tuberculata	5	25	18	0	656	133
Elimia comalensis	28	82	92	0	510	31
Planorbidae						
Gyraulus parvus	0	0	0	0	0	25
Heliosoma anceps	4	7	0	0	0	0
Hydrobiidae						
Pyrogophorus coronatus	0	0	0	0	16	6
Cincinattia comalensis	0	3	11	0	14	51
Physidae						
Physa virgata	0	0	0	0	0	1
Totals:	1329	208	240	13	1837	350

Macrophytes: Transect 1-green filamentous algae; Transect 2-*V.americana*; Transect 3-*Potamogeton pectinatus*, *L. repens*, *Hydrocotyle* and a red alga; Transect 4-*V.americana*; Transect 5-*Sagittaria platyphylla*; Transect 6-*C. caroliniana*; Transect 7-green flamentous algae (*Spirogyra*, *Closterium*) and *Chara*; Transect 8-*C.caroliniana* and *L. repens*.

Table 3. Comparison of the overall maximum, minimum and average density (n=4) of M. cornuarietis across all major macrophyte communities over six sampling intervals. Numbers are in millions of snails per 14 acres.

Season	Maximum	Minimum	Mean
Summer 91	10.1	2.3	6.4
Fall 91	14.6	2.6	7.5
Winter 91	5.8	0	2.6
Spring 92	5.4	.62	3.7
Summer 92	4.6	2.1	3.6
Fall 92	6.5	.62	3.1

Table 4: Each number represents grams of Vallisneria americana dry weight per enclosure area ($0.45m^2$). Net shows the amount of plant biomass lost or gained in relation to treatment density of snails.

Enclosures	Initial	Final	Net
x4 densities			
1.	404	108	-75
2.	401	344	-15*
3.	824	106	-88
mean	543	186	-59
x2 densities			
1.	206	145	-30
2.	653	481	-26
3.	273	104	-64
mean	377	243	40
x1 densities			
1.	481	476	-1
2.	204	220	+9
3.	273	252	-6
mean	319	316	0.67
controls			
1.	280	322	+13
2.	190	292	+35
3.	660	803	+18
mean	376	472	22

*could not maintain 200 snails

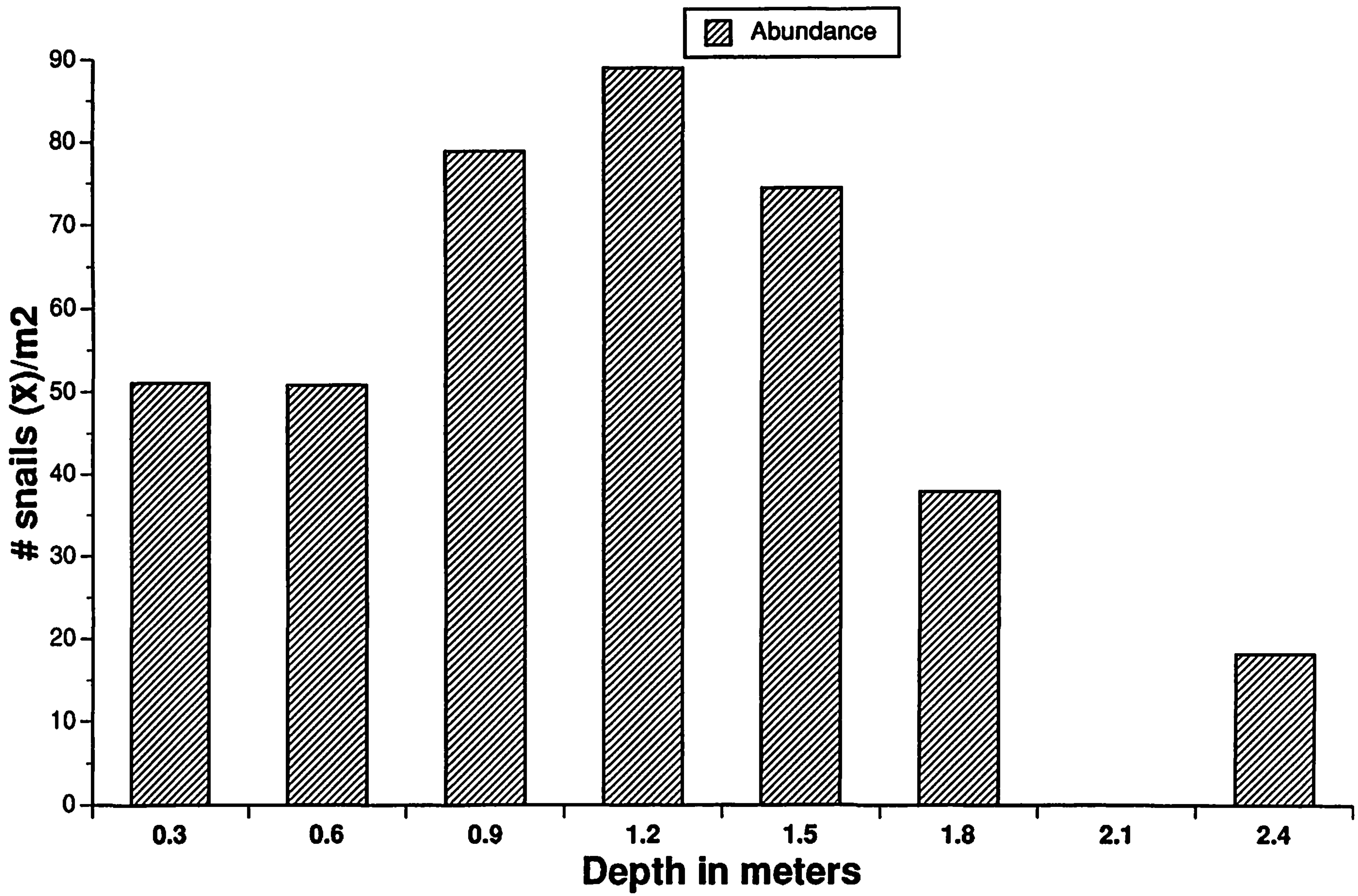

Figure 3. Relationship between mean abundance of M. cornuarietis and water depth.

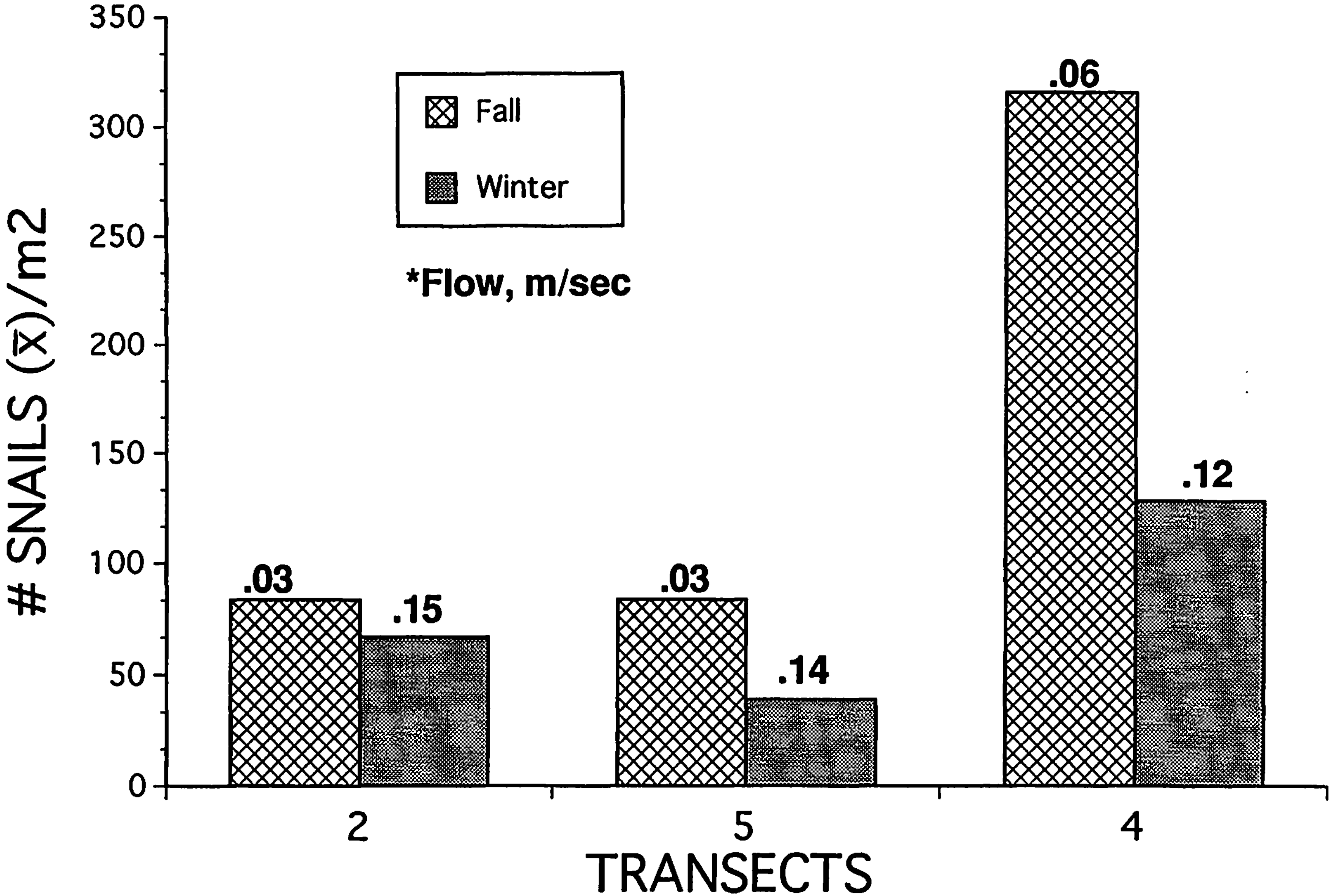

Figure 4. Relationship between abundance of M. cornuarietis and current velocity at different transects between Fall 91 and Winter 91. Current velocity in meters per second is indicated by the number over each bar.

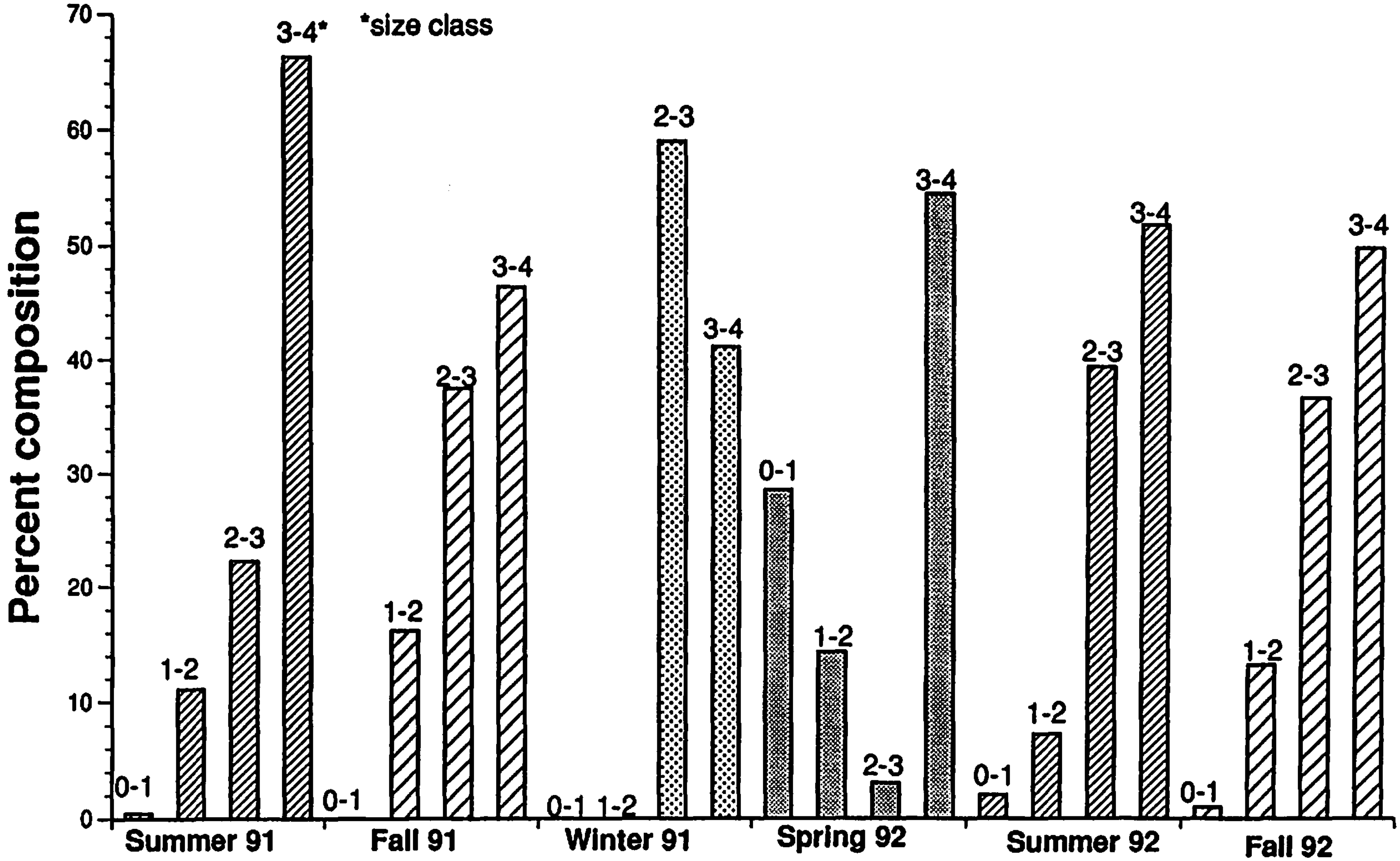

Figure 5. Size class distribution of M. cornuarietis at each sampling interval. Size class, in centimeters, is indicated by the numbers over each bar.

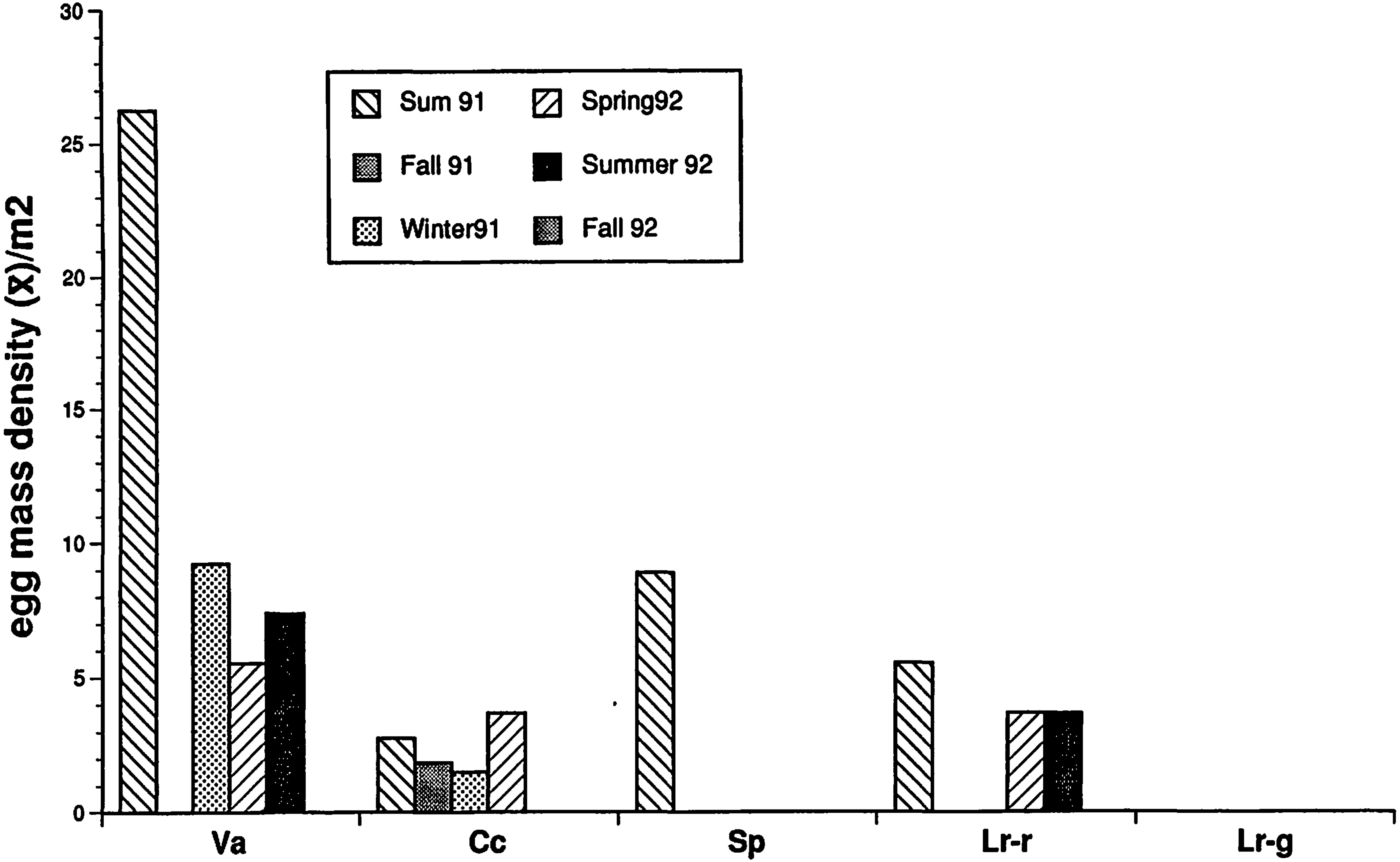

Figure 6. Mean density of egg masses per square meter in each major macrophyte community over the six sampling intervals. Va=V. americana, Cc=C. carolinana, Sp=S. platyphylla, Lr-r=L. repens (red), and Lr-g=L. repens (green)

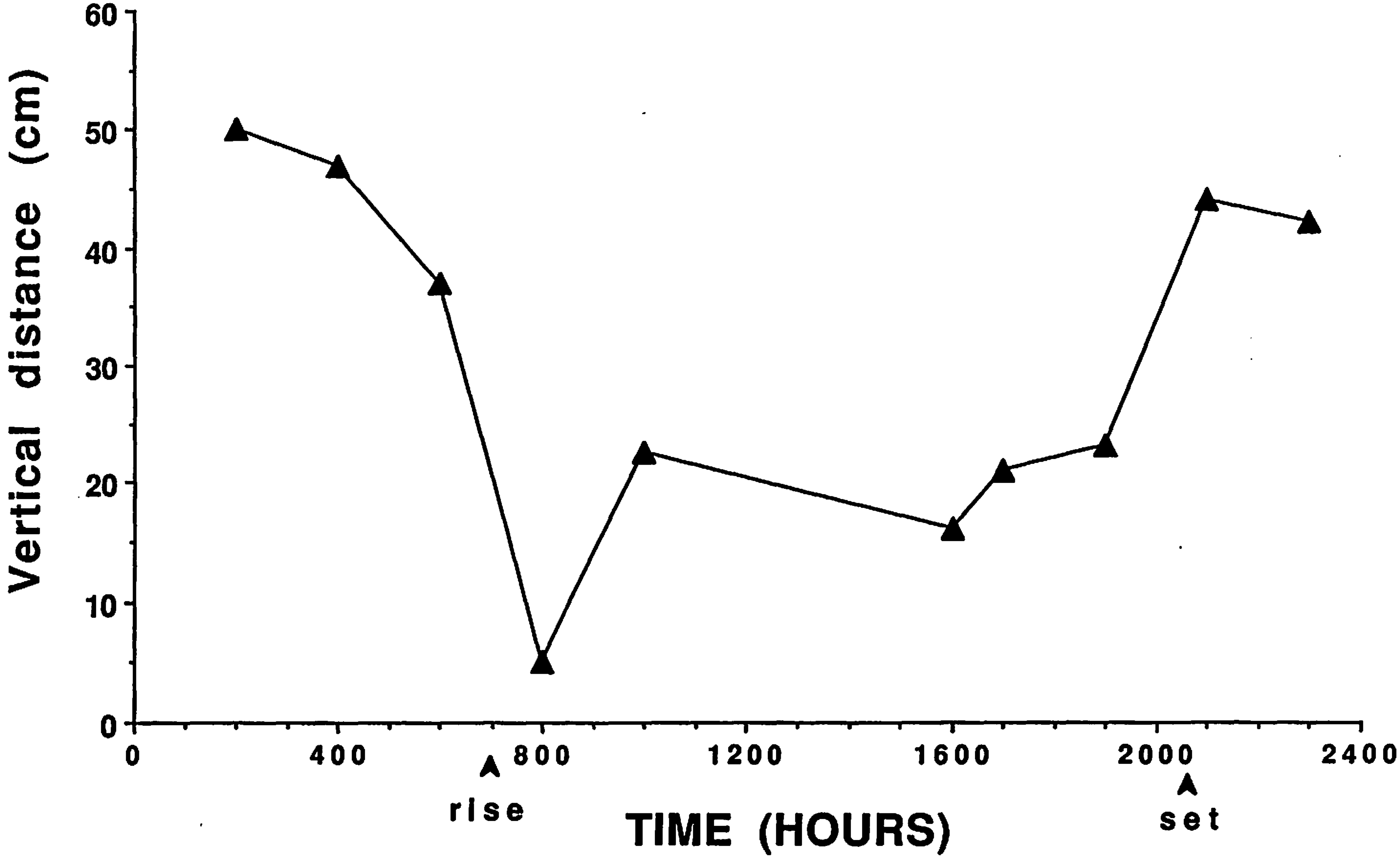

Figure 7. Vertical distance traveled by M. cornuarietis over a twenty-four hour period. Sunrise and sunset occurred at 0700 hours and 2030 hours respectively.

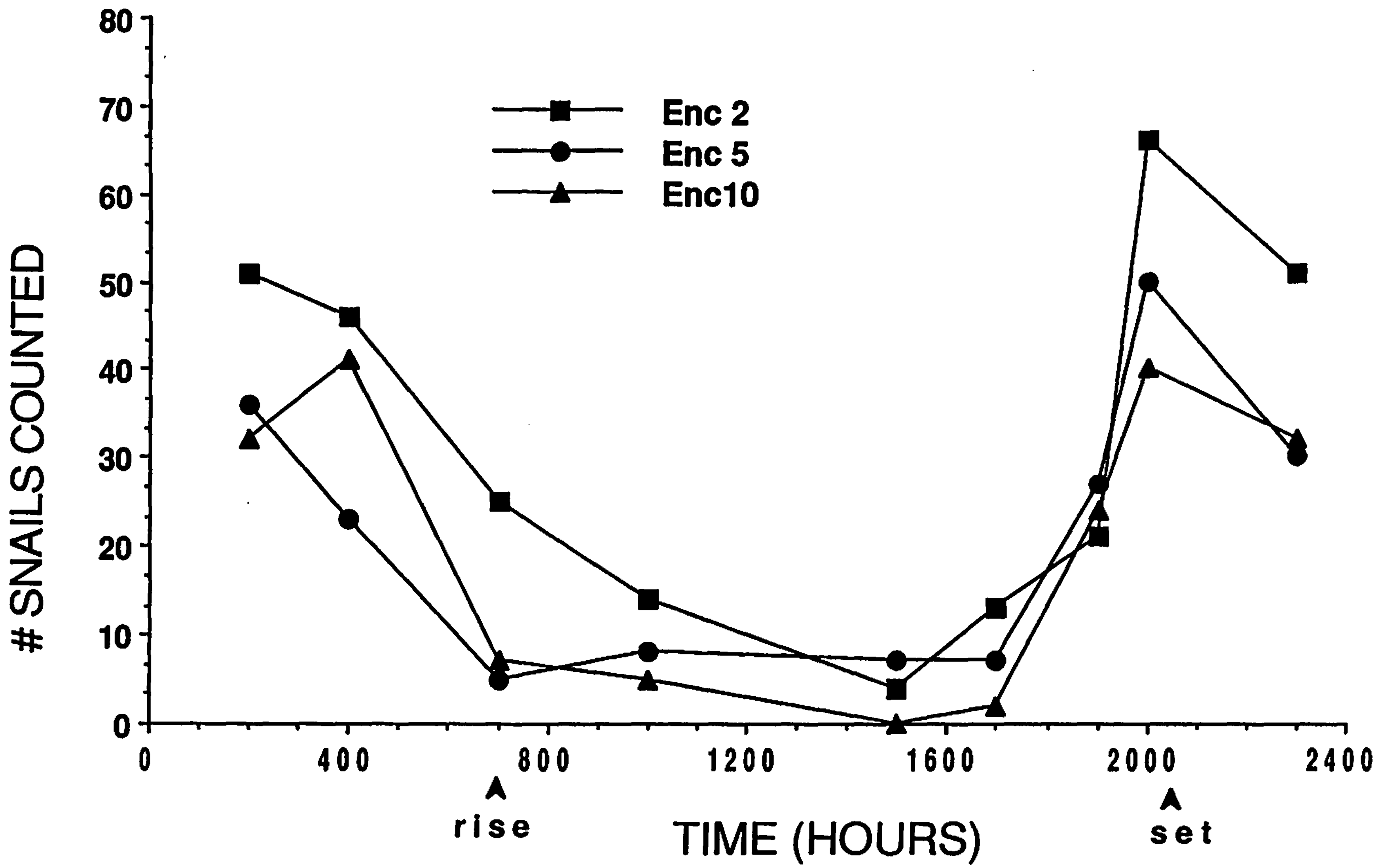

Figure 8. Compares the numbers of M. cornuarietis counted in three enclosures (100 snails per 0.45 square meters) over a twenty-four hour period. Sunrise and sunset occurred at 0700 hours and 2030 hour respectively.

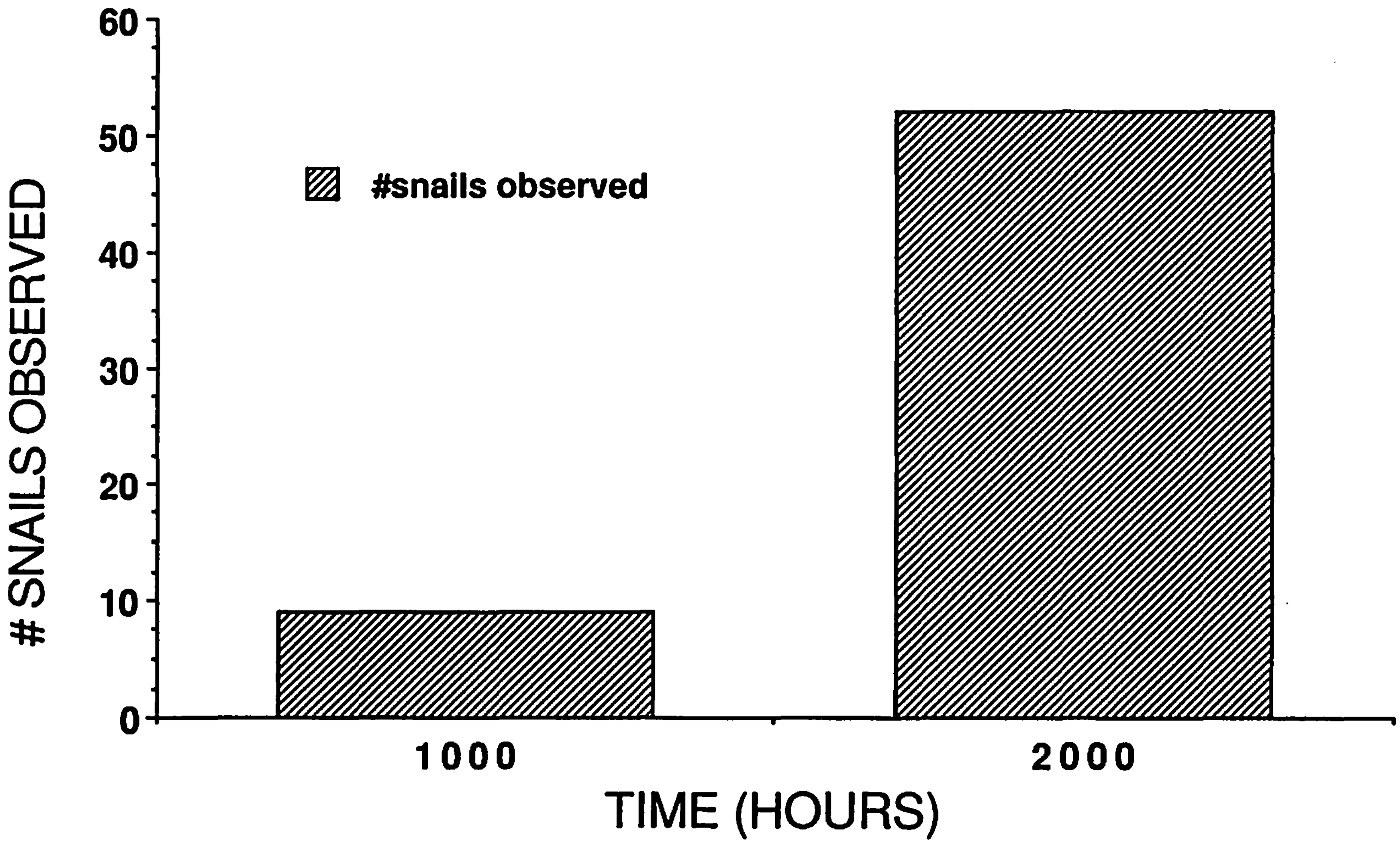

Figure 9. Contrasts numbers of M. cornuarietis counted in enclosure 5 (x2 density) at ten o'clock a.m. and eight o'clock p.m.

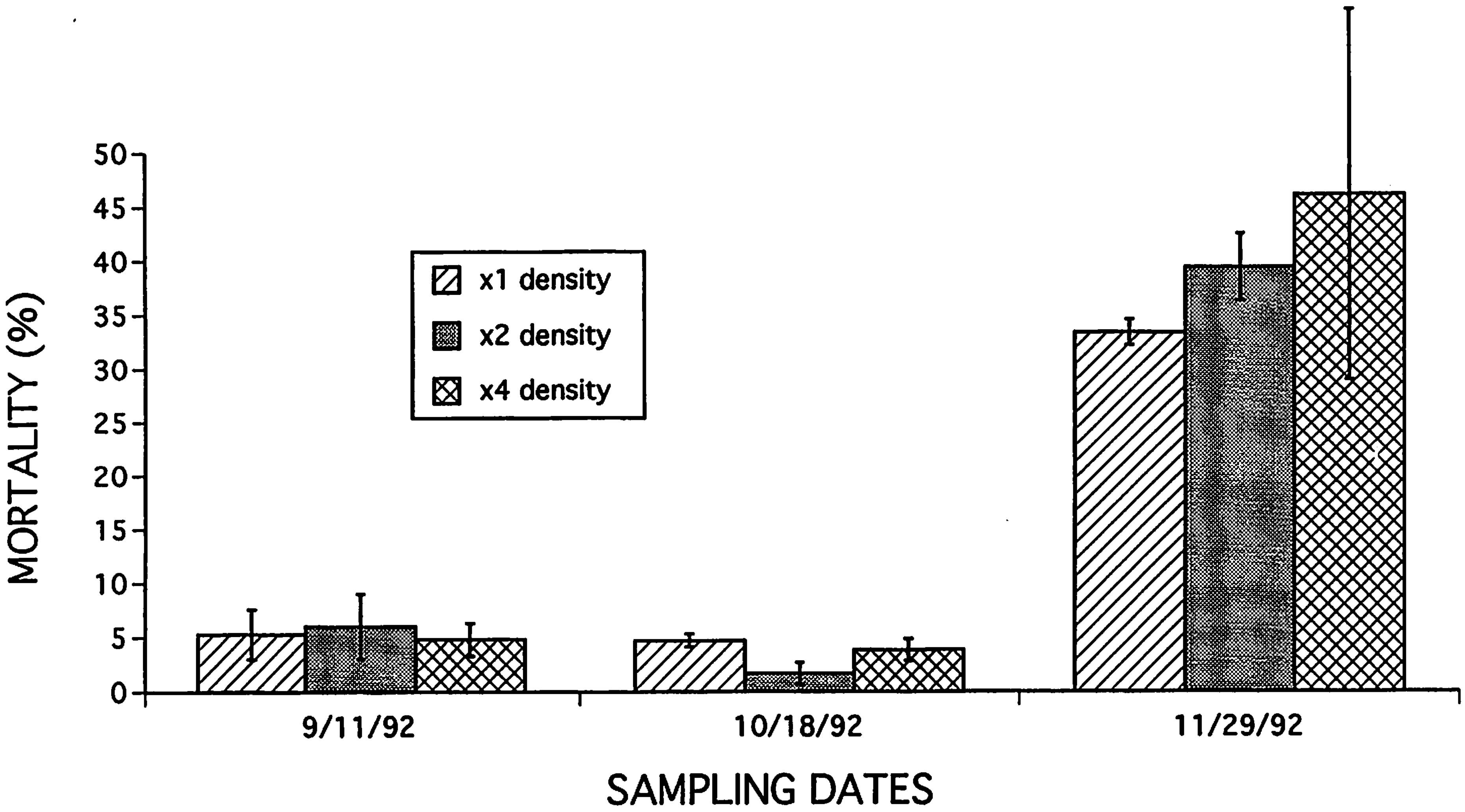

Figure 10. Snail mortality at different snail densities in experimental enclosures over a three month period.

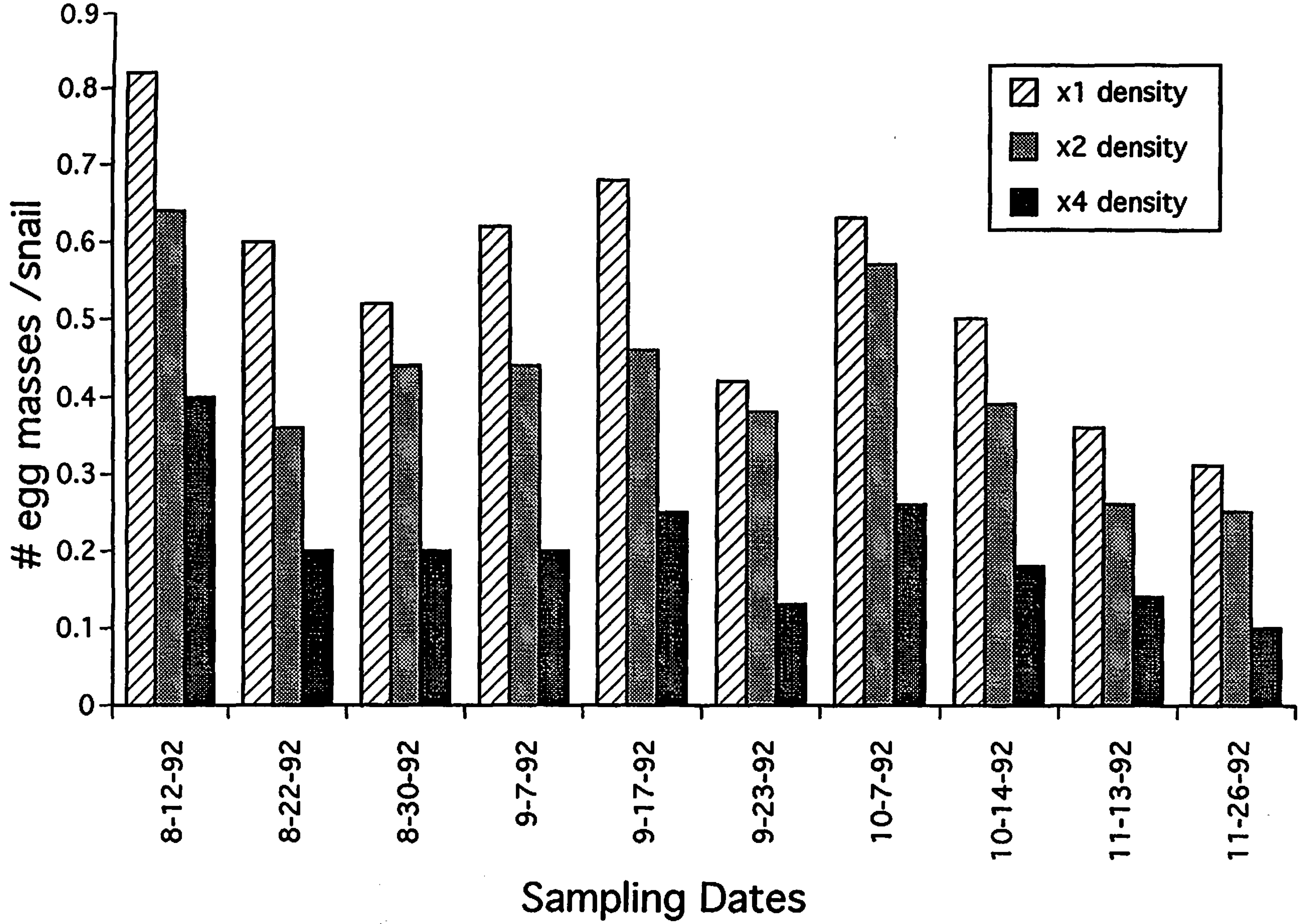

Figure 11. Egg mass production by M. cornuarietis in relation to snail density in experimental enclosures containing V. americana.

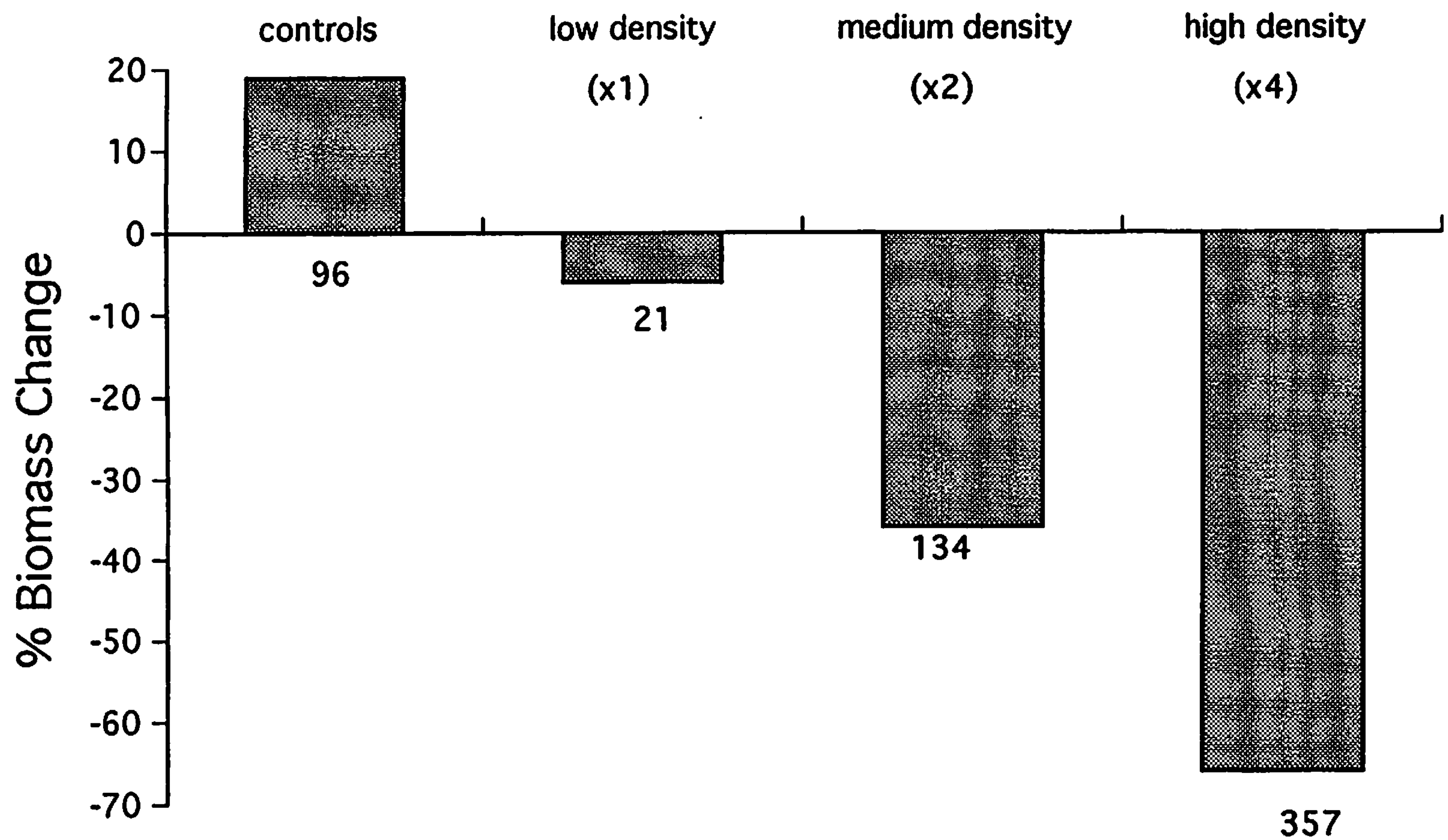

Figure 12. Relative and quantitative changes in biomass of V. americana in enclosures containing different densities of M. cornuarietis. Numbers over bars represent loss in dry weight (grams per 0.45 square meters).

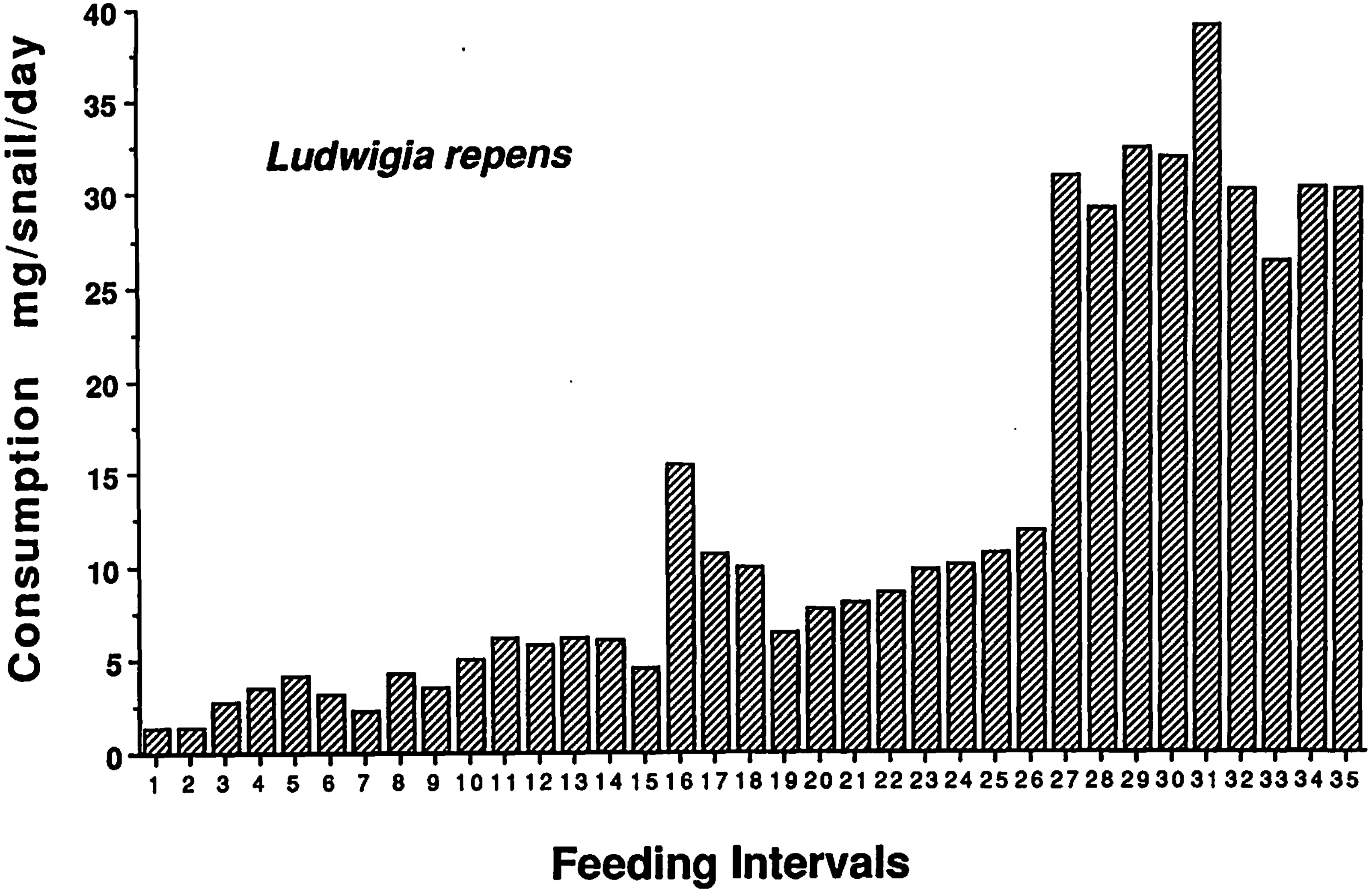

Figure 13. Mean consumption values for M. cornuarietis during each feeding interval when fed a diet of L. repens.

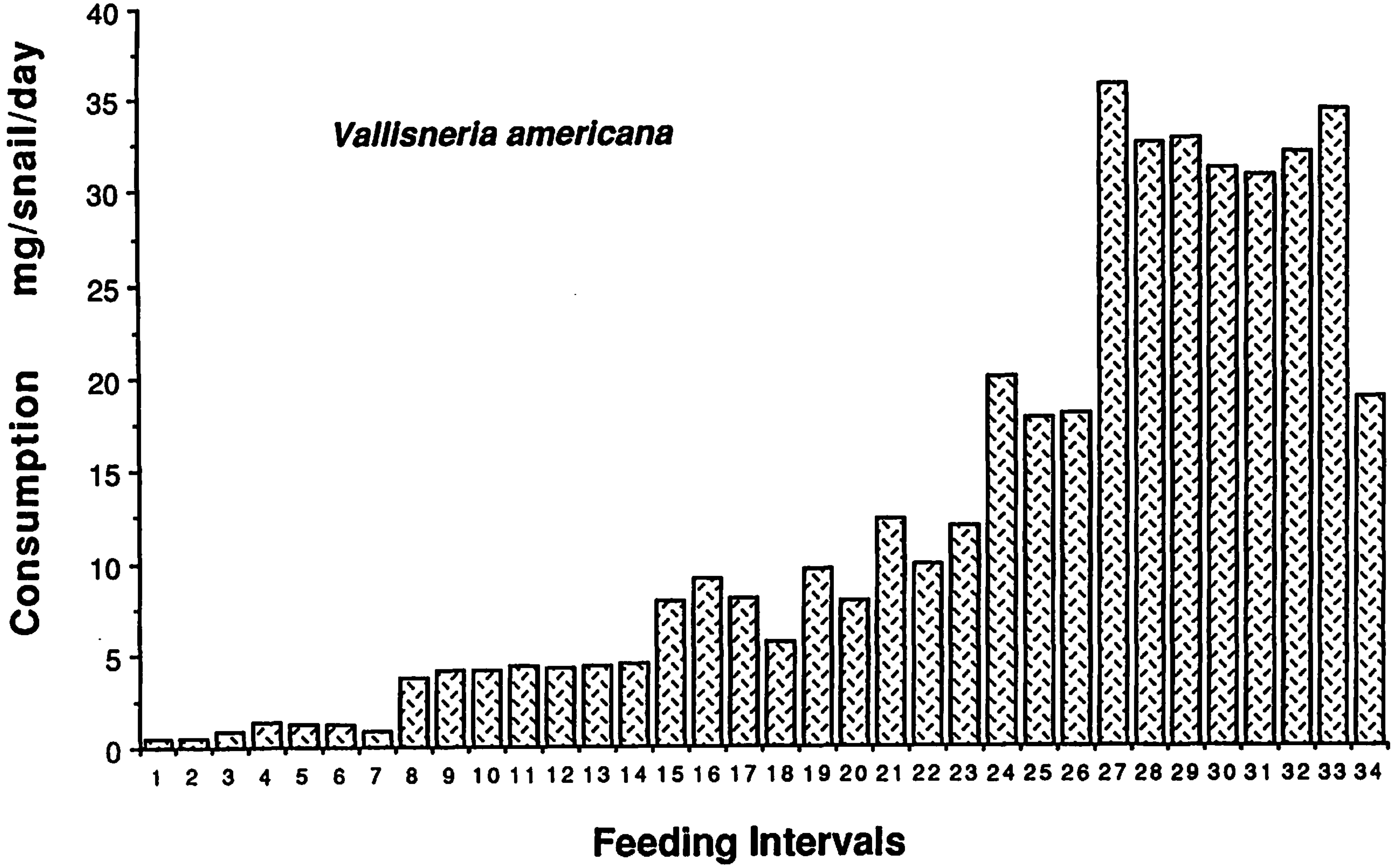

Figure 14. Mean consumption values for M. cornuarietis during each feeding interval when fed a diet of V. americana.

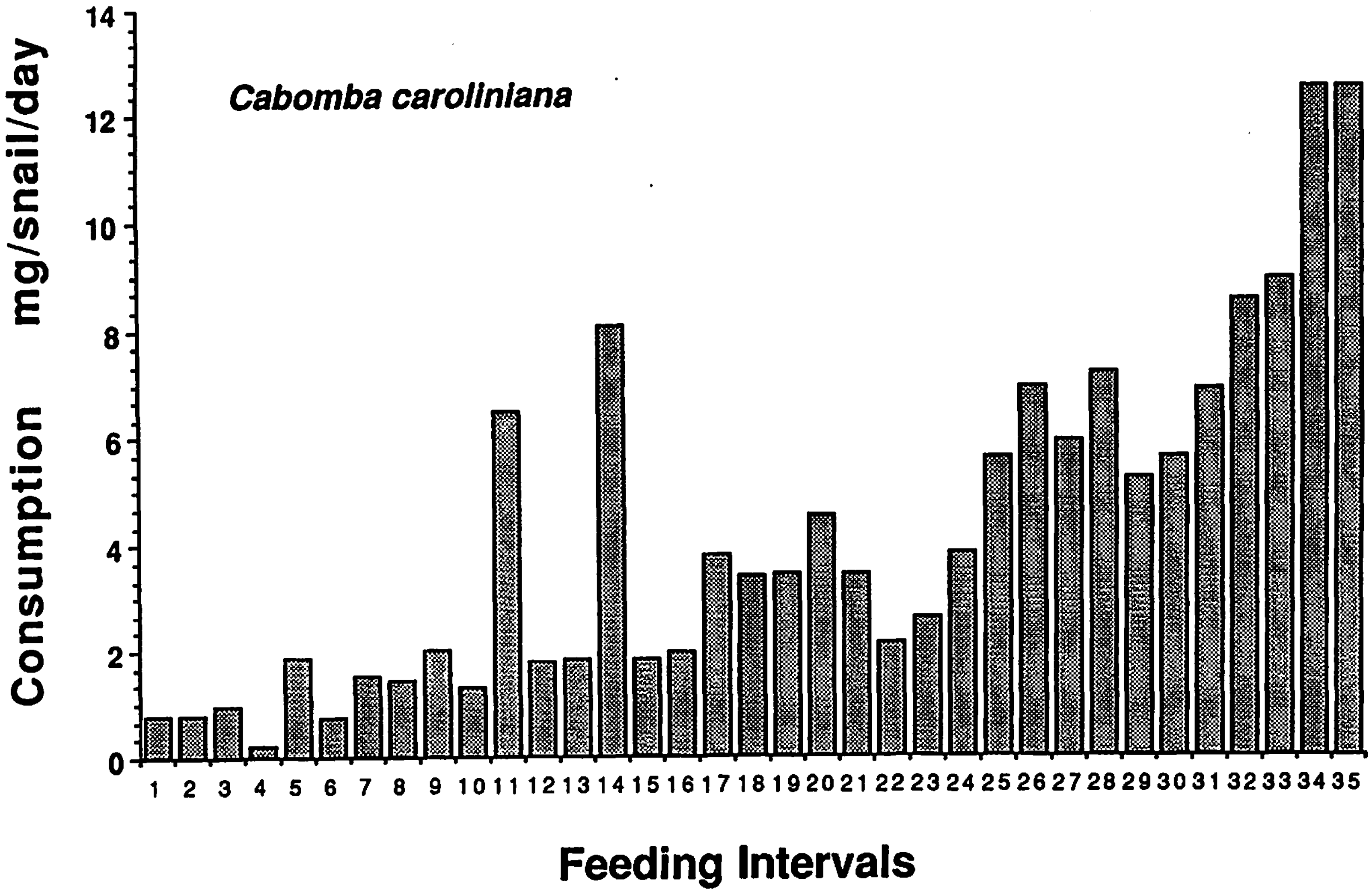

Figure 15. Mean consumption values for M. cornuarietis during each feeding interval when fed a diet of C. caroliniana.

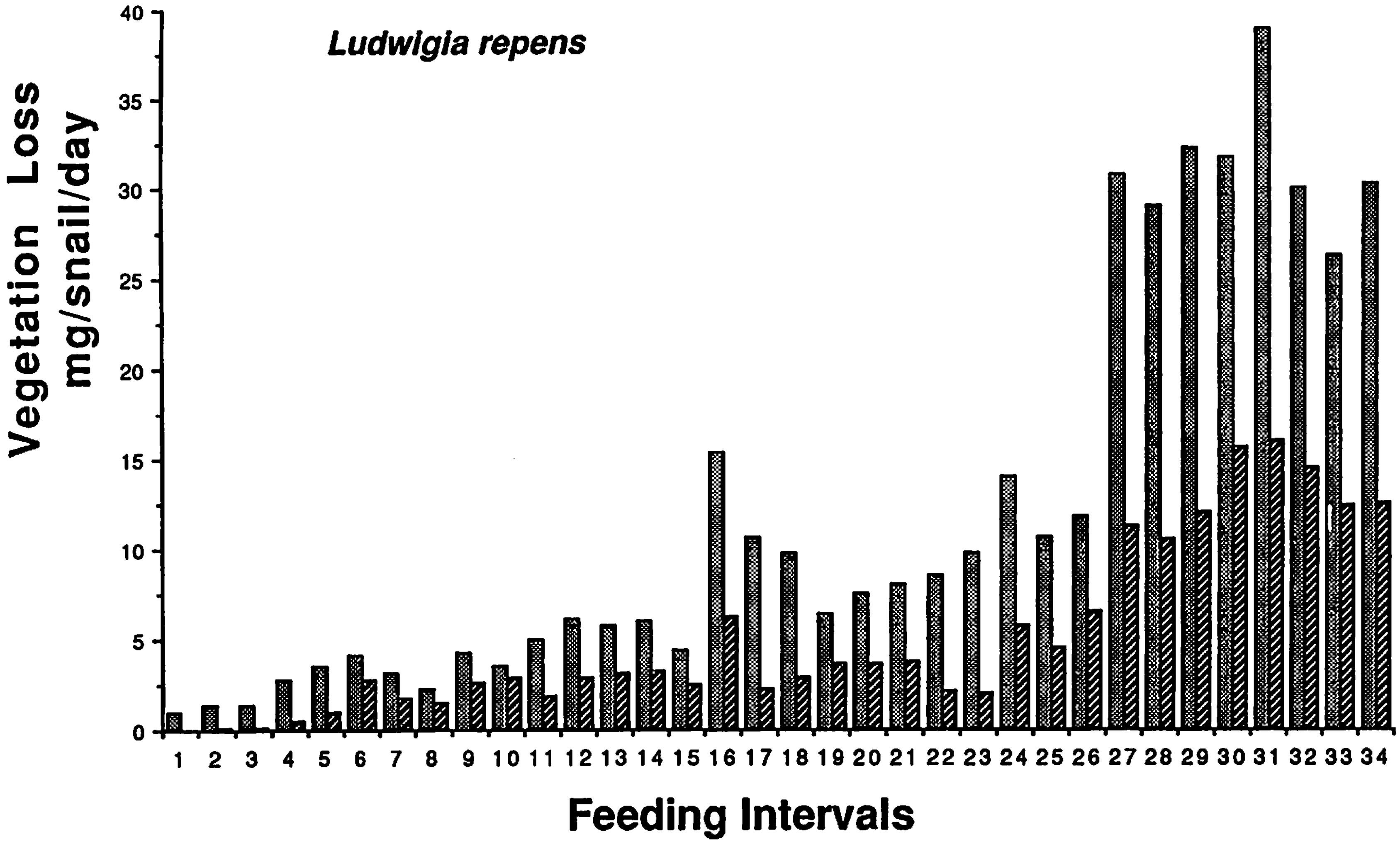

Figure 16. Comparison of mean consumptive versus clipped vegetation losses by M. cornuarietis for each feeding interval during growth when fed a diet of L. repens.

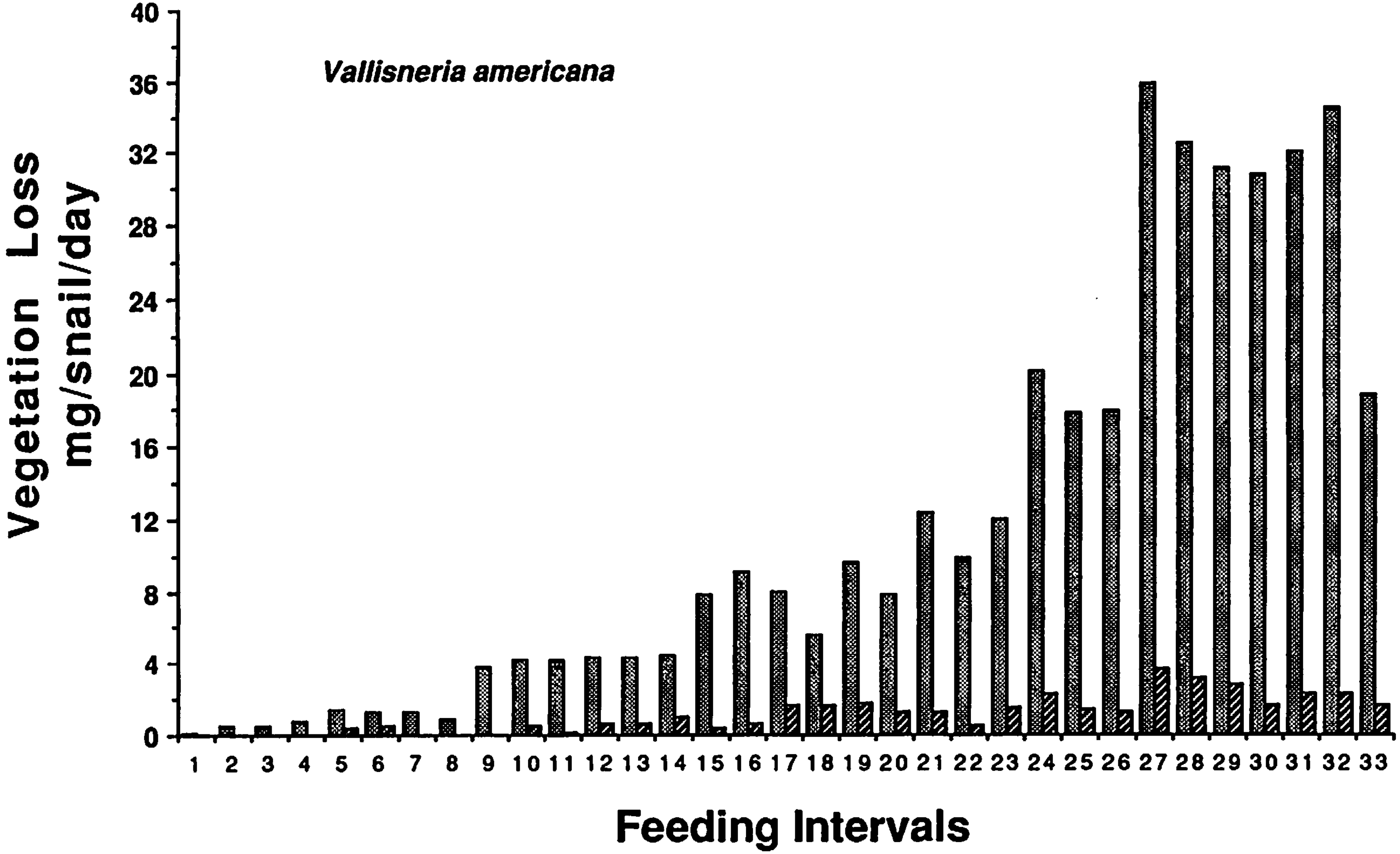

Figure 17. Comparison of mean consumptive versus clipped vegetation losses by M. cornuarietis for each feeding interval during growth when fed a diet of V. americana.

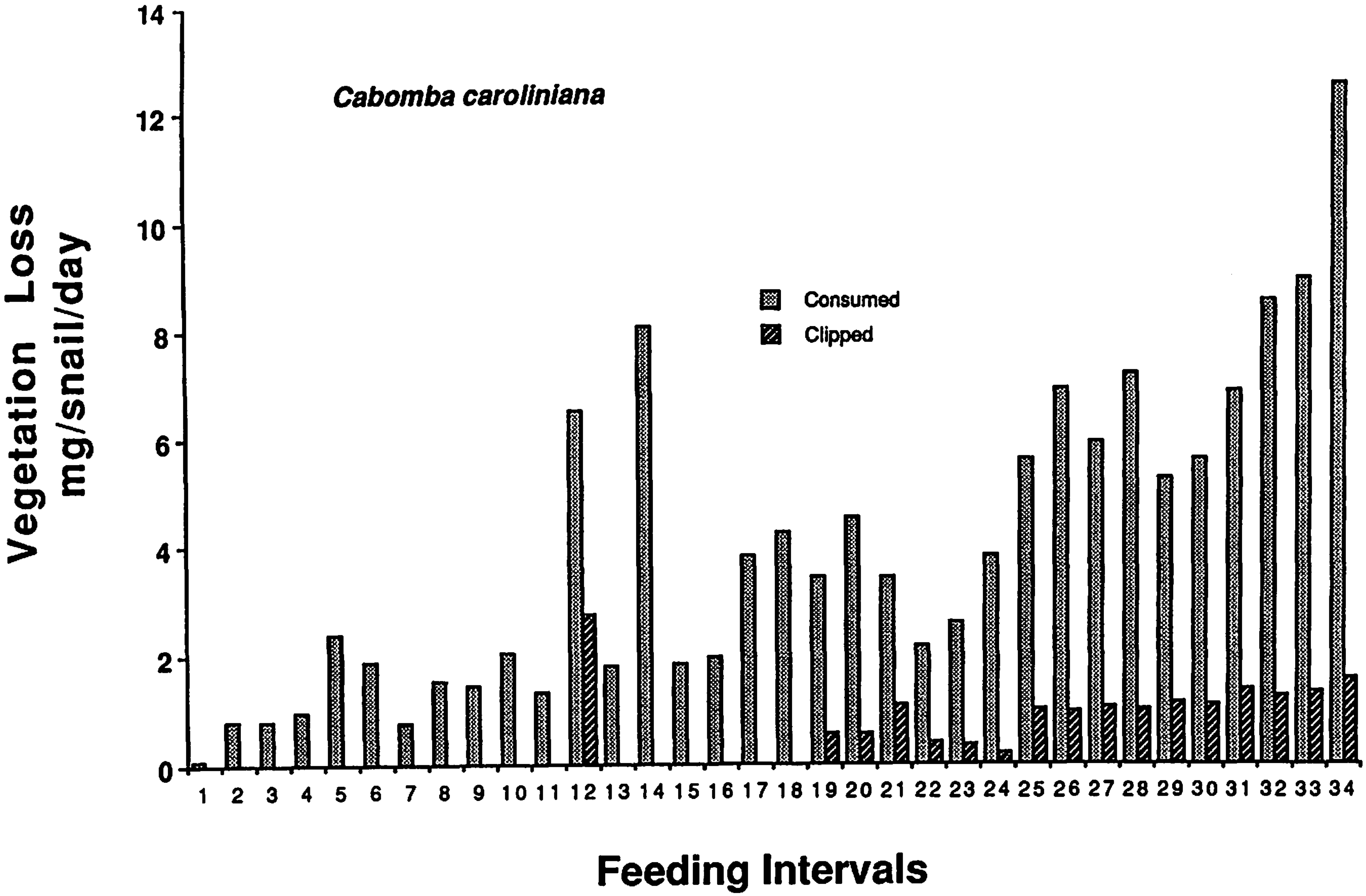

Figure 18. Comparison of mean consumptive versus clipped vegetation losses by M. cornuarietis for each feeding interval during growth when fed a diet of C. caroliniana.

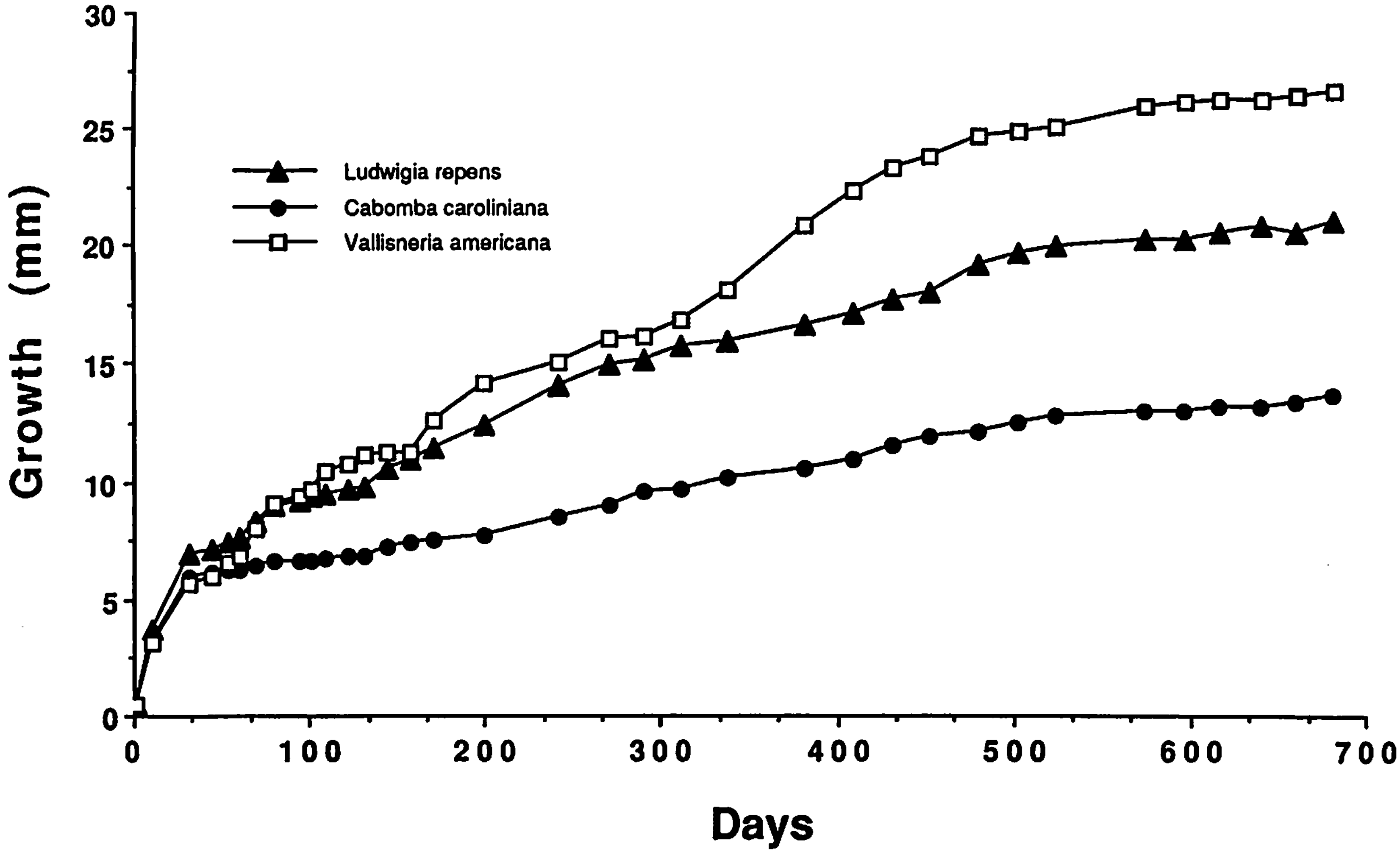

Figure 19. Mean growth over time of M. cornuarietis when fed diets of different species of aquatic macrophytes.

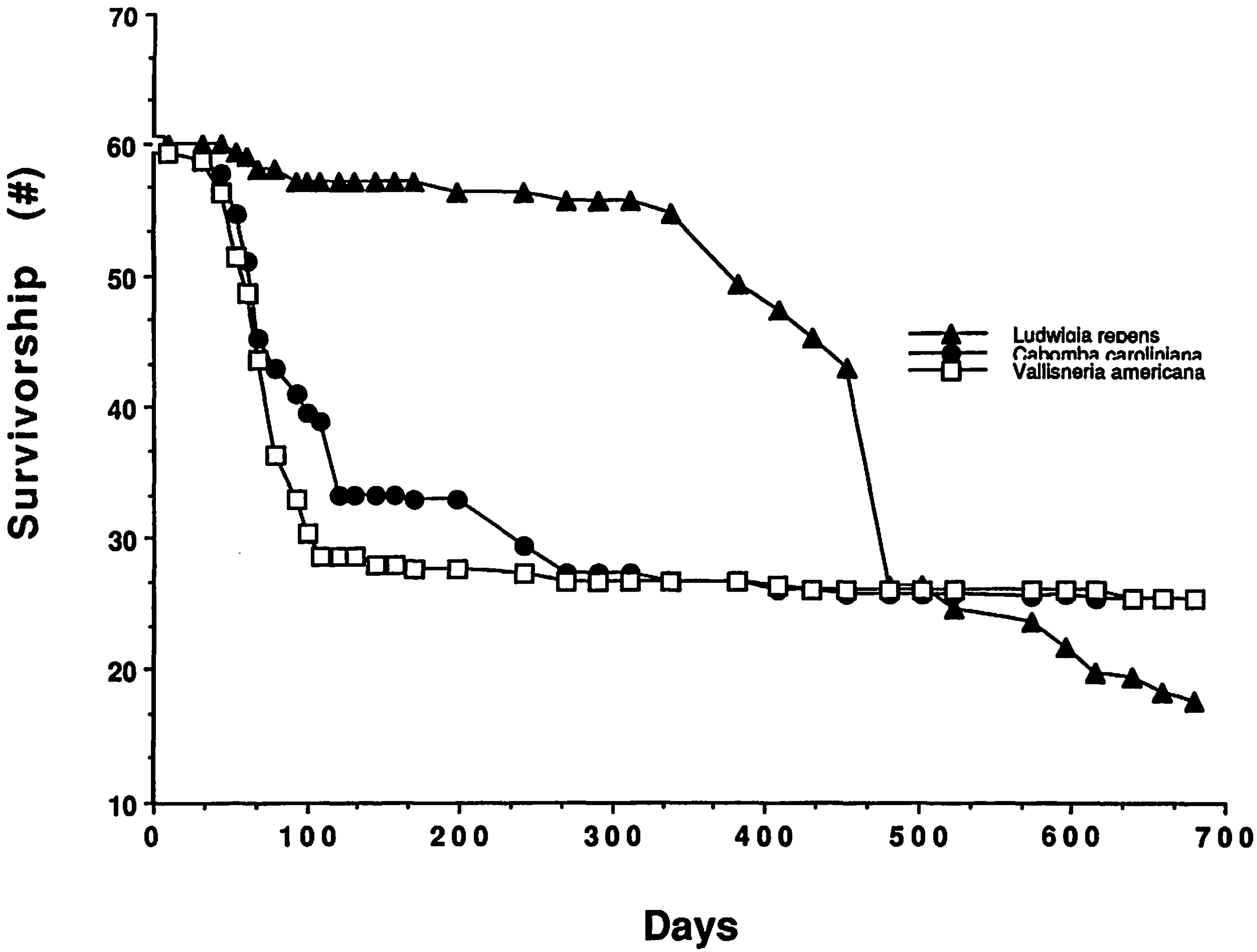

Figure 20. Mean survivorship of M. cornuarietis when fed diets of different species of aquatic macrophytes.

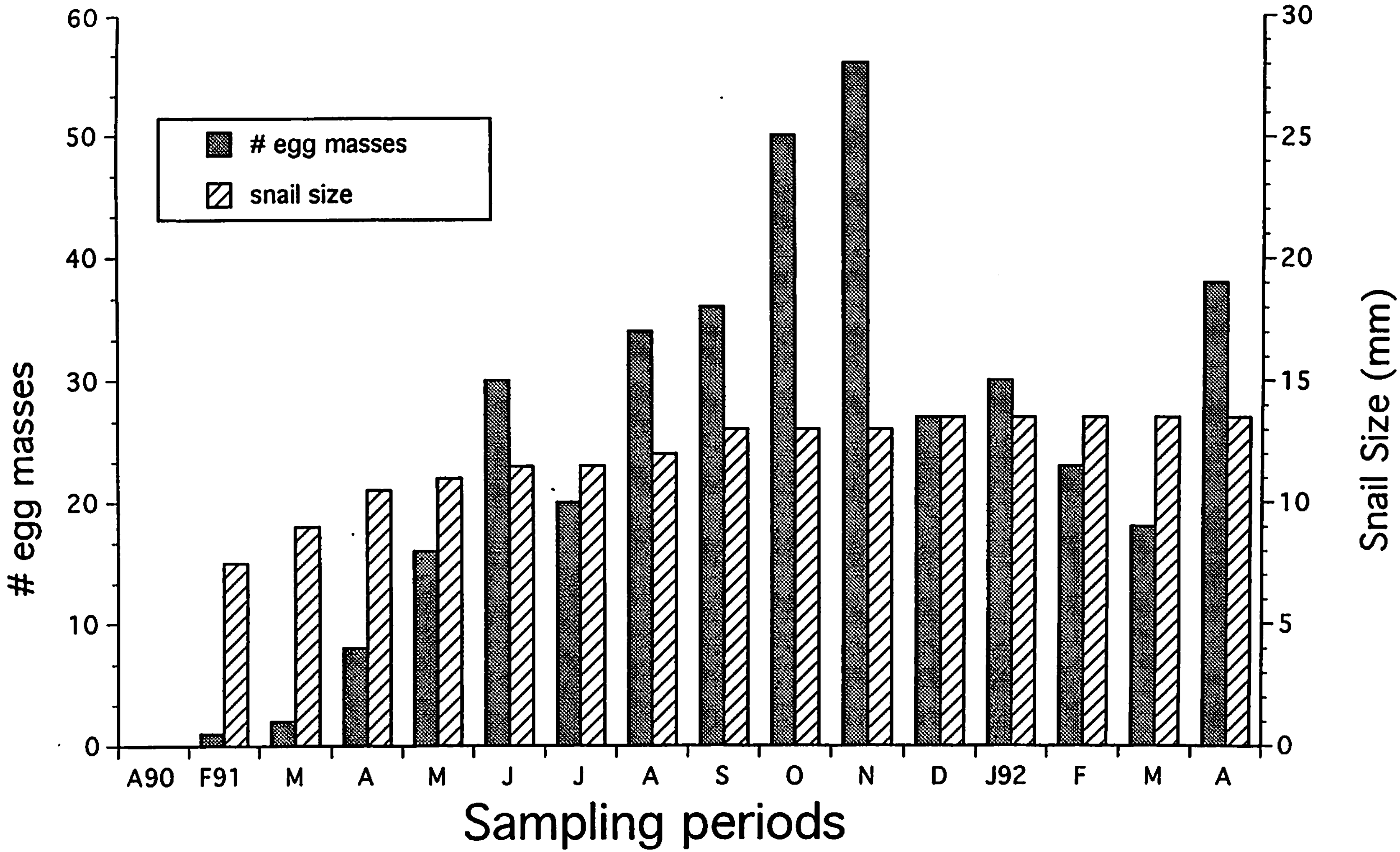

Figure 21. Egg production and size of M. cornuarietis when fed V. americana.

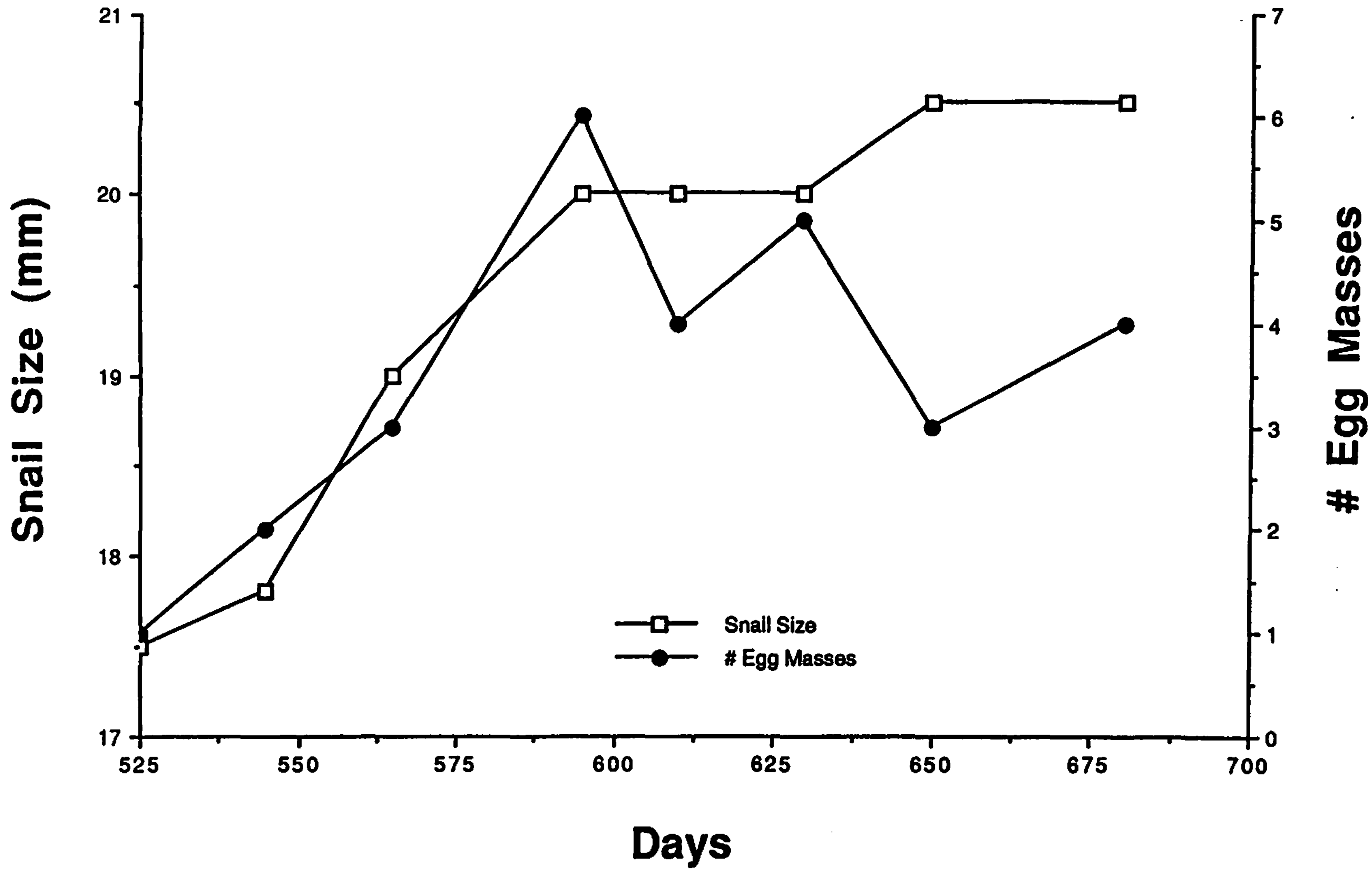

Figure 22. Egg production and snail size of M. cornuarietis when fed L. repens.

PHASE IV

Professional and educational results of funded research on Comal Springs

PUBLICATIONS

Horne, F.R., T.L. Arsuffi and R.W. Neck. 1992. Recent introduction and potential botanical impact of the giant rams-horn snail, Marisa cornuarietis, in the Comal Springs ecosystem of central Texas. Southwestern Naturalist 37:194-196.

Bowles, D.E. and T.L. Arsuffi. In Press. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: a consideration of their importance, threats to their existence and efforts for their conservation. Aquatic Conservation.

INVITED SYMPOSIA PRESENTATIONS AT PROFESSIONAL SCIENTIFIC SOCIETIES RESULTING FROM FUNDED RESEARCH ON COMAL SPRINGS:

Arsuffi, T.L., M.D. Skalberg and M.C. Badough. 1992. Habitat and community modification in Comal and San Marcos Springs by an introduced herbivorous snail: Assessing impacts on control measures. Special Symposium: Research, conservation and management of spring systems in Texas. Annual Meeting. Texas Academy of Science. Wichita Falls, TX.

Arsuffi, T.L., E.W. Chilton II, M.D. Skalberg and M.C. Badough. 1992. Habitat and community modification by introduced aquatic herbivores: II. Impacts on biodiversity and ecosystem dynamics by giant rams-horn snails, (Marisa cornuarietis). Special Symposium: The biology and impact of exotic species in North American freshwaters. Annual Meeting. North American Benthological Society. Louisville, KY (May).

Chilton II, E.W. and T.L. Arsuffi. 1992. Habitat and community modification by introduced aquatic herbivores: I. Impacts on biodiversity and ecosystem dynamics by grass carp (Cteropharyngodon idella). Special Symposium: The biology and impact of exotic species in North American freshwaters. Annual Meeting. North American Benthological Society. Louisville, KY (May).

Arsuffi, T.L. and G. Longley. 1992. Endangered spring ecosystems associated with the Edwards Aquifer region of central Texas: Threats and conservation efforts. Special Symposium: Science policy connections in the conservation of freshwater ecosystems. Annual Meeting. North American Benthological Society. Louisville, KY (May).

Bowles, D.E. and T.L. Arsuffi. 1992. Unique and endangered aquatic insect habitats in Texas with emphasis on the Edward's Plateau. Special symposium: Endangered aquatic habitats. Annual Meeting. Entomological Society of America. Baltimore, MD (December).

Arsuffi, T.L., D.E. Bowles and C.B. Barr. 1993. Ecological structure and biodiversity of benthic communities associated with Karst topographic springs of the Edwards Aquifer region of central Texas. Special Symposium: Aquatic biodiversity of springs. Annual Meeting. North American Benthological Society. Calgary, Alberta, Canada (May).

PRESENTATIONS TO PROFESSIONAL SCIENTIFIC SOCIETIES RESULTING FROM PAST FUNDED RESEARCH ON COMAL SPRINGS (15).

Skalberg, M.D. and T.L. Arsuffi. 1991. Feeding and performance of the giant rams-horn snail, Marisa cornuarietis (Pilidae) on different aquatic macrophytes. Annual Meeting. Texas Academy of Science. Nacodoches, TX (March).

Skalberg, M.D. and T.L. Arsuffi. 1991. Feeding and performance of the giant rams-horn snail, Marisa cornuarietis (Pilidae) on different aquatic macrophytes. Annual Meeting. North American Benthological Society. Santa Fe, New Mexico (May).

Skalberg, M.D. and T.L. Arsuffi. 1991. Feeding and performance of the giant rams-horn snail, Marisa cornuarietis (Pilidae) on different aquatic macrophytes. Annual Meeting. Ecological Society of America. San Antonio, TX (August).

Owen, J.M., F.M. Oxley, I.A. Malekpourani, K.B. Mayes and T.L. Arsuffi. 1991. Detritivory by the introduced giant rams-horn snail, Marisa cornuarietis, in spring systems of central Texas. Annual Meeting. Texas Academy of Science. Nacogdoches, TX (March).

Owen, J.M., F.M. Oxley, I.A. Malekpourani, K.B. Mayes and T.L. Arsuffi. 1991. Detritivory by the introduced giant rams-horn snail, Marisa cornuarietis, in spring systems of central Texas. Annual Meeting. North American Benthological Society. Santa Fe, New Mexico (May).

Owen, J.M., F.M. Oxley, I.A. Malekpourani, K.B. Mayes and T.L. Arsuffi. 1991. Detritivory by the introduced giant rams-horn snail, Marisa cornuarietis, in spring systems of central Texas. Annual Meeting. Ecological Society of America. San Antonio, TX (August).

Skalberg, M.D., M.C. Badough and T.L. Arsuffi. 1992. Biological impact of the giant rams-horn snail, Marisa cornuarietis on the plant communities of Comal Springs ecosystem of central Texas. Annual Meeting. Texas Academy of Science. Wichita Falls, TX (March).

Skalberg, M.D., M.C. Badough and T.L. Arsuffi. 1992. Biological impact of the giant rams-horn snail, Marisa cornuarietis on the plant communities of Comal Springs ecosystem of central Texas. Annual Meeting. Southwestern Association of Naturalists. Junction, TX (April).

Skalberg, M.D., M.C. Badough and T.L. Arsuffi. 1992. Biological impact of the giant rams-horn snail, Marisa cornuarietis on the plant communities of Comal Springs ecosystem of central Texas. Annual Meeting. North American Benthological Society. Louisville, KY (May).

Badough, M.C., M.D. Skalberg and T.L. Arsuffi. 1992. Distribution, abundance and diel vertical migration habits of the exotic giant rams-horn snail, Marisa cornuarietis, in the Comal Springs/Landa Lake ecosystem of central Texas. Annual Meeting. Texas Academy of Science. Wichita Falls, TX (March).

Badough, M.C., M.D. Skalberg and T.L. Arsuffi. 1992. Distribution, abundance and diel vertical migration habits of the exotic giant rams-horn snail, Marisa cornuarietis, in the Comal Springs/Landa Lake ecosystem of central Texas. Annual Meeting. Southwestern Association of Naturalists. Junction, TX (April).

Badough, M.C., M.D. Skalberg and T.L. Arsuffi. 1992. Distribution, abundance and diel vertical migration habits of the exotic giant rams-horn snail, Marisa cornuarietis, in the Comal Springs/Landa Lake ecosystem of central Texas. Annual Meeting. North American Benthological Society. Louisville, KY (May).

Konu, Ozlen, D. Moorhead and T.L. Arsuffi. 1992. An energy allocation model for Marisa cornuarietis. Annual Meeting. Southwestern Association of Naturalists. Junction, TX (April).

Badough, M.C., M.D. Howard and T.L. Arsuffi. 1993. Distribution, abundance and predator avoidance behavior of the exotic rams-horn snail (Marisa cornuarietis) in the Comal Springs ecosystem of central Texas. Annual Meeting. Texas Academy of Science. Denton, TX (March); Annual Meeting. North American Benthological Society. Calgary, Alberta, Canada (May).

Howard, M.D., M.C. Badough and T.L. Arsuffi. 1993. Direct and indirect effects of herbivory by the exotic giant rams-horn snail (Marisa cornuarietis) on eelgrass (Vallisneria americana) communities in the Comal Springs ecosystem of central Texas. Annual Meeting. Texas Academy of Science. Denton, TX (March); Annual Meeting. North American Benthological Society. Calgary, Alberta, Canada (May).

Owen, J.M. and T.L. Arsuffi. 1993. Regional patterns in the functional feeding group composition of macroinvertebrates in karst topographic streams of the Edwards Plateau. Annual Meeting. Texas Academy of Science. Denton, TX (March); Annual Meeting. North American Benthological Society. Calgary, Alberta, Canada (May).

INVITED SEMINARS AND PUBLIC LECTURES RESULTING FROM PAST FUNDED RESEARCH ON COMAL SPRINGS.

Arsuffi, T.L. 1990. Biology of the Comal River: a focus on endangered species. Invited presentation. Sigma Xi - The Scientific Research Society of North America. Central Texas Chapter. Temple, TX (September).

Arsuffi, T.L. 1990. Endemic invertebrates of the Comal Springs. Presentation to New Braunfels Rotary Club. New Braunfels, TX (July).

Arsuffi, T.L. 1990. The role of springflow in the maintenance of biodiversity in the Comal and San Marcos River ecosystems. Expert testimony. Special Texas Legislative Hearings on the Edwards Aquifer. Southwest Texas State University. San Marcos, TX (September).

Arsuffi, T.L. 1991. The aquatic biology of Comal Springs. Rotary Club International. New Braunfels, TX (March).

Arsuffi, T.L. 1991. Stream ecology: balancing the ecosystem. San Marcos River Foundation's "Stroll Along the River Program". River Awareness Month. San Marcos, TX (March).

Arsuffi, T.L. 1991. Understanding rivers: past, present and future ecological research on the San Marcos River. San Marcos River Foundation's "Stroll Along the River Lecture Series". River Awareness Month. San Marcos, TX (March).

Arsuffi, T.L. 1991. Invertebrate session of endangered species resources forum workshop. Texas Parks & Wildlife Dept. Austin, TX (April).

Arsuffi, T.L. 1991. Freshwater Ecology: San Marcos River Field Studies. Southwest Wild: School science teachers workshop. San Marcos, Tx (June).

Arsuffi, T.L. 1991. Endangered species in relation to urban planning and development. Texas Chapter of American Planning Commission. New Braunfels, TX (July).

Arsuffi, T.L. 1992. Exotic species and water quality. Statewide conference for Texas Water Monitors. Texas Water Commission. Austin, TX (February).

Arsuffi, T.L. 1992. Biology and ecology of Comal Springs. Sierra Club - San Antonio Chapter. New Braunfels, TX (March).

Arsuffi, T.L. 1992. Threats to the biodiversity of Comal Springs. Kiawanis Club. New Braunfels, TX (April).

Arsuffi, T.L. 1992. Exotic species, water quality and Comal Springs. Friends of Rivers. New Braunfels, TX (April).

Arsuffi, T.L. 1992. Population dynamics, distribution and dispersal patterns of introduced giant rams-horn snails, Marisa cornuarietis, and their ecological impact on the flora and fauna of south central Texas springs and rivers. Department of Biological Sciences, Texas Tech University. Lubbock, TX (May).

Arsuffi, T.L. 1992. Biology and ecology of the San Marcos River. Audubon Society - San Antonio Chapter. San Marcos, TX (May).

Arsuffi, T.L. 1992. Environmental constraints and ecological adaptations of aquatic insects in running water ecosystems. Southwest Wild: School science teachers workshop. San Marcos, TX (June).

Arsuffi, T.L. 1993. Endangered spring ecosystems associated with the Edwards Aquifer region of central Texas: Threats and conservation efforts. Public Lecture - City of San Marcos. Sponsored by the San Marcos River Foundation (February).

Arsuffi, T.L. 1993. The San Marcos River. Lecture to 25 Bowie Junior High School students. (March).

Arsuffi, T.L. 1993. The San Marcos River. Series of lectures to 200 Owen Goodnight Junior High School students (April).

Arsuffi, T.L. 1993. The San Marcos River. Lecture to First Lutheran Church Bible Studies Class (June).

Arsuffi, T.L. 1993. Ecology of macroinvertebrates in the San Marcos River. Southwest Wild: School science teachers workshop. San Marcos, TX (June).

OTHER PUBLIC RELATIONS.

Interviews and stories for San Marcos Daily Record, New Braunfels Herald Zeitung, San Antonio Light News, San Antonio Express News, Austin Chronicle, Austin American Statesman, Houston Post, Dallas Morning News, Christian Science Monitor, National Geographic Society and the New York Times.

Interviews and stories for television news stations from Austin, San Antonio and Dallas.

Resource person on springs for visits by the Texas House Subcommittee on Natural Resources and Bruce Babbitt - Secretary of the Interior.

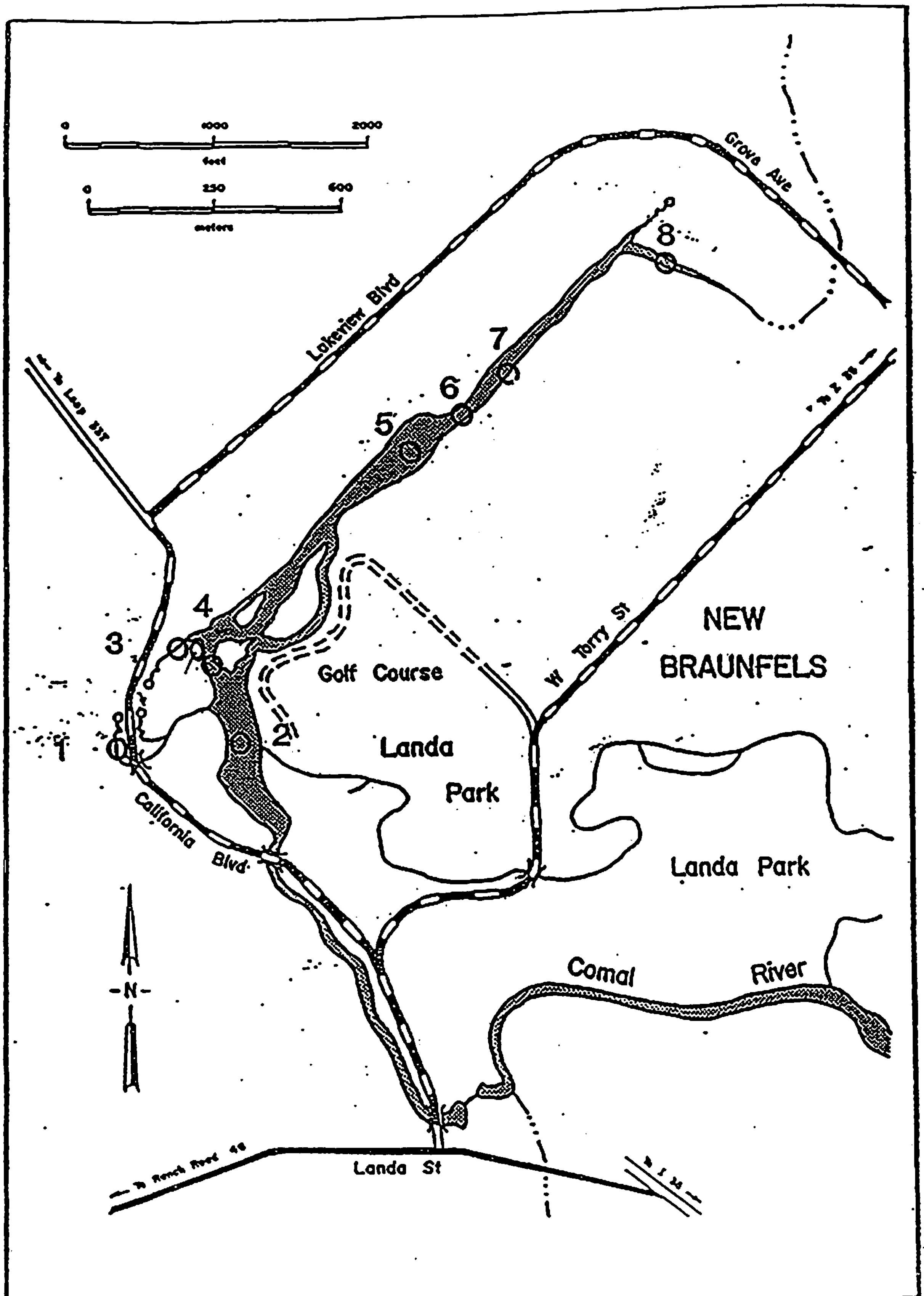

Figure 1. Eight collecting stations for Comal Springs and Landa Lake.

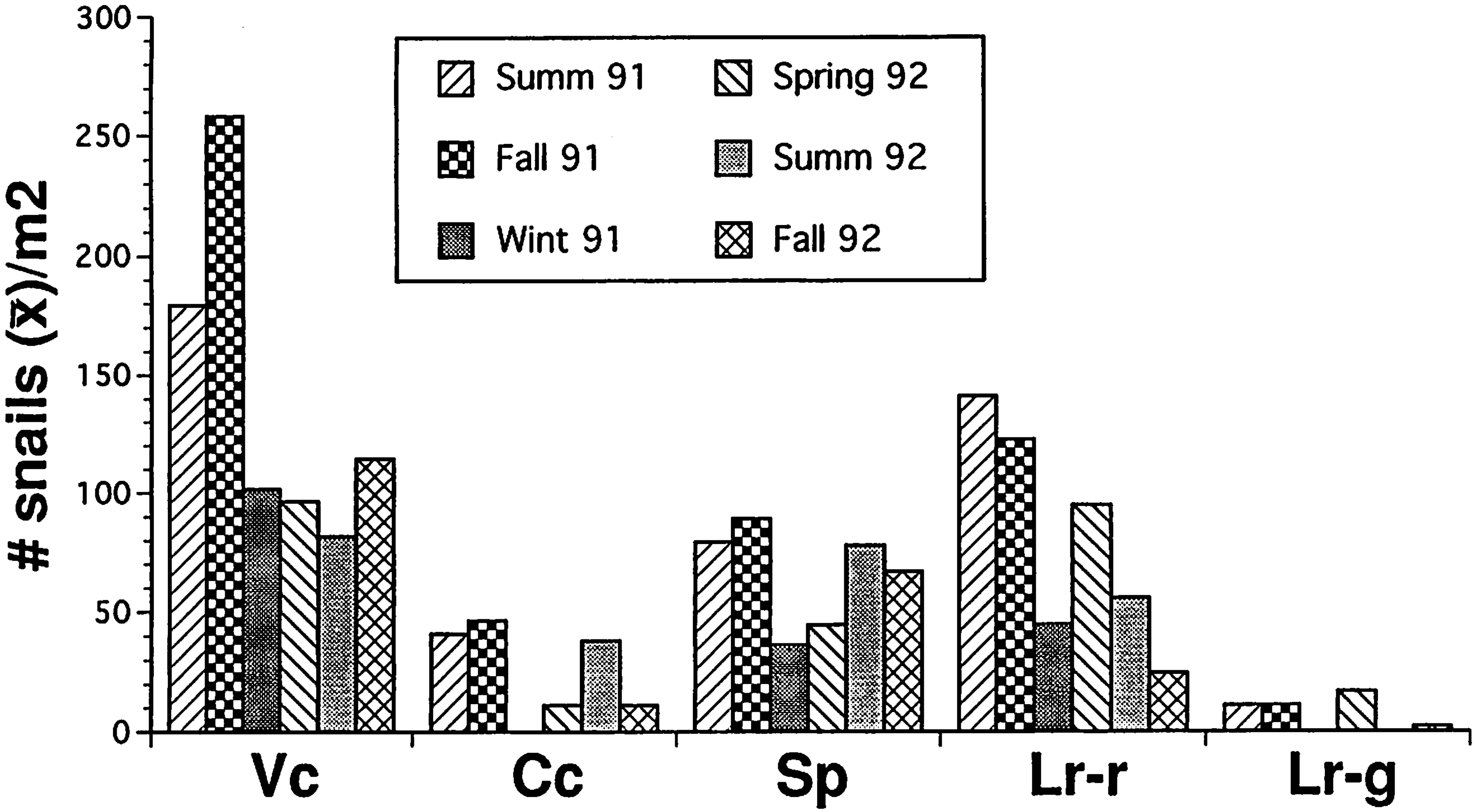

Figure 2. Comparison of the mean abundance of M. cornuarietis in each major macrophyte community at each sampling interval. Va=V. americana, Cc=C. caroliniana, Sp=S. platyphylla, Lr-r=L. repens (red), Lr-g=L. repens (green).