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A TAXONOMIC REVIEW OF THE *GYRAULUS* SUBGENUS *TORQUIS*

Younghun Jung and John B. Burch[1]

ABSTRACT – *Torquis* Dall 1905 is a subgenus of *Gyraulus* 'Agassiz' Charpentier 1837, and contains some of the smaller and most widespread members of the genus. From our observations on authentic and other materials of the nominal species, and from original descriptions, we conclude that there are only three valid species of *Torquis* known at present in North America: *G. parvus* (Say 1817), *G. circumstriatus* (Tryon 1866) and *G. huronensis* Burch & Jung 1990. *Gyraulus hornensis* F.C. Baker 1934 may be a subspecies of *G. parvus*. Synonyms of *G. parvus* are *concavus* "Anthony" Adams 1840, *elevatus* Adams 1841, *vermicularis* Gould 1847, *billingsii* Lea 1864, *similaris* F.C. Baker 1919 and *albolineatus* Henderson 1933. Synonyms of *G. circumstriatus* are *walkeri* Vanatta 1902 and *hendersoni* Walker 1929. *Gyraulus latistomus* F.C. Baker 1932 is not a species of *Torquis*, and probably not even a member of the genus *Gyraulus*.

Key words – Nomenclature, taxonomy, *Gyraulus* 'Agassiz' Charpentier, *Torquis* Dall, *G. albolineatus* Henderson, *G. billingsii* Lea, *G. circumstriatus* (Tryon), *G. concavus* "Anthony" Adams, *G. elevatus* Adams, *G. hendersoni* Walker, *G. hornensis* F.C. Baker, *G. huronensis* Burch & Jung, *G. latistomus* F.C. Baker, *G. parvus* (Say), *G. similaris* F.C. Baker, *G. vermicularis* Gould, *G. walkeri* Vanatta.

Introduction

The genus *Gyraulus* comprises a large group of very small species of freshwater snails belonging to the pulmonate family Planorbidae. Although the various species each have circumscribed and often limited distributions, the genus itself is worldwide in distribution, occurring abundantly and commonly in diverse aquatic habitats on all of the continents. Some of the species are implicated in the mediation of parasitic diseases to wild and domestic animals, and to man.

Several groups of species (*i.e.*, subgenera) comprise the genus *Gyraulus*. One of these groups, the subgenus *Torquis*, contains some of the smaller members of the genus (and of the family), and includes one of the most widespread and common of the North American freshwater snails, *G. (Torquis) parvus* (Say, 1817).

The name *Torquis* was introduced to the nomenclatural literature by Dall (1905, pp. 83, 86) as a section of the subgenus *Gyraulus* of the nearly all-inclusive genus *Planorbis*. Dall characterized *Gyraulus* [*sensu lato*] as follows:

> Shell small, flattish, with few, rapidly increasing whorls, fully exposed above and below, with a nearly median periphery, spirally striate and hispid; aperture simple, sharp-edged, oblique. Type *Planorbis albus* Müller.

In subdividing *Gyraulus*, he characterized his new subtaxon as follows:

> Section *Torquis* Dall, *nov. sect.* Like *Gyraulus s.s.* but with more rounded, less rapidly increasing whorls, not hispid or spirally striate, the aperture expanded and slightly thickened in the adult. Type *P. parvus* Say.

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Since Dall's time, with taxonomic progress in the Planorbidae, the genus *Planorbis*, from which the family Planorbidae derives its name, is now used in a much more restricted sense, and includes only a few species found in Eurasia and Africa. Many of the planorbid subgenera of Dall's day have been raised one taxonomic level higher, and are now recognized as full genera. Such is the case for *Gyraulus*, which is no longer considered a subgenus, but as a full genus, and its former section *Torquis* has been raised accordingly to the subgeneric level.

In surveying the literature on the planorbid snails of North America, 13 nominal species were found which either seemingly definitely belonged to the *Gyraulus* subgenus *Torquis*, or had been assigned there by one or more recent authors. These nominal species are as follows, listed in chronological order, with original author, date of description, originally assigned genus for each species, original locality cited, and the original literature citation.

parvus Say 1817, *Planorbis*, in the Delaware [River], Conchology, in Nicholson, 1816-1817, *Am. Ed. Brit. Encyclop., Dict. Arts Sci.*, etc., 1st ed., vol. 2, pt. 2, 15 pp., 4 pls.

concavus "Anthony" Adams 1840, *Planorbis, Am. J. Sci. & Arts*, p. 374.

elevatus Adams 1841, *Planorbis*, in a small spring in a rocky cavity, in South Boston, *Bost. J. Nat. Hist.*, vol. 3, no. 3, pp. 327-328, pl. 3, fig. 16.

vermicularis Gould 1847, *Planorbis*, interior of Oregon, *Proc. Boston. Soc. Nat. Hist.*, vol. 2, p. 212.

billingsii Lea 1864, *Planorbis*, Ottawa River, Canada West (E. Billings!), *Proc. Acad. Nat. Sci. Philad.*, vol. 16, p. 111.

circumstriatus Tryon 1866, *Planorbis (Gyraulus)*, artificial pond at Weatogue, Conn. (S. Shurtleff!), *Am. J. Conchol.*, vol. 2, no. 2, p. 113, pl. 10, figs. 6-8.

walkeri Vanatta 1902, *Planorbis parvus*, Hartland, Vt. (from Bryant Walker), *Nautilus*, vol. 16, no. 5, p. 58.

similaris F.C. Baker 1919, *Planorbis*, Smartweed Lake, altitude 8575 feet, East Lake, near Tolland, altitude 8850 feet, *Bull. Am. Mus. Nat. Hist.*, vol. 41, no. 13, pp. 532-533.

hendersoni Walker 1929, *Gyraulus vermicularis*, ditch at Phoenix, Ore., *Nautilus*, vol. 42, no. 3, pp. 104-105.

latistomus F.C. Baker 1932, *Gyraulus*, McAree Lake, Rainy River District, western Ontario, Canada, *Nautilus*, vol. 46, no. 1, pp. 6-9(9).

albolineatus Henderson 1933, *Gyraulus vermicularis*, Weiser River at Starkey, Idaho, *Nautilus*, vol. 47, no. 2, pp. 78-79, pl. 6, fig. 3.

hornensis F.C. Baker 1934, *Gyraulus*, Birch Lake, Horn River, about 75 miles above the Mackenzie River, Mackenzie District, Canada (E. J. Whittaker), *Can. Field-Nat.*, vol. 48, no. 8, p. 135.

huronensis Burch & Jung 1990, Shore of Lake Huron, north of Hammond Bay, T. 37 N., R. 2 E., Section 14, Bearinger Township, Presque Isle County, Michigan, *Walkerana*, 3(10), p. 217, figs. 1-5.

In dealing with the nominal taxa of the *Torquis* group, first it was necessary to assess the validity, from a taxonomic point of view, of the described taxa. We were able to study authentic specimens of all except four of the nominal species listed above. Observations were made on *Gyraulus Torquis* shells from three museums: the Museum of Zoology, The University of Michigan (UMMZ), the National Museum of Natural History, Smithsonian Institution (USNM), and the Museum of Comparative Zoology, Harvard University (MCZ). Presented below are our observations. The nominal species are treated in sequence according to their chronological order of introduction to the taxonomic literature.

In the subgenus *Torquis*, the first to be named was *Gyraulus parvus*. This species not only has nomenclatural priority over all the others, but it also is the type species of the subgenus *Torquis*. It was named and described in the very first article by an American author on American mollusks (Say, 1817). His original description is as follows:

> Shell horn colour or blackish; whorls four, crossed by minute wrinkles; concave above and beneath, and equally exhibiting the volutions; body generally subcarinate on the margin; lip rounded, and not vaulted above nor thickened; mouth within bluish white.
>
> Breadth one-fifth of an inch.
>
> Animal aquatic brown, tentacula long, filiform, whitish, with a darker central line, tail rounded.
>
> Plate 1, fig. 5.
>
> Probably the same species with that figured by Lister, tab. 139, fig. 45; it is very numerous in the river Delaware, in company with the two preceding shells [*Planorbis* (= *Planorbella*) *trivolvis* (Say) and *Planorbis* (= *Helisoma*) *anceps* Menke].

No type material is available for *Gyraulus parvus* (Say). The types of this important species are lost (see H.B. Baker, 1964). However, there is not much doubt that the species Say described as *"Planorbis" parvus* is the species we still call *G. parvus*. Also, which extant species is *G. parvus* can be inferred from the historical opinions of other malacologists. Further, since the description of *G. parvus* is the first description of a species of the *Torquis* group in the Western Hemisphere, its priority is important: one of the extant species of the *Torquis* group in North America *must* bear its name, unless, of course, an older name for a conspecific can be found either paleontologically or extralimitally. In regard to the taxon *Torquis* itself, Say's *"Planorbis" parvus* is the type species of that generic-group name by original designation (Dall, 1905).

It was 23 years before the next name for a *Torquis* group species appeared. In 1840, Adams, as an aside to another *Gyraulus* species he was describing, listed *"Planorbis concavus"*:

> *P. concavus*, Anthony MSS., resembles this species [*"Planorbis" virens* Anthony 1840], but is more convex above and concave beneath.

Such a name introduced to the taxonomic literature nowadays would be considered a *nomen nudum*, but in those early times nomenclatural usage was not governed by strict rules, and so, if *Gyraulus concavus* were considered clearly distinct from any other member of the genus, and had chronological priority, we would use the name today.

Authentic material of Adams' (1840) *"Planorbis concavus* Anthony ms." seems to be available in a lot of the United States National Museum of Natural History (USNM 8509), which bears the notation on its label *"concavus* Anthony, *teste* Anthony." Binney (1865) said that these specimens were "labeled by J. G. Anthony *Pl. concavus*. ... No description was ever published, as Mr. Anthony informs me, owing to the doubts of its being distinct." In terminology of taxonomic types, these specimens then would be called "ideotypes," *i. e.*, specimens identified by the original author as being his/her own described species. It is possible that these USNM specimens are also syntypes.

There are eight specimens in USNM lot no. 8509, one of which is shown in Fig. 1a. In the lot, two specimens are separated out from the other six by a cotton barrier. Seven of the eight specimens clearly go together. Their morphologies are virtually the same, and they have the same kind of adhering debris. The other specimen, attached to a piece of plasticine, is a specimen of *Gyraulus circumstriatus* (with a broken shell). The surface appearance and adhering debris of this eighth specimen indicate that it was not from the same locality as the other seven, or at least not from the same microhabitat. Possibly this specimen, from some other locality, was included with the other seven for comparative purposes, and then not removed from the vial.

The specimen separated out with the specimen of *Gyraulus circumstriatus* is the largest of the three, measuring 3.54 mm in major diameter. It is pale horn in color and has a slightly depressed spire. The body whorl angle, as seen in apertural view of the shell, is inverted. The last one-third of the body whorl on the spire side is opaque white. The first several whorls of the umbilical depression are only slightly depressed. The basal periphery of half of the penultimate whorl is on the same plane as most of the last whorl. The last one-fourth of the last whorl is slightly deflected. The shell is sculptured with fine transverse lines. Spiral lines are mostly absent; a few nearly obsolete ones are on the base and on the spire side. The whorls are ovate in cross-section, giving the whorls on the spire side a flattened surface appearance. The aperture lip is well formed, but not thickened. The other six specimens in the bottom of the vial are similar in appearance, with slight variations in size and appearance, but with no obvious significant difference from the larger separated specimen. These seven specimens are *Gyraulus parvus*.

Adams, in his very brief comments in the original notation of this nominal species, comparing it to *"Planorbis virens,"* mentions it as being more convex above and concave below. It should be noted, however, that these *"concavus"* specimens are indeed convex above [umbilical side] and concave below [spire side], but only slightly so.

A year later, Adams (1841a) described his *"Planorbis" elevatus:*

> *P. testâ parvâ, pallidâ, suprà elevatâ, infrà altè umbilicatâ; anfractibus quatuor; sutrâ valdè impressâ; aperturâ subrotundatâ; labro suprà prominente.*
>
> Shell horn color, finely striate; whorls four, as high as wide; last whorl well rounded, very indistinctly carinate below; *inclination* to the left about 48°; *right side* convex, flattened at the apex; *left side* very deeply concave; *suture* deeply impressed; *aperture* round-ovate, large, with its upper extending much beyond its lower margin.
>
> Greatest breadth, .17 inch; least breadth, .13 inch; height, .06 inch.
>
> Cabinets of Bost. Soc. Nat. Hist.; of Middlebury College; of S. S. Haldeman, of Marietta, Pa.; of J. G. Anthony, of Cincinnati; and my own.
>
> Habitat. This species was discovered in the summer of 1838, in a small spring in a rocky cavity, in South Boston. Nearly a hundred specimens were obtained, and a much larger number were left. Visiting the same spot a few

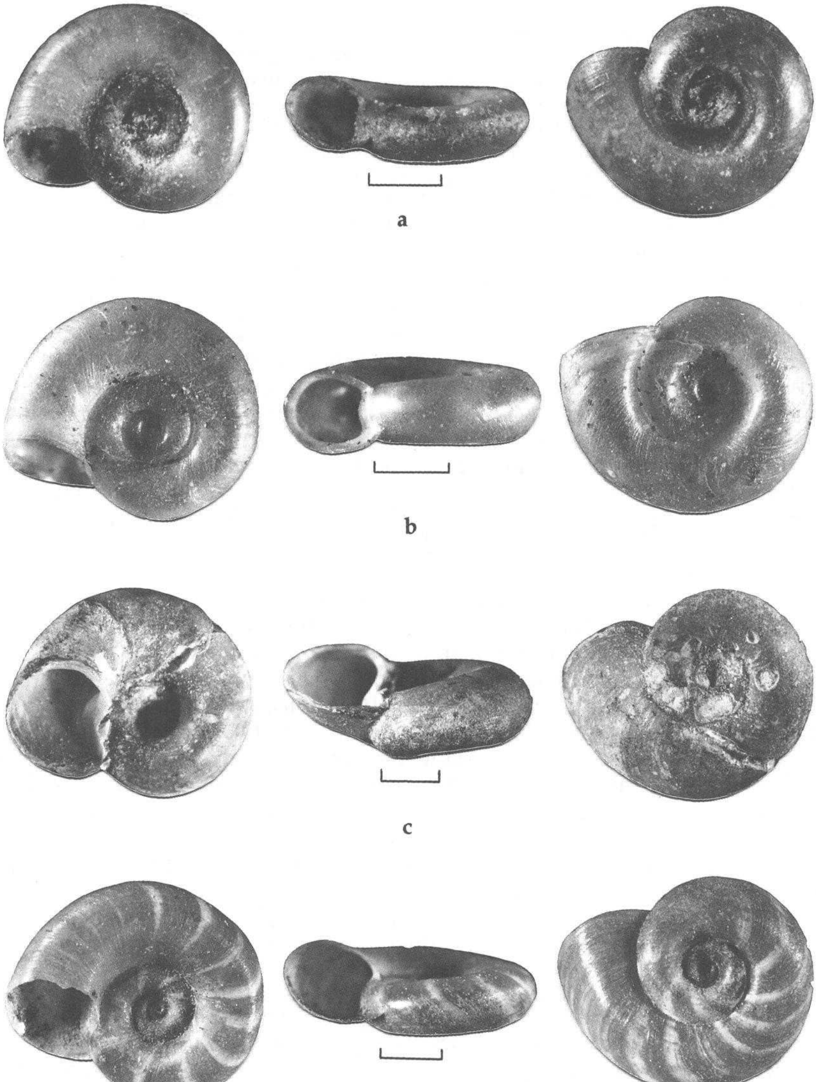

FIG. 1. Shells of *Gyraulus (Torquis)* species. **a**, *G. concavus* ("Anthony" Adams), an ideotype (?syntype), USNM 8509 [= *G. parvus*]; **b**, *G. parvus* (Say), from Hartland, Windson, Co., Vt., in swamp, B. P. Ruggles!, [= *G. parvus*], from the same locality as the types of *G. parvus walkeri* (Vanatta), USNM 572328; **c**, *G. latistomus* F.C. Baker, holotype, McAree Lake, Rainy River District, western Ontario, UI Z32340; **d**, *G. vermicularis albolineatus* Henderson, holotype, Weiser River at Starkey [? or 7 mi. above Midvale], Idaho, UC 17475. Scale lines = mm.

days since, (July, 1840,) I found the spring filled up with stones to the top of the water, and not a shell to be seen. Last summer I obtained a specimen in Lake George, N. Y. Dr. Wm. Prescott has found the species in Lynn.

REMARKS. This species much resembles *P. parvus*, Say, and for some time I doubted whether it were distinct. But the specimens uniformly differ from that shell in having the spire elevated above the plane of the last whorl, whereas in that species it is concave, and consequently this species is much more deeply umbilicated on the left side; also, that species is distinctly carinate on the middle of the last whorl, but is very indistinctly carinate below the middle, if at all.

We have not seen authentic material of Adams' (1841a) *Gyraulus elevatus*. "This species much resembles *P. parvus*, Say, and for some time we doubted whether it were distinct. But the specimens uniformly differ from that shell in having the spire [umbilicus] elevated above the plane of the last whorl, whereas in that species it is concave, and consequently this species is much more deeply umbilicated on the left [spire] side; also, that species is distinctly carinate in the middle of the last whorl, but is very indistinctly carinate below the middle, if at all" (Adams, 1841a). Adams (1841b) expressed further uncertainty about the validity of his new species later: "This species does not differ much from some varieties of the preceding [*G. parvus*], and perhaps may not prove entitled to rank as a species. All the specimens that we have seen, however, present that *constancy* of difference which is most important in distinguishing species."

Haldeman (1844) placed Adams' *Gyraulus elevatus* in the synonymy of *G. parvus*. "Except *P.* [*Menetus*] *dilatatus*, this [*Gyraulus parvus*] is our smallest species; individuals of a fourth of an inch in size being of rare occurrence. Its smaller transverse diameter, and the more open concavity of the left side, distinguish it from small specimens of *P.* [*Gyraulus*] *deflectus*, to which it is allied by a tendency to deflect the last whirl towards the left, and of which Fig. 20 presents an extreme case. Individuals in which this character is pretty well developed, constitute *P.* [*G.*] *elevatus*, Adams." Binney (1865) followed Haldeman in synonymizing *G. elevatus* with *G. parvus*. We concur with both their opinions.

The next species to be described was by Gould (1847) from collections made in western North America by the U.S. Exploring Expedition:

PLANORBIS VERMICULARIS. Tasta parva, fornicata: spira planulata, apice depresso, anfr. 4, cylindraceis, ultimo prope aperturam deflexo; subtus concava; apertura perobliqua, elliptica.

Lat. 1/5, alt. 1/15 poll. *Hab.* Interior of Oregon.

About the size and form of *P. deflectus*, Say, but is less depressed, the whorls more cylindrical, and not compressed at the periphery.

Type material of *Gyraulus vermicularis* is no longer available (see H.B. Baker, 1964). The original description and figures of *G. vermicularis* are good enough, however, to leave little question that Gould had a member of what was later called the subgenus *Torquis*. Binney in 1865 said, "I have seen no specimens of this species." This is perhaps a significant statement, because Binney had access to all of the major collections in the east.

Henderson (1907) recognized *Gyraulus parvus* for Colorado, but later (*e.g.*, Henderson, 1924, 1929), influenced by F.C. Baker, referred western *parvus*-like specimens to G. *vermicularis*. F.C. Baker (*e.g.*, 1928) believed that "west of the Rocky Mountains [*G. parvus*] is replaced by *vermicularis*, which is not a synonym of *parvus.*" But, Bequaert & Miller (1973) placed *G. vermicularis* in the synonymy of *G. parvus*, and Wu (1989) did not recognize *G. vermicularis* as a species occurring in Colorado. We concur at present with the opinions of Bequaert & Miller, and Wu.

Seventeen years later, also from western North America, Lea (1864) described *Gyraulus billingsii*:

PLANORBIS BILLINGSII.-Testâ lœvi, planulatâ, supernè plano convexâ, subtus lato umbilicatâ, estriatâ; anfractibus quaternis; labro acuto; aperturâ grandiusculâ, subrotundâ, obliquâ.

Hab.- Ottowa River [*sic*], Canada West, E. Billings, Esq.

Two years later (1866), Lea elaborated on his very brief original description:

PLANORBIS BILLINGSII. Pl. 23, fig. 72. Testâ lœvi, planulatâ, supernè plano convexâ, subtus lato umbilicatâ, estriatâ; anfractibus quaternis; labro acuto; aperturâ grandiusculâ, subrotundâ, obliquâ.

Shell smooth, flattened, plano-convex above, widely umbilicate below and without striae; whorls four, outer lip acute; aperture rather large, rounded and oblique.

Proc. Acad. Nat. Sci. [Philadelphia], 1864, p. 111.

Hab. - Ottawa River, Canada West, E. Billings, Esq.

My cabinet and cabinet of Mr. Billings.

Diam. .18.

Remarks. - Mr. Billings sent me many of this small species some years since. I have never been able to place it with any of the species I know. It is near to *parvus*, Say, but differs in having a wider umbilicus, in having a more oblique aperture and exhibiting one more whorl. Some specimens, received subsequently from Prof. Daniels, Palmyra, Wisconsin, belong to this species. I have great pleasure in naming it after E. Billings, to whom I am indebted for many shells from Canada.

We have not seen authentic material of Lea's *Gyraulus billingsii*. His description does not really differentiate this species from *G. parvus*. Lea's (1866) figure [pl. 23, fig. 72] indicates a shell much like that of *G. parvus*. La Rocque placed Lea's *G. billingsii* in the synonymy of *G. parvus*, and until we see authentic material that might prove otherwise, we concur.

Tryon (1866) in the same year described *"Planorbis" circumstriatus*:

Description. - Shell small, rugose, generally distorted in adult specimens (the whorls not proceeding in the same plane, but elevated or depressed below it at times); volutions four, convex, increasing very slowing in diameter, with deeply impressed suture, towards the aperture deflected; below concave, but exhibiting all the volutions, with two or three raised revolving lines; aperture small, very oblique. Light horn color.

Dimensions. - Diameter 6 mill., height 1½ mill.

Habitat. - Artificial pond at Weatogue, Conn. Dr. S. Shurtleff.

My cabinet. Cabinet of Mr. Lea. Cabinet of Dr. Shurtleff.

Observations. - This species is of the same size as *Planorbula armigera*, Say, and its upper surface is remarkably like that shell. It differs, however, in its unarmed, oblique aperture, and concave, lineated under surface.

The deflected aperture reminds one of *Pl. deflectus*, but from that, as well as *parvus* and *albus*, it is distinguished by the slow increase in the size of the whorls. [*Gyraulus albus* is a European species.]

The remarkable raised revolving lines are visible on the under surface of all the adults before me, but on a number of young shells I can detect no trace of them.

The material of *Gyraulus circumstriatus* Tryon that we observed was from the U. S. National Museum of Natural History, lot no. 120938 (Fig. 2a,b,c). The specimens have exactly the same data as given in Tryon's (1866) original description: artificial pond, Weatogue, Connecticut, Shurtleff! A small slip is in the tray noting "locotypes" [= topotypes]. The specimens, from the Isaac Lea collection, are probably ideotypes, and also possibly syntypes. There are 12 specimens in this lot, three of which are separated by a piece of cotton and accompanied by a small slip of paper noting "Fig." We cannot verify that figures of these specimens were ever published. One of the 12 specimens is an abnormally large specimen, measuring 6.7+ mm in major diameter and having about 5 whorls. However, most specimens in the lot were of more normal size, *i.e.*, 4 mm or slightly less in major diameter. Shells in this more normal size range have about four whorls. In some specimens, the last part of the last whorl is considerably deflected; in other specimens this last part of the body whorl is not deflected at all. The first several umbilical whorls are slightly depressed on some specimens, but not depressed on others. The whorls are nearly round in cross-section. The periphery (*i.e.*, the edge of the body whorl farthest from the shell aperture when the shell is viewed in apertural view) is also round on most specimens. The spire is only slightly depressed on most of the 12 specimens; it is moderately depressed on several specimens and hardly depressed at all on one. The color of the 12 specimens varies from tan to rather dark horn, and the surface is semi-glossy in appearance. There is some very fine spiral striations on the umbilical side of the body whorls in a few places on some specimens. When spiral striation occurs, it is generally subobsolete. Spiral striae on the spire side varies from none, to small patches, to being quite noticeable on the largest specimen. But generally, spiral striation is very sparse. Several of the specimens, especially the two largest, have an irregularity in the direction of growth of the last whorl.

Shortly after the turn of the century, Vanatta (1902) described a subspecies of *"Gyraulus parvus"* after Bryant Walker, the leading North American freshwater malacologist at that time:

> PLANORBIS PARVUS WALKERI n. var.
>
> This variety is similar to *P. parvus*, but distinguished by having the lip internally thickened.
>
> Types in coll. of Academy of Natural Sciences, no. 81143 from Hartland, Vt., gift of Mr. Bryant Walker; cotypes in coll. Walker.
>
> It also occurs at the following Michigan localities: Oakland Co.; Detroit; Cambridge, Sewell Co.; Antrim Co.; Fenton, Genesee Co.; Lake near Charlevoix; and Grand Rapids, all communicated by Mr. Bryant Walker.

The University of Michigan, Museum of Zoology's paratype lot (UMMZ 89719, from the Bryant Walker Collection) contains 12 specimens (Fig. 2d). Of these, 10 have thickened apertural lips, the character Vanatta used to distinguish *"Gyraulus parvus walkeri"* from "*P. parvus.*" However, this thickening of the inside of the apertural lip, called the "varix," is a transverse shell deposition which is normally produced by freshwater pulmonate snails in north temperate regions when they overwinter. Those snails that survive the winter, begin adding shell in the direction of the shell's spiral when warm weather returns, so the succeeding part of the whorl (*i.e.*, the later growth)

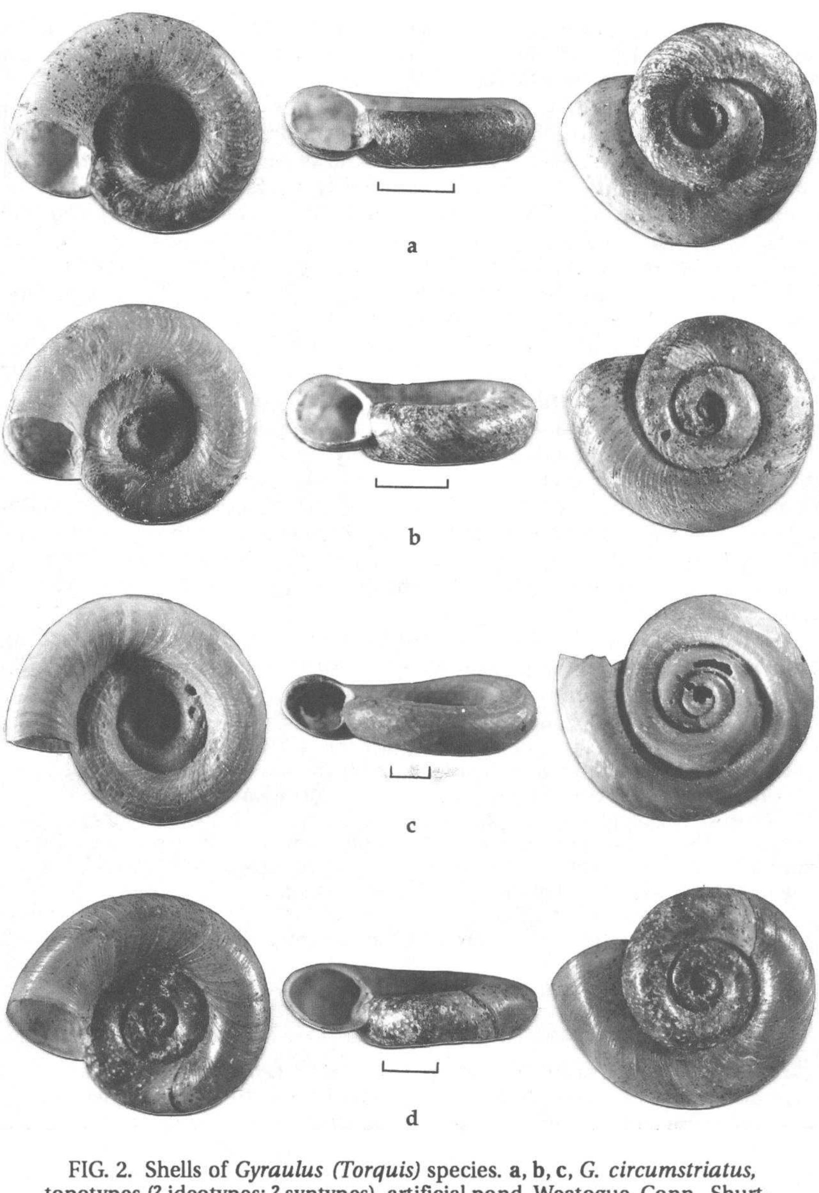

FIG. 2. Shells of *Gyraulus (Torquis)* species. **a, b, c,** *G. circumstriatus*, topotypes (? ideotypes; ? syntypes), artificial pond, Weatogue, Conn., Shurtleff!, USNM 120938; **d,** *G. parvus walkeri* (Vanatta), paratype, Hartland, Vt., UMMZ 89719. Scale lines = mm.

does not have the thickened apertural lip. In the two largest specimens in the paratype lot, shell growth has proceeded quite a bit beyond the varix, so that the shells no longer have a thickened lip.

The characteristics of the specimens in this paratype lot clearly indicate that they are *Gyraulus circumstriatus*, as was previously pointed out by Pilsbry (*fide* Winslow, 1926). The whorls increase very slowly in size, they are round in cross-section, there is an irregularity in the last whorl in some specimens, and the last whorl of some specimens show spiral malleations. The largest specimen in the lot measures 5.87 mm in major diameter.

There is a lot of one specimen of "*Gyraulus parvus walkeri* (Vanatta)" in the U. S. National Museum of Natural History (cat. no. USNM 572328) from the "Type Locality" ["Hartland, Vermont, in swamp, B.P. Ruggles"], Frank C. Baker Collection no. 3542. A slip of paper with this specimen says "Fig.," indicating that it was figured somewhere. We have not been able to determine where (or if) a figure of this specimen was actually published. We have figured it in our Fig. 1b. This specimen, while also apparently from Ruggles and from the town of Hartland, is not necessarily from the type lot, or from the exact same locality. For example, its surface-adhering debris is not the same as on the Walker paratypes. This is a small specimen (3.28 mm in major diameter) of 3½+ whorls, with hardly depressed spire, but with a somewhat depressed umbilicus. Although it has a slightly thickened lip (the character on which the subspecies was based), this is a specimen of *Gyraulus parvus*, not *G. circumstriatus*.

F.C. Baker, who later was to succeed Bryant Walker as America's leading freshwater malacologist, described the first of his species of *Gyraulus* in 1919, *Gyraulus similaris* as follows:

> Shell thin, yellowish or brownish-horn, translucent in immature shells, opaque in adult shells; upper surface slightly concave in the middle, lower side concave; whorls 4, regularly increasing in diameter, rounded above and below; periphery rounded near the base of the shell, the body whorl sloping upward at an angle of 45 degrees in some specimens, and abruptly rounding into the base of the shell below; umbilicus very broad, not very deep, showing all of the whorls; aperture ovate and oblique in the immature shell, round and parallel with the whorls in the adult shell; sculpture consisting only of fine growth-lines; lip simple, not thickened within.
>
> Height, 2.5; greatest diameter, 6.2; aperture height, 2; diameter, 2 mm. Holotype.
>
> Height, 1.7; greatest diameter, 4.7; aperture height, 1.4; diameter, 1.5 mm. Paratype.
>
> Smartweed Lake, altitude 8575 feet, East Lake, near Tolland, altitude 8850 feet.

We have not seen authentic material of Baker's *Gyraulus similaris*. In his original description, Baker compares this species mostly to a Pleistocene fossil found in Illinois, *G. altissimus* (Baker, 1919), but also with *G. parvus*. "*Similaris* differs from *parvus*, which it somewhat resembles, in its larger size, rounder aperture, and the peculiar reamed-out appearance which is so characteristic of the lower surface of *parvus*." Henderson (1912, p. 62) referred topotypes to *G. parvus*. Bequaert & Miller (1973) placed Baker's *G. similaris* in the synonymy of *G. parvus*. Wu (1989) did not list *G. similaris* for Colorado, so obviously he did not recognize it as a valid species. Until we see type material of this species, we will concur with the opinions of Henderson, Bequaert and Miller, and (apparently) Wu.

In one of the last papers of his long career, Walker (1929), described a subspecies in the *Torquis* group after his friend (and the collector of the specimens), Junius Henderson:

> GYRAULUS VERMICULARIS HENDERSONI n. v. In general appearance similar to the typical form, but smaller and with a varix or callus deposit inside of the lip. Dark reddish brown. Major diam.. 3.5, minor diam. 3 mm.
>
> Types No. 89534 Coll. Walker. Paratypes in the collection of Junius Henderson.
>
> Type locality: Ditch at Phoenix, Ore. Also Loon Lake, 38 miles N. of Spokane, Wash.; Lagoon 14 miles S. W. of Spokane, Wash.
>
> This form bears the same relation to typical *vermicularis* that var. *walkeri* does to *G. parvus.*

The holotype of *Gyraulus vermicularis hendersoni* Walker 1929 is in The University of Michigan, Museum of Zoology (cat. no. UMMZ 89931, from the Bryant Walker Collection) (Fig. 3a). It was collected from a ditch at Pheonix, Jackson County, Oregon by Junius Henderson. It is a horn-colored [not "reddish brown" as in the original description] shell of 3.50 mm major diameter, which has a slight distortion of growth of the last whorl. The umbilicus is depressed; the spire only very slightly depressed. The whorls are round in cross section. Inside the aperture there is a varix. There is additional shell growth slightly beyond the lip edge. This is a specimen of *Gyraulus circumstriatus.*

Three years later, F. C. Baker (1932) described another *Gyraulus* species. He did not assign it to the *Torquis* group, but instead compared it to *G. deflectus,* a member of the subgenus *Gyraulus s.s.* Clarke (1973) relegated Baker's new species to the synonymy of *G. parvus*:

> GYRAULUS LATISTOMUS, new species.
>
> Shell resembling *Gyraulus deflectus obliquus* but smaller, the whorls rounded with no sign of angulation; whorls three, rapidly enlarging in diameter; sculpture of growth lines only; spire flat, apex sunken below general surface; umbilicus deep and wide; last whorl deflected near aperture; aperture oblique, expanded, the upper part extending far forward of the basal part; inner lip forming a callus which spreads over the columellar region.
>
> Height 2.4; Gr. Diam. 4.4; Ap. breadth 1.5; Diam. 1.3; Height 1.0 mm. Holotype.
>
> Height 1.8; Gr. Diam. 4.0; Ap. breadth 1.4; Diam. 1.2; Height 1.0 mm. Paratype.
>
> Holotype, Z32340; paratypes, Z32341, Museum of Natural History, University of Illinois; paratype, Academy of Natural Sciences, No. 158598.
>
> Type locality: McAree Lake, Rainy River District, western Ontario, Canada.
>
> This little *Gyraulus* apparently differs from all other species now known. In a way it resembles the *obliquus* race of *deflectus,* but has a less number of whorls and the aperture is quite different. The chief feature of note is the rapid expansion of the last whorl and the very wide aperture, almost round when viewed from the under surface. It is known at present only from the type locality.

The holotype and a paratype of *Gyraulus latistomus* are in the Illinois Natural History Museum, University of Illinois (cat. no. Z 32340) (Fig. 1c). The horn-colored shell has 3½ rapidly enlarging whorls and measures 4.5 mm in major diameter. The shell is thick, and has some deep erosions. The last part of the body whorl is sharply deflected. The aperture is complete and very oblique. Its length (in direction of the shell spiral) is noticeably greater

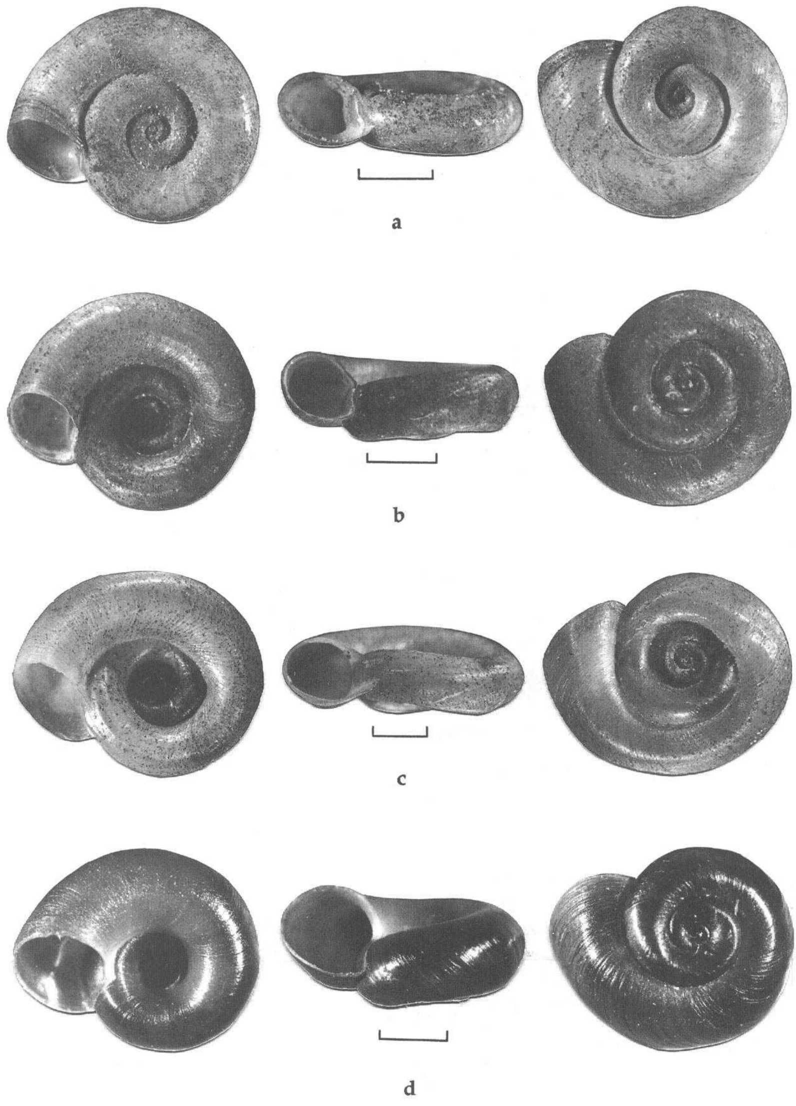

FIG. 3. Shells of *Gyraulus (Torquis)* species **a**, *G. vermicularis hendersoni* Walker, holotype, ditch at Phoenix, Jackson Co., Ore., Junius Henderson!, UMMZ 89931; **b**, *G. circumstriatus*, woods pool next to shore at Maple Bay Forest Camp Ground, Burt Lake, Cheboygan Co., Mich., UMMZ 250595; **c**, *G. circumstriatus*, intermittent small tributary to East Branch of the Maple River, Section 25, McKinley Township, Emmet Co., Mich., UMMZ 250576; **d**, *G. huronensis*, shore of Lake Huron, north of Hammond Bay, Section 14, Bearinger Township, Presque Isle County, Michigan, 250571. Scale lines = mm.

than its width (in transverse direction) as seen when looking perpendicularly to the major shell diameter. The inner lip of the holotype has a calloused hump. This is lacking on the paratype. The spire depression is rather deep and narrow. The whorls are more or less round in cross-section.

This species is not *Gyraulus parvus* as asserted by Clarke (1973), is probably not even a member of the genus *Gyraulus*, and may not even be a pulmonate.

Henderson (1933), who by this time had become, without question, the leading freshwater malacologist of western North America, named a *Gyraulus* subspecies:

> GYRAULUS VERMICULARIS ALBOLINEATUS, new subspecies. Plate 6, fig. 3. This form differs from typical *vermicularis* only in the presence of a number of white lines on the last whorl parallel with the growth lines. On the type (largest) specimen there are eight of these lines. They suggest the sutures of an exfoliated specimen of a minute fossil nautiloid, but do not form partitions or apparently even internal calluses. The white lines are due to periodical changes in pigmentation, not to accidental discoloration. The type measures 4 mm in width. I obtained six specimens from the Weiser River at Starkey, Idaho, in 1930. They are in the University of Colorado Museum (No. 17475). It is interesting to note that a single specimen of *Lymnaea* (*Fossaria*) *obrussa* from the same locality exhibits the same characteristic. [On the locality label with the type specimens, someone (presumably Henderson) later crossed out "Starkey" and wrote in "7 mi. above Midvale."]

The holotype of *Gyraulus vermicularis albolineatus* is in the University of Colorado Museum (cat. no. 17475) (Fig. 1d). It has 3¾ whorls and measures 4.35 mm in major diameter. The spire is moderately depressed. The basal periphery of the last two whorls on the umbilical side are nearly in the same plane. The last part of the last whorl is very slightly depressed. The whorls are ovate in cross-section. The lip is sharp. There are some very faint subobsolete spiral lines on the last half of the body whorl. The color of the shell is tan and white. Tan transverse bands alternate with white or very pale horn transverse bands, giving the shell a zebrated appearance. As seen from the umbilical side, there are six of these lighter bands on the body whorl, and an additional four bands (two are mostly rather faint) on the penultimate whorl.

This specimen is *Gyraulus parvus*. The alternating white lines are ecologically induced. [Henderson noted that a specimen of *Fossaria obrussa* from the same locality had the same alternating dark and light bands.]

The next taxon of the subgenus *Torquis* to be described was *Gyraulus hornensis* by F. C. Baker (1934) from the far north:

> Shell depressed, the periphery rounded; colour light corneous, surface shining; sculpture of fine, oblique lines of growth with very fine spiral lines, more or less conspicuous; nuclear whorls small, rounded, spirally striate in sculpture; whorls about four, rapidly enlarging, the last somewhat expanded near the aperture, roundly angled at the periphery of the last whorl, the upper part of the body whorl slightly flattened; spire flat, the whorls coiled in the same plane; the body whorl may be nearly in line with the spiral turns or it may be deflected about a third of the distance from the aperture; sutures deeply channelled; base concave exhibiting all of the whorls, the umbilical region wide, but the body whorl well rounded, not flattened or having a reamedout appearance; aperture obliquely, ovately rounded; lip thin, sharp, simple, or slightly thickened with a callus deposit; parietal wall with a white callus.

Height	Gr. Diameter	Aperture height	Diameter in mm.	
1.5	4.5	1.2	1.5	Holotype
1.3	4.2	1.0	1.2	Paratype
2.0	4.6	1.5	1.6	Paratype

The last specimen with deflected body whorl.

TYPE LOCALITY: Birch Lake, Horn River, about 75 miles above the Mackenzie River, Mackenzie District, Canada. Collected by Mr. E. J. Whittaker, July, 1921.

TYPES: Museum of Natural History, University of Illinois, No. Z13072a.

The holotype and three paratypes of *Gyraulus hornensis* are in the Illinois Natural History Museum, University of Illinois (all with the cat. no. Z13072a) (Fig. 4a). The holotype is tannish-horn in color, has four whorls and measures 3.83 mm in major diameter. The spire is only slightly depressed. The last part of the last whorl is slightly deflected. The aperture lip and inner aperture are not thickened, but the lip is well formed. The parietal wall is slightly callused. The umbilical 2½ whorls are deep [the paratypes do not have this feature]. There are some subobsolete spiral lines on the body whorl. Spiral striae are very clear on the second whorl. As noted by Baker, the body whorl is well rounded, and the whorls are more or less round in cross-section. On the holotype (but not on the paratypes), the lower part of the body whorl is flattened. On the three paratypes (but not on the holotype), transverse striae are coarser than on typical *G. parvus.*

The three paratypes measure 4.38, 4.30 and 3.23 mm in major diameter. [Measurements given by Baker are: holotype, 4.5 mm; paratypes 4.6 and 4.2 mm in diameter.]

These specimens remind us of *Gyraulus parvus,* yet they are slightly different in several ways. The Rainy River District of the Northwest Territory of Canada is in the far north and, as yet, not accessible to us. Because we do not feel absolutely certain about synonymizing *G. hornensis* with *G. parvus,* at present we are inclined to recognize it as a subspecies of *G. parvus.*

The last species to be named in the *Torquis* group is *Gyraulus (T.) huronensis* Burch & Jung 1990. The description of the shell was as follows:

> *Gyraulus (Torquis) huronensis,* new species, ... [from diagnosis] [is] a small North American planorbid snail having a thick, solid shell, mahogany red or Hay's russet in color, with a characteristic spireward deflection of the body whorl and a relatively (to other *Torquis* members) deep and narrow inverted spire. The whorls on the spire side (the topographically lower side in an active snail) are rounded. ... Description [of shell]: small, discoidal, with inverted spire and a somewhat dome-shaped umbilical side (the topographically right side, but actually the dorsal side in reference to the way the crawling snail carries its shell). The shell is thick, mahogany red or Hay's russet in color (Ridgeway's (1912) color standards) and has a relatively narrow and deeply inverted spire (on topographically the left side, but actually the "base" or ventral side in reference to the active shell). The major diameter of the shell of large specimens with four whorls reaches 5 mm.

The original descriptions of nominal species given above, portraying seemingly different characteristics for each of the species in comparison with the others known at the time, were clear enough to the original authors. However, due to the difficulty of conveying reliable visual images from their

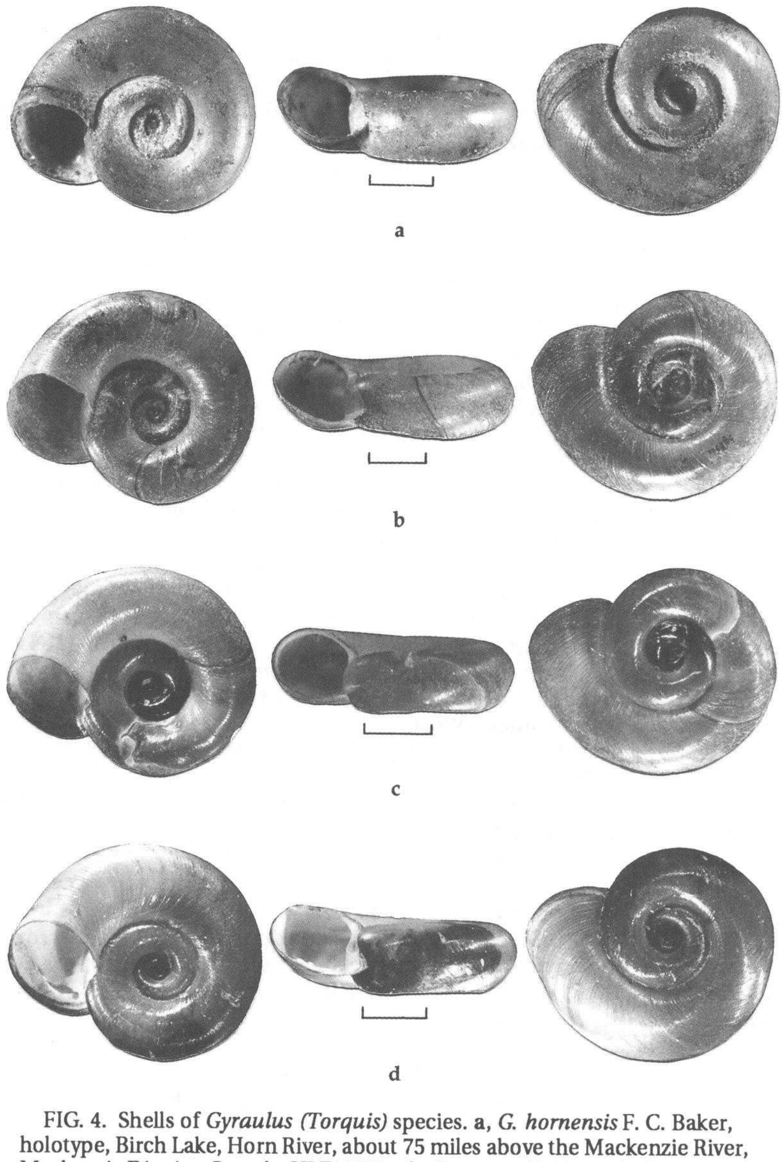

FIG. 4. Shells of *Gyraulus (Torquis)* species. **a**, *G. hornensis* F. C. Baker, holotype, Birch Lake, Horn River, about 75 miles above the Mackenzie River, Mackenzie District, Canada, UI Z13072a; **b**, *G. parvus* (Say), roadside swamp along Levering Road, Section 34, McKinley Township, Emmet Co., UMMZ 250587; **c**, *G. parvus* (Say), Lancaster Lake, Section 8, Munro Township, Cheboygan Co., Mich., UMMZ 250576; **d**, *G. parvus* (Say), Hook Point lagoon, Douglas Lake, Section 22, Munro Township, Cheboygan Co., Mich., UMMZ 250587. Scale lines = mm.

strings of words that were precise enough in a comparative way for fellow naturalists to recognize the previously described species, different authors named entities that were very close in morphological similarities. Compounding this problem was the relative lack of or difficulty in communication in the early years, the large size of North America and the great geographic distances between naturalists, and, for many workers, the lack of authentic comparative material.

DISCUSSION

Visual comparisons of 12 of the nominal species placed in *Torquis* show that three stand out as being noticeably different, *i.e.*, they would fit the definition of a morphological species. These are *Gyraulus parvus*, *G. circumstriatus* and *G. huronensis*. But, even among *G. parvus* and *G. circumstriatus* the distinctions are blurred in some specimens and in some museum lots. The other nine nominal species all seem clearly to be synonyms of either *G. parvus* or *G. circumstriatus* (except for *G. hornensis*, which has a few small differences; we are treating it as a subspecies at present). From a nomenclatural and systematic view, this reduces much clutter in the *Torquis* group, and clears the way for more indepth systematic and biological studies.

With this concept of the Torquis group in mind, the nomenclature of the subgenus may be reviewed as follows: *Gyraulus parvus* was the first species of the *Torquis* group to be named and described (Say, 1817). Dall (1905) made *G. parvus* the type species of his section *Torquis*. After Say's description, *Gyraulus parvus* was redescribed as a "new" species by Adams (1841; as "*Planorbis*" *elevatus*, from a spring in South Boston), by Gould (1847; as "*P.*" *vermicularis*, from the interior of Oregon), and by Lea (1864; as "*P.*" *billingsi*, from the Ottawa River, Canada West).

The next species of the *Torquis* group to be described was *Gyraulus circumstriatus* by Tryon (1866). The single character which most clearly distinguishes *Gyraulus circumstriatus* from *G. parvus* was given by Tryon: the slow increase in the size of the whorls. He also noted another distinguishing characteristic of *G. circumstriatus:* the commonly distorted shell in adult specimens. Other characteristics mentioned by Tryon are not necessarily diagnostic for *G. circumstriatus* (*e.g.*, the spiral lines, which in his specimens are a form of malleation). More recent descriptions of shells of *G. circumstriatus* and *Gyraulus parvus* add little of value as diagnostic characters.

The third and final species to be named in the *Torquis* group is *Gyraulus (T.) huronensis* (Burch & Jung, 1990).

The shells of *Gyraulus parvus*, *G. circumstriatus* and *G. huronensis* are small and planorbiform in shape. *Gyraulus parvus* and *G. circumstriatus* are most similar, and their morphologies can be compared as follows. The size of adult shells of both species is generally 3 to 4 mm in diameter, although in both species a few large specimens reach 5 mm or more in diameter. In average size (50 specimens measured), the shell of *G. circumstriatus* (3.67 mm) is somewhat larger than *G. parvus* (3.20 mm). In shells of the same diameter, *Gyraulus circumstriatus* has more whorls than *G. parvus* and is more tightly coiled. The whorls in *G. parvus* increase more rapidly in diameter than those of *G. circumstriatus*. This is especially noticeable in comparing the last whorls of the two species. The adjoining surface of the whorl with the preceding whorl is wider in *G. parvus* than in *G. circumstriatus.* Both species have a flat umbilicus and shallow, wide spire. The shape of the outer aperture is rounded-ovate in *G. parvus* and elongated-ovate in *G. circum-striatus* when the shell is viewed from the umbilical side. However, when the shell is seen in apertural (side) view, the shape of the inner and outer aperture is more rounded-ovate in *G. circumstriatus* than in *G. parvus* be-cause *G. parvus* is deflected to the umbilical side. The average body whorl height in *G. parvus* (0.814 mm in 50 specimens) is greater than in *G. circumstriatus* (0.814 mm in 50 specimens) when measured in side view. In both species, the length of the aperture is greater than the width, and the shell height is greater than the aperture height. Also, on the umbilical side, the shell diameter is less than on the spire side, producing an inverted body whorl angle. The color of *G. circumstriatus* is brown to very dark brown, which may be the result of its eutrophic habitat. *Gyraulus parvus* has a fresh yellowish-brown color, which may be the result of living in clean, running water.

The shell of *Gyraulus huronensis,* when compared to *G. parvus* and *G. circumstriatus,* is thicker, more solid, dark red or russet in color, and has a narrower, deeper inverted spire (Fig. 3d).

All three *Torquis* species (*Gyraulus parvus, G. circumstriatus* and *G. huronensis*) have fine transverse growth lines and lack spiral sculpture, except for the embryonic shell. SEM pictures of the embryonic shell show spiral striae sculpture in all three species. There seems to be little difference between the three species in this regard.

The major shell character used to distinguish between *Gyraulus parvus* and *G. circumstriatus,* the relative increase in whorl width, can be seen in our locally collected specimens. Whorls of the shell of *Gyraulus parvus* (Fig. 4b,c,d) increase with moderate rapidity; they increase more slowly in *Gyraulus circumstriatus* (Fig. 3b,c).

In addition to the 12 nominal species that clearly belong to the *Torquis* group, one other species, *Gyraulus latistomus,* needs to be mentioned. *Gyraulus latistomus* was included in our original list of *Torquis* species on the authority of Clarke (1973). However, in his original description, F.C. Baker (1932) compared *G. latistomus* with *G. deflectus obliquus,* not with a *Torquis* species. From our inspection of the holotype of *G. latistomus,* we conclude that it is not a *Torquis* species. In fact, it is probably not a *Gyraulus* species.

In addition to the four names of valid taxa (*i.e., Gyraulus parvus, G. circumstriatus, G. huronensis* and (?) *G. hornensis*), there seems to be at least one other species in the *Torquis* group, a diploid (n = 18, 2n = 36), based on somewhat fragmentary information of chromosome numbers (Natarajan *et al.,* 1965). The determination of this diploid species is one of the taxonomic points that needs yet to be resolved in *Torquis.*

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SEASONAL STUDIES ON *POMACEA PALUDOSA* IN CUBA

Gloria Perera and Mary Yong[1]

ABSTRACT. – Studies carried out in a Cuban lake having a dense population of *Pomacea paludosa* (Say) showed that the abundance of this snail varies according to abiotic factors, of which temperature and total hardness exert the most visible effect. Previous studies showed that the pH found in Cuban lakes is not as great a limiting factor for *P. paludosa* as it is for other snails. The reproductive peaks of *P. paludosa* were November and January, with a high density of egg masses (84 egg masses/m^2) on emergent vegetation. The highest percentage of adults was found during the warm season.

KEY WORDS – *Pomacea paludosa*, ecology, population dynamics, Cuba.

INTRODUCTION

Pomacea paludosa (Say) (Fig. 1) is the most common freshwater snail in Cuba, even on the Isle of Youth (Yong & Perera, 1984). It is the largest of our freshwater mollusks, reaching over 60 mm in shell-length. The biology of *P. paludosa* is of special interest for several reasons. It is of concern from the medical standpoint because of its ability to serve as intermediate host of *Angiostrongylus cantonensis* Chen, the causative agent of eosinophilic meningoencephalitis (Aguiar *et al.*, 1981), as well as for several trematodes that produce dermatitis (swimmer's itch) (Leedom & Short, 1981). *Pomacea paludosa* also has an economic importance because it is consumed in various Latin American countries, and locally in Cuba, and additionally, it is used in the handicraft industry.

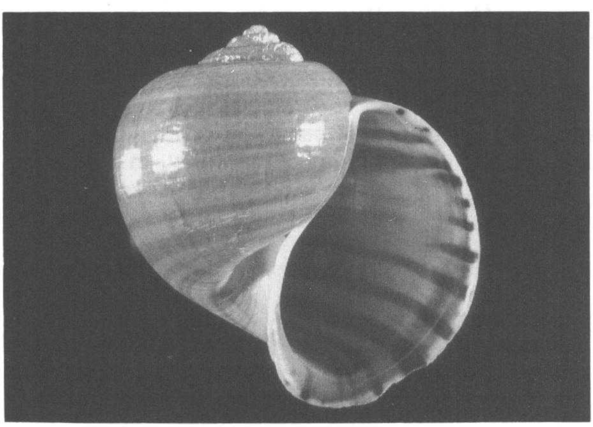

FIG. 1. Shell of *Pomacea paludosa* from El Rubio.

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Ferrer *et al.* (1989), studied aspects of the life history of *Pomacea paludosa,* while Perera *et al.* (1991) made anatomical and morphometrical studies. Seasonal studies of the density of *Pomacea paludosa,* as well as its reproductive peaks, are important because of the snail's medical and economical importance. The effectiveness of *Pomacea paludosa* as a biological control agent for pulmonate snails has been observed in the field (Perera, unpublished data), and other species of the same genus have been reported as effective competitors elsewhere (Paulinyi & Paulinyi, 1972; Milward de Andrade, 1978; Seytor *et al.*, 1985; Pointier, 1988).

MATERIALS AND METHODS

The studies were carried out under natural conditions between November 1988 and July 1991 in El Rubio Lake, near Havana. This is an artificial lake with shores that in the recent past were covered by *Typha dominguensis* Persoon and that are now bare because of a hurricane that changed the ecology. Gramineans dominate the habitat and the aquatic vegetation is limited to *Egeria densa* Planchon, which serves as the major food source for *Pomacea paludosa.*

Sampling was done manually with a sieve every fortnight in a 15-minute unit of time between 10:00 AM and 11:00 AM, always by the same person. The sampling was done in such a manner as to cover the bottom as well as the habitat's different strata of vegetation. The distance from the shore at which the sampling was done varied from 0.1 to 10 m. The maximum depth sampled was 0.85 m. The mollusks collected were counted and measured with a caliper (to an accuracy of 0.1 mm). From these data, the density and the evolution of the size-classes were determined.

Abiotic factors such as temperature, total hardness, pH, oxygen saturation and salinity, among others, were measured regularly, and ecological data such as distance from the shore, depth, coverage of vegetation and presence of migratory birds were recorded.

Voucher specimens have been deposited in the Malacological Collection of the Institute of Tropical Medicine, Havana, Cuba, and in the Museum of Zoology, University of Michigan, Ann Arbor, Michigan, U.S.A.

RESULTS

The variation of the density of *Pomacea paludosa* during the study period is shown in Fig. 2. At the beginning of the study, in November 1988, the

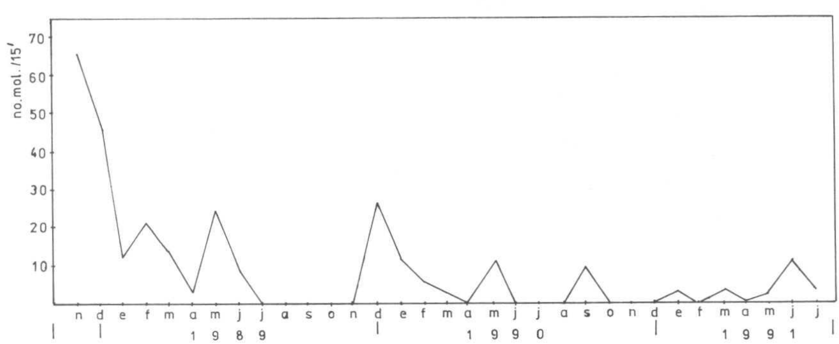

FIG. 2. Density of *Pomacea paludosa* during a 32-month period in El Rubio Lake.

snail density is notably high. In the months of February, May and December of 1989, May and September 1990, and June 1991, there was also an increase of snail densities, although not very great. The evolution of size-classes can be seen in Fig. 3. The samples in which a great number of juveniles were found are considered as the reproductive peaks. Such a peak was observed in November 1988, when an exceptionally large number of juveniles were present. The other reproductive peaks do not appear in a regular frequency, but coincide with months in which the temperature (Fig. 4) was not high. During the remainder of the year, adults were the predominant life history stage in the habitat.

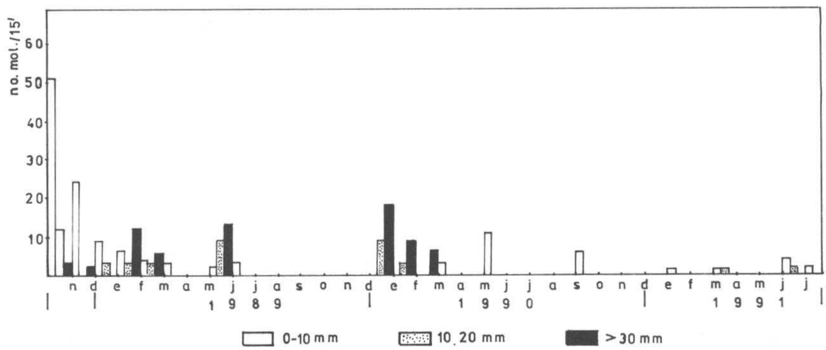

FIG. 3. Population dynamics expressed through size-class variation in El Rubio Lake during the study period.

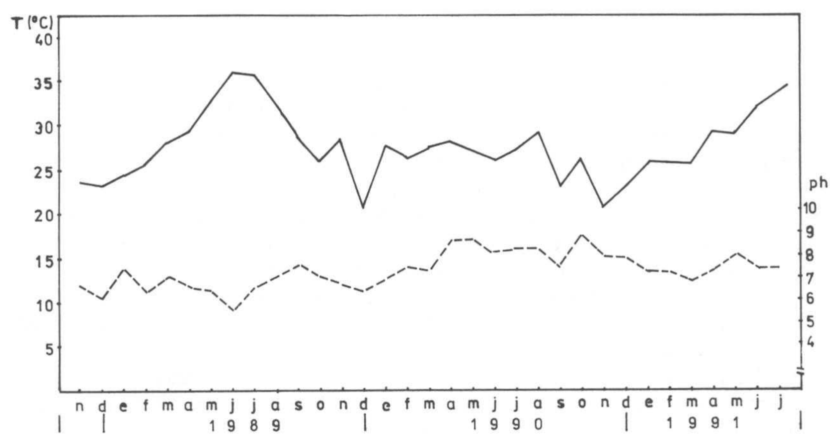

FIG. 4. Variation of temperature (T) and pH in El Rubio during the study period.

A large number of egg masses were also observed on emergent aquatic vegetation. The mean number of egg masses during the reproductive peaks was 84 egg masses/m^2.

Fig. 4 shows the variation of temperature and pH, and Fig. 5 shows the variation of total hardness and salinity. The temperature had more or less

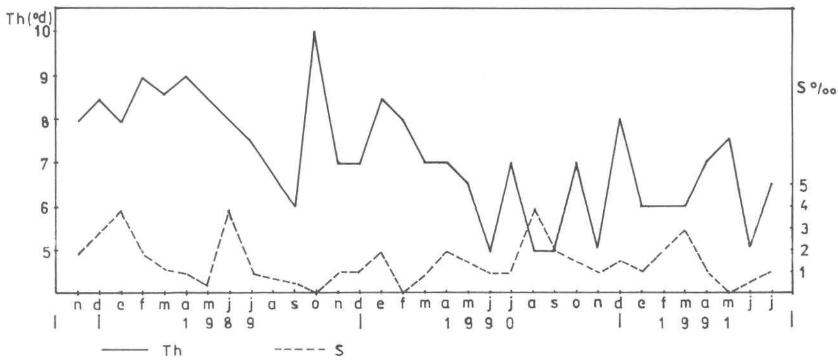

FIG. 5. Variation of total hardness (Th) and salinity (S) in El Rubio during the study period.

regular fluctuations except for the very high values found between June and July (1989 and 1991) while the pH had little variability. Total hardness had some slight variations. The largest peak was found in October 1989. Salinity varied from 0 to 4‰, being the values adequate for the development of snails.

DISCUSSION

Pomacea paludosa had the highest densities of juveniles during the months with lower temperatures, while the greatest densities in adult populations occurred in the months with higher temperatures. The unusually great abundance of juveniles in November 1988 may have been due to the consequences of exceptional meteorological conditions in June 1988, which changed the ecology of the lake. Six months later, the habitat was recovering and stabilizing, but the snail populations had experienced drastic changes. Perera & Yong (1984) showed that pH does not seem to affect the development of *Pomacea paludosa,* since this species is predominant in lakes with pH as low as 5.1. Total hardness may favor the density of the juveniles, since they need medium-hard waters for the development of their shells. According to Hubendick (1947), total hardness (regarded as calcium concentration), is an important factor for determining presence and well-being of snails. In waters with low calcium content, the shell is fragile and the abundance of mollusks is low. This factor is, in most cases, limiting for the existence of freshwater snails (Okland, 1983). Salinity does not seem to exert any influence since its variation remains within the limits of a stenohaline species. The oxygen saturation percentages varied slightly, being between 60%-80%.

As the habitat stabilized and the species balance recovered, the density then had only relatively moderate fluctuations, which may be associated with the changes of abiotic factors, mainly temperature and total hardness.

It should be mentioned that in the months when snail density was at a minimum, a great number of empty shells (with no sign of bird predation) were observed on the shores of the lake. This observation suggests that the restoration of the population begins after the summer months.

These results lead to the conclusion that the best time of the year to harvest *Pomacea paludosa* (for food consumption or for its use as a biological control agent) is during the warm season, leaving the cooler months for reproduction and the re-establishment of the population. Immediately after the summer months, a large number of empty shells can be collected for handicraft purposes.

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THYSANOPHORA HORNI (GASTROPODA: THYSANOPHORIDAE) IN SOUTHERN TEXAS: HABITAT CHARACTERIZATION AND LIMITS FOR PALEOENVIRONMENTAL RECONSTRUCTION

Raymond W. Neck[1]

ABSTRACT – *Thysanophora horni,* which has usually been characterized as a saxicolous terrestrial gastropod, has been found in leaf litter samples from southern Texas where surface rocks are absent. Newly reported collections indicate the occurrence of *T. horni* in wooded plant communities with locally conserved moisture. Use of this species as a paleoenvironmental index species is limited by broad geographic occurrence and likelihood of multiple invasions into the southern United States by stock of different geographical origins.

KEY WORDS – *Thysanophora horni,* index species, saxicolous, leaf litter, terrestrial gastropod.

INTRODUCTION

Thysanophora horni (Gabb, 1866) is a small terrestrial gastropod (3.5-5 mm diameter) that ranges from northern Mexico northward to central Texas and westward to Arizona (Pilsbry, 1940: 987; Bequaert & Miller, 1973: 55). Texas records are restricted to the South Texas Plains, Hill Country, and Trans-Pecos (Fullington & Pratt, 1974: 27, 46; Hubricht, 1985: 145). *Thysanophora horni* apparently is a Neotropical gastropod that has invaded portions of the more temperate part of the Nearctic Region (Bequaert & Miller, 1973: 54). The species was originally described from Fort Grant, Arizona, at the junction of the Arivapa and San Pedro rivers (Gabb, 1866). Pilsbry (1900) discussed characteristics of the shell of *T. horni* but gave no habitat analysis.

The purposes of this note are to document published and personal observations of living populations of *Thysanophora horni* in non-saxicolous as well as saxicolous habitats and to more accurately characterize the optimal microhabitat of this species in southern Texas. Such an ecological characterization is necessary to determine if *T. horni* can be utilized to produce accurate environmental reconstructions from Pleistocene and Holocene gastropod assemblages. A good paleoenvironmental index species must have a definable habitat that can be described in relation to geological, meteorological, or biological factors.

LITERATURE REVIEW

Malacologists have generally considered *Thysanophora horni* to be characteristic of saxicolous (rocky) substrates. Fullington & Pratt (1974: 27)

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reported it to be a "rare snail found among rocks in rather dry situations." Pilsbry (1940: 987) reported it from "both calcareous and volcanic soils ... usually found under stones, but sometimes under dead cacti or among grass roots." Records from western Texas, New Mexico, and Arizona often have no habitat notes (Pilsbry, 1889, 1897-1898: 105; Pilsbry & Ferriss, 1906; Hanna, 1923; Skinner, 1942), but those records with notes on environmental setting usually mention rocky habitats (Pilsbry & Ferriss, 1915b; Metcalf, 1970a, 1972, 1984), or montane areas that are presumably rocky (Dall, 1897; Ashmun, 1899; Ferriss, 1919; Pilsbry & Ferriss, 1909, 1910, 1911, 1915a, 1917, 1918, 1923). Ferriss (1915) found *T. horni* "among dry rocks on southern exposures" in the Copper King Mountains, New Mexico. *Thysanophora horni* was found in "leaf debris" associated with limestone rocks at Howells Ridge, New Mexico (Metcalf & Smartt, 1974). Pilsbry (1903) reported *T. horni* "in chaparral" near Monterrey, Nuevo Leon, Mexico, while Jacobson (1952: 111) found it under rocks at Topo Chico in Monterrey. Bequaert & Miller (1973: 55) reported that *T. horni* in the American Southwest is "usually a xerophile, indifferent to nature of terrain, soils, or type of vegetation, and often found where other snails are unable to survive." The latter characteristic was also mentioned by Ferriss (1920). In Baja California, *T. horni* is widespread in the southern third of the peninsula including several Cuff islands where it is found associated with granite rocks and leaf mold (Smith, *et al.*, 1990).

Interestingly, Hubricht (1985: 35) described the habitat of *Thysanophora horni* as "under logs, dead palm fronds, and trash; usually in woods, but also in rather open scrublands." The lack of mention of rocky habitats probably reflects Hubricht's collecting experience, which concentrated more on southern Texas than the desert and montane regions of western Texas, New Mexico and Arizona.

Records of *Thysanophora horni* in western Texas are from widely scattered regions. Records from the Guadeloupe Mountains are from McKittrick Canyon and Smith Spring (Fullington, 1979: 99). Pratt (1972: 24) found a single specimen "under a log in the deciduous woodland of Pine Canyon" in the Chisos Mountains. In the Franklin Mountains, *T. horni* is widespread on plant stems, in leaf litter, under rocks, and in limestone or rhyolitic talus. Habitat preference appears to be foothills and middle elevations (1360-2120m) below the montane forest zone (Metcalf & Johnson, 1971: 95, 104). Cheatum (1935) found *T. horni* in soil (moist from a nearby spring) underneath humus from hawthorn leaves in the Davis Mountains.

Most records of *Thysanophora horni* from southern Texas contain no habitat data (Pilsbry 1889, 1897-1898: 105; Strecker, 1935; Branson, 1960; Ideker, 1979). Indeed, Pilsbry (1940: 987) stated records from Brownsville were drift specimens as were most records listed by Strecker (1935: 14). However, Ferris (1920) previously had reported that *T. horni* "at Brownsville, Texas, is at home in leaf mold of the mesquite thickets." Bequaert & Miller (1973: 56) reported *T. horni* from "well-shaded leaf litter of damp, wooded bottomland" in Santa Ana National Wildlife Refuge, Hidalgo Co. As there are no rocky outcrops in the Brownsville/Santa Ana area, *T. horni* must live in a variety of non-saxicolous habitats. Occurrence of *T. horni* in the Rio Grande floodplain contrasts with the apparent absence of this species in the floodplain of the Nueces River (Singley, 1889). Singley (1893: 304) was unable to locate *T. horni* at either Corpus Christi or Galveston, both of which localities were reported by Binney (see Binney & Bland, 1869; also see Pilsbry 1897-1898).

METHODS

Soil samples have been obtained from numerous localities in southern Texas as part of a more comprehensive study of ecological and biogeographical relationships of terrestrial gastropods of Texas. Soil samples are subdivided via a series of nested soil sieves. Standard sieve sizes utilized are #2, #4, #8, #16, and #30. Snails are hand-picked from the resultant subsamples.

Thysanophora horni has been observed in and collected from the following collection localities:

Living collections

Bandera Co. Lost Maples State Park: 9 Jan 1975, soil/rock sample from under log on limestone slope of Glen Rose Formation, open deciduous broadleaf/juniper woodland.

Cameron Co. Brownsville: 9 July 1975, soil sample from remnant brush/palm woodland along Resaca de la Palma at Honeydale Road; 11 July 1975, second-growth thorn woodland on slope of artificial levee bordering Rio Grande (Fort Brown loop levee).

Rabb Palm Grove: remnant palm woodland on Resaca, 2 Nov 1983 and 21 Mar 1984, soil sample under fallen palm log.

Esperanza Ranch site: remnant native brush/palm woodland along Resaca de la Palma on eastern margins of Brownsville, 23 Dec 1980 and 22 Oct 1984, soil samples under palm log, mesquite trunk, and low area with leaf litter.

Resaca de la Palma State Park: Texas ebony-colima-brasil thorn woodland associated with remnant levee bordering Resaca de la Palma, 17 Jan 1979 and 12/13 Nov 1984, soil samples under downed wood.

West Palm Grove: Mexican palmetto - Texas sugarberry - tenaza woodland, 22 Oct 1984, soil samples under palm fronds and petiole bases.

Comal Co. New Braunfels: Landa Park, 12 June 1976, underneath rocks and railroad ties on clay soil developed from limestone of Edwards Formation (slope above Comal Springs), open deciduous woodland.

Goliad Co. Goliad State Park: 6 March 1975, under native calcareous sandstone of Goliad Formation and imported flagstone along nature trail, subtropical thorn woodland.

Kinney Co. Kickapoo Cavern State Park: Paper-shell pinyon woodland on slope above draw in Pine Canyon, 3 August 1988, soil sample under pinyon log with limited pinyon litter.

Presidio Co. Big Bend Ranch State Natural Area: Desert cottonwood woodlands on benches above various drainages, associated with springs, various dates from 13 Oct 1988 to 13 March 1989, soil samples under cottonwood logs and leaf litter.

Val Verde Co. Seminole Canyon State Park: Chisos red oak - Mexican redbud slope woodland below rock shelter in Presa Canyon, 26 April 1978, soil sample under oak leaf litter.

Debris collections

Presidio Co. Big Bend Ranch State Natural Area: fossil (early Holocene, Pleistocene?) shells in modern flood debris of South Fork of Alamo de Cesario Creek (Terlingua Creek drainage), downstream of Los Alamos, 12 March 1987, shells originated from unknown Quaternary deposits slightly upstream.

Val Verde Co. Seminole Canyon State Park: debris from high water level of Amistad Reservoir (Rio Grande) in Seminole Canyon (below Fate Bell Shelter #2), 29 July 1975, origin of shells could be anywhere in drainage of Seminole Canyon plus upstream portions of Rio Grande and all of Pecos River drainage.

Fossil collection

Uvalde Co. Smyth Crossing: archeological site (41UV60) on Nueces River crossing of FM 481, alluvial soil in open woodland of live oak (see Neck, 1987).

DISCUSSION

Habitat Characterization

If *Thysanophora horni* is a Neotropical species that has invaded the southern United States, then cold winters could be a major factor in determining the location of the northern margin of its geographical range. Bequaert and Miller (1973: 55) speculated that *T. horni* was a "thermophile rather than a xerophile." Note that Ferriss (1915) reported a preference for southfacing rocks in New Mexico. Absence of *T. horni* from higher elevations of the Franklin Mountains (El Paso) suggests that extended cold periods may preclude this austral species from colder microhabitats. However, populations in West Texas and farther west occur at latitudes and elevations that are certainly cooler than much of east Texas, which is not populated by *T. horni.* While the isolated montane populations in the southwestern United States may have become locally adapted to cooler (but less extreme) temperatures, one would expect similar adaptation to cooler temperatures in eastern Texas.

In eastern Texas, *Thysanophora horni* would encounter competition from an established terrestrial gastropod fauna that is adapted to mesic woodlands. At Goliad State Park *T. horni* is found under rocks (both native calcareous sandstone and foreign non-calcareous flagstone) in areas dominated by macrosnails typical of eastern Texas (Neck, unpublished data). However, the microsnails of these areas of Goliad State Park typically occur throughout Texas (in both eastern and central portions, some even into western Texas). This microhabitat that is occupied by *T. horni* is periodically too dry for microsnails of eastern Texas to survive. Therefore, there is no opportunity for competitive exclusion of *T. horni* by these eastern species.

The key factor limiting the geographical range and habitat occurrence of *Thysanophora horni* in southern Texas appears to be soil moisture. Moderate soil moisture levels are amenable to survival as long as the soil is not often saturated. This requirement for non-saturated soil moisture levels is almost eliminated in the mesic thorn woodland and palm grove areas of the Lower Rio Grande Valley of Texas. The Rio Grande, prior to recent reservoir construction, annually or semi-annually overflowed its bank. *Thysanophora horni* in these areas, is typically found in microhabitats characterized by slightly higher elevation and well-drained soils.

Occurrence of *Thysanophora horni* in these mesic floodplain habitats contrasts with its distribution in Arizona and New Mexico where "it is mainly a shell of low treeless mountains and foothills, not ascending to the humid, forested levels" (Pilsbry, 1940: 987). Possibly colder temperatures at higher elevations (above 1370m) preclude the occurrence of *T. horni* although Pilsbry (1940: 987) found it at 2120m in western Chihuahua. This latter locality was verified by Miller in 1966 (Bequaert & Miller, 1973: 55). Hoff (1962) did not find *T. horni* in central and north central New Mexico, possibly because mesic habitats suitable for terrestrial gastropods occur at elevations above the lower thermal limit of this species. The thermal limit of this species is probably related to sufficient period of warmth to allow successful reproduction, rather than an absolute low temperature limit.

Utilization in Paleoenvironmental Reconstruction

Thysanophora horni has been characterized as a species that "adapts to a wide variety of environments, from very dry (arid) to moderately humid (mesic)" (Bequaert & Miller, 1973: 55). Hubricht (1985: 34) reported that *T. horni* is "found under logs, dead palm fronds, and trash; usually in woods, but also in rather open scrubland." Such catholic habitat requirements could limit the value of this species in paleoenvironmental reconstructions.

Bequaert & Miller (1973: 56) remarked on the "puzzling" scarceness of *Thysanophora horni* in fossil assemblages. Fossil occurrences listed were from Arizona (Skinner, 1942: 152) and western Texas (King, 1948: 145; Metcalf & Johnson, 1971). However, *T. horni* has been reported in fossil deposits in western Texas and southern New Mexico by Metcalf and associates in montane habitats and caves (Metcalf, 1970b; Metcalf & Johnson, 1971; Metcalf & Smartt, 1974; Ashbaugh & Metcalf, 1986).

However, *Thysanophora horni* does appear to be less common than expected in fossil (alluvial) deposits (Metcalf, 1967, 1969). Rarity of *T. horni* from fossil deposits is intriguing because of its presence in modern Rio Grande drift (Metcalf, 1967; Branson, 1969). Clapp (1913) reported *T. horni* common in Rio Grande drift collected by R.D. Camp at Brownsville. McGee (1965) also reported *T. horni* as "abundant in drift in Cameron County." Ferriss (1924) reported *T. horni* "scarce in the drift" of the Devil's and Nueces rivers, Texas. Other records of *T. horni* in flood debris accumulations (Hinkley, 1907; Strecker, 1935; Branson, 1960; Branson *et al.*, 1966; Cheatum *et al.*, 1972) exist. Gardner (in Vanatta, 1928) reported *T. horni* from drift deposits from the Atascosa River, Live Oak Co., Texas. Vanatta (1912) reported *T. horni* in river drift from the Frio River (Frio Co.) and the Rio Grande (Maverick Co.), both in Texas. Hubricht (1960) recovered a few shells of *T. horni* from beach drift shells from Boca Chica and South Padre Island (just north of the mouth of the Rio Grande, Cameron Co., Texas). However, several collections of drift from New Mexico and Arizona reported by Walker (1915) did not include *T. horni*. Analysis of modern drift samples when compared to alluvial paleoassemblages and modern faunas can provide taphonomic information that will assist in paleoenvironmental reconstruction.

CONCLUSION

Thysanophora horni is apparently a thermophile, as suggested by Bequaert & Miller (1973: 55), that is limited by extended cold periods at increasing latitude and elevation. While the species may be excluded from eastern Texas by high soil moisture levels, the occurrence of *T. horni* in deep southern Texas appears to be limited to areas of locally high soil moisture levels, probably because increased soil temperatures produce higher rates of evaporation. Resultant soil desiccation reduces suitable microhabitat to areas that collect and conserve more moisture than the surrounding areas. In rocky areas, *T. horni* may be found as a fossil in cave and colluvial deposits but is rare in alluvial deposits downstream of these areas. Shells of *T. horni* can be abundant in alluvial deposits in non-rocky areas.

Utilization of *Thysanophora horni* as a significant indicator of paleoenvironmental microhabitats is somewhat limited because of the lack of an apparent constantly preferred microhabitat. In montane areas, *T. horni* could be useful to indicate relative temperature levels, in particular the relative length of inactivity periods resulting from cold weather. In southern Texas (and possibly the Hill Country of Texas), *T. horni* may be utilized to investigate relative moisture levels in relation to the length of drought periods. The southwestern desert and central southern Texas populations of *T. horni* appear to be geographically delineated, but represent a single species that may have colonized the southern United States from slightly different genetic stock and probably at different times. Ability to utilize *T. horni* in reconstruction of paleoenvironments will depend upon the familiarity of the worker involved with the particular environmental constraints acting upon this species in the area being studied.

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INFLUENCE OF TEMPERATURE ON THE GROWTH OF THE PESTIFEROUS LAND SNAIL *ACHATINA FULICA* (GASTROPODA: ACHATINIDAE)

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ABSTRACT – Growth rates in the giant African land snail, *Achatina fulica*, were studied under six constant temperatures, *viz.*, 10°, 15°, 20°, 25°, 30° and 35°C, and also under room temperatures (24.5°–32.8°C). The snails were supplied with different kinds of plant foods, either separately or collectively, to note any specific influence of the different food-plants. Under similar humid conditions, the snails (zero-day old) failed to maintain their activity while exposed to constant temperatures of 10°, 15° and 35°C. However, the snails maintained at 20°, 25° and 30°C exhibited a gradually higher growth rate with the increase of temperatures in 5°C increments. The highest growth rate was noted in the snails maintained at room temperatures. Of the five types of plant-foods offered, the snails consumed the most *Lactuca sativa*, irrespective of temperatures, while *Trichosanthes anguina, Basella rubra, Dolichos lablab* and *Cucurbita maxima* were next in order. At 20°C, the snails fed *L. sativa, T. anguina* and the mixed plant-food thrived beyond 24 weeks, while those fed *B. rubra, C. maxima* and *D. lablab* failed to survive beyond 7, 8 and 13 weeks, respectively. Biochemical experiments showed that the amount of carbohydrate, fat, protein and water per gram wet tissue of these plant-foods varied with the species. *Lactuca sativa* contained the highest (0.9393 g) and *D. lablab* contained the lowest (0.8014 g) amount of water; *C. maxima*, contained the most carbohydrate (0.016 g) and protein (0.05013 g), but the least fat (0.0002 g); *L. sativa*, had the least carbohydrate (0.00816 g) and protein (0.01255 g), but the most fat (0.00054 g) per gram wet tissue. In 24 weeks *A. fulica* gained in body weight, on an average, 16.3 g from *T. anguina*, 10.816 g from *L. sativa*, 4.01 g from *D. lablab*, 3.566 g from *C. maxima* and 2.288 g from *B. rubra*. Since the minimum growth level was highest for *T. anguina*, and the snails had the highest growth rate in accordance with the data obtained on 'minimum growth level' for each plant-food, it is suggested that the growth rate in *A. fulica* is determined by the 'minimum growth level' caused by the plant-food, and the 'minimum growth level' is influenced by temperature.

KEY WORDS – *Achatina fulica*, temperature, plant food, growth rates.

INTRODUCTION

The giant African land snail *Achatina fulica* Bowdich is a serious agri-horticultural pest in most of the Indo-Pacific countries (Mead, 1961, 1979; Godan, 1983; Raut & Ghose, 1984). It eats a wide range of food-plants and can live in a variety of climatic conditions. For these reasons, a wide range of variation in growth rates for *A. fulica* have been noted by workers from different parts of the globe, both in nature and under laboratory conditions (Mohr, 1949; Lange, 1950; Rees, 1950; Mead, 1961; Ghose, 1963; Kondo, 1964; Kekauoha, 1966; Raut & Ghose, 1978, 1984; Subba Rao *et al.*, 1981). Similarly, the impact of biotic and abiotic factors on growth rates of other

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terrestrial and aquatic snail species has been noted by DeWitt (1954), Frömming (1954, 1956), Fried & Goodchild (1963), Wolda (1971, 1973), Pollard (1973), Steen *et al.* (1973) Masurekar & Bangalkote (1976), Williamson (1976), Oosterhoff (1977) and Daguzan (1985). Regarding *Achatina fulica*, Ghose (1963) studied a number of parameters, *viz.*, length of shell, breadth of shell, number of spiral, length of shell aperture, breadth of shell aperture, length of ocular tentacle, length of ventral tentacle, length of visceral stalk, breadth of visceral stalk, length of foot, breadth of foot, body weight, rate of heart beat and rate of movement in his studies, while others (Mohr, 1949; Lange, 1950; Rees, 1950; Mead, 1961; Kondo, 1964; Kekauoha, 1966; Raut & Ghose, 1978) noted the growth rate only in shell length. In *A. fulica*, Ghose (1963) found that growth rate is maintained at a faster but uniform rate until the attainment of sexual maturity, and Kondo (1964) observed a similar phenomenon up to the adolescence stage. Other workers have also noted faster growth rates in other species of snails and slugs prior to attainment of sexual maturity.

It is believed that a number of biological and ecological factors are involved in regulation of the growth rate in molluscs. Since land molluscs become inactive with the fall of relative humidity (RH) below the critical level (Godan, 1983), temperature is considered as an important decisive factor in the life cycle of pulmonates in temperate and cold countries (Hyman, 1967). In cold countries, at the onset of winter snails cease their growth, bury themselves and pass into a quiescent state, starting to grow again in spring when the temperature rises to a certain point, (e.g., given as 13°C for the freshwater snail *Lymnaea humilis*; McCraw, 1961). Growth is inhibited by low temperatures in *Australorbis (= Biomphalaria) glabratus* (Michelson, 1961), *Bulinus truncatus* (Gaud & Dupuy, 1955) and *Helix aspersa* (Herzberg & Herzberg, 1960). Vaughn (1953), to the contrary, noted faster growth at low temperatures in *Lymnaea stagnalis*. However, in tropical and temperate countries terrestrial molluscs usually remain active throughout the year if RH and soil moisture are maintained at a favourable range. The freshwater snail *Lymnaea stagnalis* feeds on a number of food-plants at a varying rate under different conditions (Steen *et al.*, 1973; Mooij-Vogelaar & Steen, 1973). Steen *et al.* (1973) also found that growth rate in *L. stagnalis* was greatly influenced by the quantity of food. Although the quality of food controls the growth rate in *Helix pomatia* (Pollard, 1973) and *Cepaea nemoralis* (Oosterhoff, 1977), the influence of physical factors on growth is equally important. Daguzan (1985) demonstrated in France that *Helix aspersa* of commercial size could be produced within six months at 20°C, instead of 12 to 18 months under natural conditions. Although the combined effect of temperature and the quality of food-plants on the growth rate of the snails is not known, the influence of food (Wolda *et al.*, 1971), nutrients (Coe, 1948; Ino, 1953, 1958) and temperature (Loosanoff & Davis, 1952; Vaughn, 1953; Frömming, 1954; Gaud & Dupuy, 1955; Davis & Guillard, 1958; McCraw, 1961; Michelson, 1961; Herzberg & Herzberg, 1960) on the growth of some molluscs have been recorded.

Since land snails are moisture-loving creatures, a favourable range of RH and soil moisture is needed for *Achatina fulica* to be active. One assumes that the snails are getting such a range of RH and soil moisture in the areas where they occur. *Achatina fulica* thrives under a wide range of temperatures and accepts different kinds of plants as food, but the rate of growth varies with the different ecological conditions. In the present study, an attempt was made to determine the influence of temperature on growth rates of *A. fulica* in relation to different food-plants, to observe the rates of gain of important food constituents (carbohydrate, fat and protein) by the snails from these plant-food sources, and to determine the role of these food constituents in regulating the growth rate of *A. fulica*.

MATERIALS AND METHODS

A large number of sexually mature *Achatina fulica* were collected from their local habitats in Ballygunge, Calcutta, India, on 3 June 1985. They were released in a terrarium measuring 50 x 20 x 30 cm in size on the same day. The terrarium was provided with loose, moist soil up to 10 cm deep. The snails were supplied with lettuce (*Lactuca sativa*) regularly as their food. To keep the snails active, the soil of the terrarium was kept moist by regularly spraying with water. A strict hygienic condition was maintained throughout by removing the faecal pellets and unconsumed plant-foods. The snails started depositing eggs within a fortnight. The eggs hatched between 1-17 days after deposition. The newly-hatched (zero-day old) snails were used for the studies on growth rates of shell length, shell breadth, number of whorls, length of shell aperture, breadth of shell aperture, length of ocular tentacle, length of foot and body weight.

To study the influence of temperature on the growth rates of *Achatina fulica*, six B.O.D. chambers, each with a fixed temperature grade (10°, 15°, 20°, 25°, 30° and 35°C), were used. Wooden boxs measuring 35 x 10 x 20 cm were used to maintain the snails in each B.O.D. chamber. Each box was filled with loose, moist soil up to 5 cm deep. The upper side of the box was covered by a 0.1 mm mesh nylon net to prevent the snails from escaping. The required number of newly-hatched snails were released into the box and the box was placed inside the B.O.D. chamber. Similarly, one experiment was conducted under room temperature simultaneously with the experiments designed for fixed temperature grades. Thus, a total of seven experiments were conducted at the same time.

To study the influence of foods, if any, the same food-plants in the same portions were given in excess to the snails regularly. Depending on their agricultural importance, five plant species, *viz.*, snake gourd (*Trichosanthes anguina* Linnaeus), bean (*Dolichos lablab* Linnaeus), lettuce (*Lactuca sativa* Linnaeus), gourd (*Cucurbita maxima* Duchesne) and basella (*Basella rubra* Linnaeus) were used in the experimental studies. At the same time, one experiment was conducted with mixed food, *i.e.*, all five plant-foods were supplied together to the snails in excess in each of the six fixed temperatures, and in room yemperatures. Thus, growth rates were recorded under seven temperature grades with the supply of six types of foods. All the experiments with any one type of food were conducted simultaneously.

For each experiment, 10 newly-hatched (zero-day old) snails were used. Prior to the release of the snails into the experiment box, measurements were taken of all of the parameters considered for the study of growth. Also, records were maintained separately for all snails in regard to specific box. The plant-foods were weighed regularly before being supplied to the snails. Food materials not consumed by the snails were collected the next morning and weighed to determine the actual amount consumed by the snails. The record of food consumption was maintained daily until the experiments were terminated. Since the snails become sexually mature at the age of six months and they exhibited a varying rate of growth following the attainment of sexual maturity, the experiments were conducted for a period of 24 weeks. Data on the rates of growth in regard to eight different parameters were taken weekly throughout the study period. In all the experiments, 85-95% RH and 30-40% soil moisture were maintained throughout by spraying regularly with water.

To study the impact of food-plants on the growth of *Achatina fulica*, the total amount of carbohydrate, fat, protein and water received by the snails from the plant-food source was noted. For the same proximate constituents (except minerals and vitamins), *i.e.*, for the carbohydrate, fat, protein and water of the plants offered as foods, the amount of the carbohydrate, fat, protein and water in the snails' tissues were measured. The estimation of carbohydrate was made following the standard method proposed by Harding & Downs (1933) and modified by Plank (1936). The fat was estimated following the method described by ISI (1981). For estimation of protein, the Micro-Kjeldahl method described by ISI (1981) was followed. The wet tissues were dehydrated to determine the amount of water present in the plant foods, and in the body of the snails. Ranganna's (1978) method was followed for determination of water in both plant and snail tissues. Based on the amount of carbohydrate, fat, protein and water present in per gram wet plant tissue, the total amount of carbohydrate, fat, protein and water received by a snail during the 24-week period from the plant-food source was calculated. Also, the net gain of carbohydrate, fat, protein and water by the snails at the end of 24 weeks was determined following assay of the total tissues of the individual snails.

In 1985, experiments with only one food-plant, *viz.,Trichosantes anguina* were conducted. In 1986 and 1987, four sets of experiments with four types of food-plants were completed separately. The food-plants *Dolichos lablab* and *Cucurbita maxima* were tried in 1986, while in 1987 *Basella rubra* and *Lactuca sativa* were used. In 1988, experiments with only 'mixed food' were conducted. The experiments were started on 7 July 1985, and all the experiments were completed by December, 1988.

Voucher specimens are in the Zoological Survey of India, Calcutta (Reg. No. M21622/4).

RESULTS

The newly-hatched (zero-day old) snails *(Achatina fulica)* selected for the study of growth under different temperatures with varied plant-foods were of different sizes. The data on the measurements of eight different parameters, *viz.*, shell length, shell breadth, number of whorls, length of shell aperture, breadth of shell aperture, length of ocular tentacle, length of foot, and body weight of the snails taken at the time of initiation of experiments, are shown in Table 1. Data on the net growth of these parameters at the time of termination of the experiments are presented in Table 2 and the variations in the growth rates in shell length are presented in Fig. 1. The snails showed the maximum increase in regard to these parameters while maintained at room temperatures. Of the six constant temperature grades, 10°, 15° and 35°C were unfavourable for snail activities, while gradually higher rates of growth were noted in snails maintained in 20°, 25° and 30°C temperatures. However, the growth rates varied with the types of plant-foods offered. Irrespective of growth parameters, the snails fed on *Trichosanthes anguina* exhibited the highest growth in all tolerable temperatures. Growth rates noted in snails fed with 'mixed plant food' were second only to those of *T. anguina-fed* snails. Growth rates in individuals fed with *Lactuca sativa, Dolichos lablab, Cucurbita maxima* and *Basella rubra* were next in order.

Achatina fulica consumed all of the five types of plant-foods supplied. The rate of consumption varied with the type of plant food and the temperature grades in which the snails were exposed (Table 3). Temperatures of 20°, 25° and 30°C were favourable for feeding, but the snails consumed the maximum food at room temperature. The amount of food consumption was gradually less with the lowering of temperatures from 30° to 20°C. While the snails failed to take in food materials at 10° and 15°C, they were able to swallow a negligible amount of food within a period of 0-50 hours while exposed to 35°C. In these three temperature grades – 10°, 15° and 35°C, the snails became inactive within 3-5, 10-14 and 40-50 hours, respectively, following exposure immediately after birth. At 20°C, the snails fed with *Basella rubra, Dolichos lablab* and *Cucurbita maxima* failed to survive beyond 7, 13 and 8 weeks, respectively. During that period, an individual consumed 0.382 g *B. rubra*, 1.08 g *D. lablab* and 0.195 g *C. 4maxima* while being maintained separately. The snails ate *Lactuca sativa* maximum in all tem-

TABLE 1. Measurements (average) of *Achatina fulica* of zero-day taken initially for experimental studies.

GROWTH PARAMETERS

Temperature (°C) / Plant Species	Shell length (mm)				Shell breadth (mm)				Number of whorls				Length of shell aperture (mm)			
	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)
T. anguina	5.1	5.2	5.1	5.0	4.2	4.3	4.1	4.0	2.0	2.1	2.0	1.9	4.1	4.3	4.2	3.9
L. sativa 5.4	5.1	5.1	5.2	4.4	4.3	4.2	4.2	2.1	2.0	2.1	2.0	4.4	4.1	4.2	4.1	
D. lablab	5.3	5.2	5.3	5.2	4.2	4.2	4.4	4.2	2.1	2.1	2.1	2.0	4.2	4.3	4.3	3.9
C. maxima	5.2	5.1	5.2	5.2	4.3	4.2	4.2	4.1	2.1	2.0	2.1	2.0	4.2	4.2	4.2	4.0
B. rubra	5.3	5.3	5.3	5.3	4.3	4.3	4.2	4.4	2.1	2.1	2.1	2.0	4.3	4.3	4.2	4.2
Mixed*	5.1	5.1	5.2	5.2	4.3	4.3	4.3	4.3	2.1	2.0	2.0	2.0	4.2	4.3	4.2	4.1

Temperature (°C) / Plant Species	Breadth of shell aperture (mm)				Length of ocular tentacle (mm)				Length of foot (mm)				Body weight (g)			
	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)	20°	25°	30°	Room (24.5° -32.8°)
T. anguina	2.2	2.5	2.2	2.6	2.3	2.4	2.4	2.2	6.5	6.6	6.3	6.4	0.039	0.041	0.039	0.040
L. sativa	2.4	2.5	2.3	2.5	2.3	2.1	2.4	2.2	6.8	6.7	6.4	6.8	0.044	0.043	0.040	0.044
D. lablab	2.5	2.3	2.5	2.6	2.5	2.4	2.5	2.1	6.5	6.4	6.6	6.5	0.041	0.038	0.044	0.042
C. maxima	2.4	2.3	2.4	2.7	2.3	2.3	2.3	2.3	6.6	6.3	6.5	6.6	0.040	0.038	0.042	0.044
B. rubra	2.5	2.4	2.4	2.7	2.4	2.4	2.4	2.3	6.6	6.5	6.5	6.8	0.040	0.042	0.041	0.047
Mixed*	2.3	2.2	2.3	2.7	2.4	2.3	2.3	2.2	6.5	6.4	6.4	6.7	0.040	0.039	0.040	0.045

* All the five plant species were supplied together.

TABLE 2. Net growth of *Achatina fulica* maintained under different temperature grades with different food-plants.

GROWTH PARAMETERS

Temperature (°C) / Plant Species	Shell length (mm) 20°	25°	30°	Room (24.5° -32.8°)	Shell breadth (mm) 20°	25°	30°	Room (24.5° -32.8°)	Number of whorls 20°	25°	30°	Room (24.5° -32.8°)	Length of shell aperture (mm) 20°	25°	30°	Room (24.5° -32.8°)
T. anguina	26.4	33.8	40.4	46.7	14.8	17.4	21.4	24.9	2.7	3.1	3.6	4.0	15.7	18.7	23.4	26.1
L. sativa	6.0	25.0	34.7	38.4	3.0	12.4	17.5	20.0	1.0	2.9	3.4	3.5	3.4	13.6	20.7	21.9
D. lablab	3.4*	15.2	22.5	26.2	2.0*	7.9	11.4	12.6	0.6*	2.1	2.8	3.0	2.0*	8.7	12.9	14.3
C. maxima	1.3**	14.4	20.4	25.1	0.6**	7.8	10.5	12.6	0.4**	2.0	2.5	2.9	0.7**	8.2	11.5	14.2
B. rubra	0.9***	11.4	16.3	19.0	0.5***	6.2	8.8	8.4	0.4***	1.5	2.1	2.4	0.7***	6.5	9.6	9.9
Mixed	23.4	27.9	37.1	41.4	12.2	13.2	19.5	20.5	2.7	3.2	3.5	3.7	13.8	15.0	21.2	23.4

Temperature (°C) / Plant Species	Breadth of shell aperture (mm) 20°	25°	30°	Room (24.5° -32.8°)	Length of ocular tentacle (mm) 20°	25°	30°	Room (24.5° -32.8°)	Length of foot (mm) 20°	25°	30°	Room (24.5° -32.8°)	Body weight (g) 20°	25°	30°	Room (24.5° -32.8)
T. anguina	9.6	10.9	13.5	15.6	12.0	14.0	17.0	18.6	47.5	55.9	69.0	80.6	4.111	6.304	10.756	16.300
L. sativa 2.3	8.2	12.3	13.0	2.9	11.7	14.6	16.4	11.4	45.3	57.4	63.4	0.233	3.352	8.520	10.816	
D. lablab	1.3*	5.3	7.5	7.8	1.7*	6.9	10.0	11.5	6.0*	29.1	42.2	45.1	0.086*	1.302	2.661	4.010
C. maxima	0.5**	4.9	7.1	7.9	0.6**	7.2	9.3	10.6	2.5**	28.7	35.5	45.9	0.022**	1.167	2.068	3.566
B. rubra 0.4***	3.8	5.6	5.8	0.4***	5.3	7.8	8.6	1.6***	21.0	32.5	34.4	0.019***	0.733	1.574	2.288	
Mixed	8.0	8.6	12.3	14.0	10.4	12.3	15.6	18.0	43.5	48.2	61.2	71.5	2.838	4.016	9.930	12.845

*, **, ***: The snails survived for a period of 13(*), 8(**) and 7 (***) weeks, respectively, following exposure to respective temperatures after hatching.

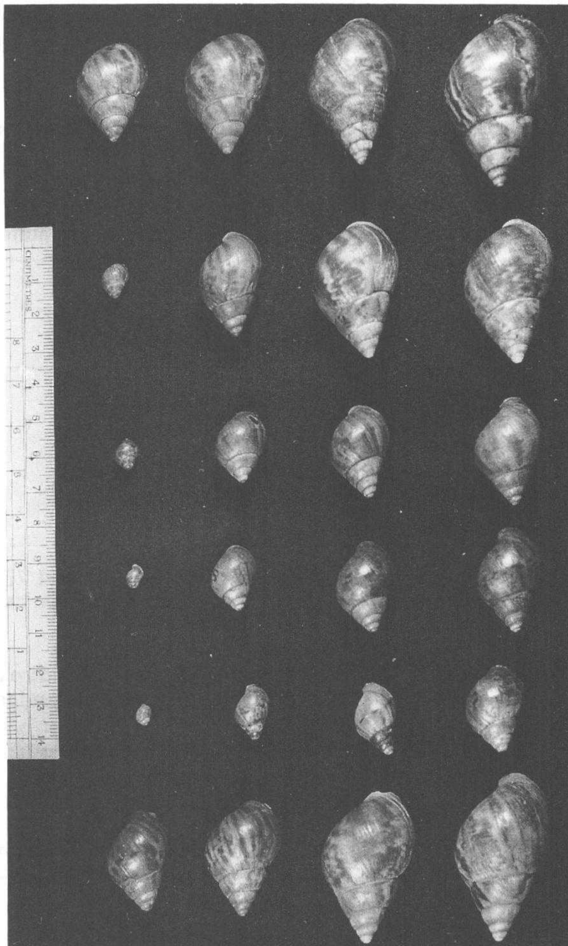

FIG. 1. Growth rate in *Achatina fulica* maintained under different temperatures with different foods. The photograph successively presents the snails exposed to 20°C, 25°C, 30°C and room temperatures (24.5–32.8°C) in rows from left to right. The shells are arranged in rows from top to bottom and indicate the shell size of *A. fulica* fed with *Trichosanthes anguina, Lactuca sativa, Dolichos lablab, Cucurbita maxima, Basella rubra* and mixed food successively. The shells shown are indicative of the growth of the shell of *A. fulica* in a period of 24 weeks, except those of the three snails as shown in the extreme left row fed with *D. lablab, C. maxima* and *B. rubra* failing to thrive beyond 13, eight and seven weeks, respectively.

perature grades and the consumption of other plant-foods was less in amount when supplied separately in all cases. From the results of experiments with 'mixed plant food,' a snail maintained at room temperature consumed 160.246 g *L. sativa*, 51.688 g *Trichosanthes anguina*, 2.976 g *B. rubra*, 2.816 g *D. lablab* and 1.24 g *C. maxima* during the period of 24 weeks (Table 4).

TABLE 3. Average total amount of each of the plant-foods consumed by *Achatina fulica* under different temperature grades in a period of 24 weeks since hatching.

Plant species	Amount consumed (g) at various temperatures (°C)			
	20°	25°	30°	Room (24.5°-32.8°)
L. sativa	5.947	85.873	166.072	225.120
T. anguina	42.064	65.254	118.128	206.910
B. rubra	0.382***	14.574	30.882	38.481
D. lablab	1.080*	12.945	25.892	37.265
C. maxima	0.195**	10.252	17.735	30.466
Mixed	47.064	78.713	156.216	218.966

*, **, ***: The snails survived for a period of 13(*), 8(**) and 7(***) weeks respectively following exposure to respective temperatures since hatching.

TABLE 4. Total amount of plant-foods consumed by *Achatina fulica* during the period of 24 weeks when supplied together, in excess, under different temperatures.

Temperature (°C)	Amount consumed (g)					
	L. sativa	*T. anguina*	*B. rubra*	*D. lablab*	*C. maxima*	Total
20	26.151	18.780	0.898	0.725	0.510	47.064
25	49.832	24.256	1.891	1.670	0.974	78.713
30	112.086	38.190	2.425	2.317	1.198	156.216
Room (24.5-32.8)	160.246	51.688	2.976	2.816	1.240	218.966

Since the snails maintained under different temperatures consumed a varying amount of plant foods (Table 3), an attempt was made to estimate the four proximate constituents, *viz.*, carbohydrate, fat, protein and water of the plant-foods. Of the five plant species, *Cucurbita maxima* and *Lactuca sativa* contained the highest (0.016g) and the lowest (0.00816 g) amount of carbohydrate, respectively; *L. sativa* and *C. maxima* contained the maximum (0.00054g) and the minimum (0.0002 g) amount of fat, respectively; *C. maxima* and *L. sativa*, had the highest (0.05013 g) and the lowest (0.01255 g) amounts of protein, respectively; and *L. sativa* had the highest amount (0.9393 g) and *Dolichos lablab* the lowest amount (0.8014 g) of water per gram wet tissue (Table 5). The estimations of total carbohydrate, fat, protein and water in the tissues of newly hatched snails are presented in Table 6. Based on the data on the mean total consumption of plant-foods by a snail during the 24-week period, calculations were made on the total gain of carbohydrate, fat, protein and water by the individual snails maintained under different temperature grades (Tables 7-10). Also, calculations on the rate of gain of these constituents by the snails from the plant-foods were made to note the variations, if any. The calculated data are presented in Tables 7-10. The total amount of carbohydrate, fat, protein and water received by the snails was estimated against individual plant-foods while supplied to the snails simultaneously in excess amount in the 'mixed food' experiment programme (Tables 11-14).

TABLE 5. Amount of some proximate constituents (g/g wet tissue) of the plants supplied as foods to *Achatina fulica*.

	Proximate constituents (g/g wet tissue)			
Plant species	Carbohydrate	Fat	Protein	Water
T. anguina	0.01554	0.00047	0.03759	0.82770
L. sativa	0.00816	0.00054	0.01255	0.93930
D. lablab	0.00973	0.00030	0.04821	0.80140
C. maxima	0.01600	0.00020	0.05013	0.82960
B. rubra	0.01050	0.00035	0.02207	0.90320

TABLE 6. Amount of proximate constituents (except minerals and vitamins) of *Achatina fulica* (without shell) of zero-day old taken from different broods.

	Proximate constituents (g) / g wet tissue	
	Range (Minimum - Maximum)	Mean ± SE
Carbohydrate	0.00578 – 0.00775	0.00696 ± 0.00045
Fat	0.00610 – 0.00755	0.00670 ± 0.00032
Protein	0.06559 – 0.06742	0.06662 ± 0.00041
Water	0.83595 – 0.85160	0.84200 ± 0.00396

Since the snails consumed a varying amount of plant-foods with the change of temperatures and the food-plant species, an attempt was made to interpret the data statistically with a view to ascertaining the influence of temperature or foods, or both, on the growth rates recorded for the snails. As the experiments were conducted initially with individuals of zero-day

TABLE 7. Net amount of carbohydrate gained by *Achatina fulica* following the consumption of plant-foods and the rate of conversion under different temperature grades.

Plant species	Carbohydrate (g)											
	20°C			25°C			30°C			Room (24.5-32.8°C)		
	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue
T. anguina	0.65367	0.03217	0.00076	1.01405	0.04780	0.00073	1.83571	0.10642	0.00090	3.21538	0.19384	0.00094
L. sativa	0.04853	0.00166	0.00028	0.70072	0.01967	0.00023	1.35515	0.06758	0.00041	1.83698	0.10504	0.00047
D. lablab		*		0.12595	0.00798	0.00062	0.25193	0.01838	0.00071	0.36259	0.02793	0.00075
C. maxima		**		0.16403	0.00799	0.00078	0.28376	0.01375	0.00078	0.48746	0.02456	0.00081
B. rubra		***		0.15303	0.00471	0.00032	0.32426	0.01055	0.00034	0.40405	0.01427	0.00037
Mixed	0.52987	0.01736	0.00037	0.83526	0.02851	0.00036	1.57526	0.09066	0.00058	2.18933	0.13224	0.00060

*, **, *** : The snails could not survive beyond 13 (*), 8 (**) and 7 (***) weeks.

TABLE 8. Net amount of fat gained by *Achatina fulica* following the consumption of plant-foods and the rate of conversion under different temperature grades.

Plant species	Fat (g)											
	20°C			25°C			30°C			Room (24.5-32.8°C)		
	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue
T. anguina	0.01977	0.02764	0.00066	0.03067	0.04253	0.00065	0.05552	0.09723	0.00082	0.09725	0.17776	0.00086
L. sativa	0.00321	0.00102	0.00017	0.04637	0.01663	0.00019	0.08968	0.06250	0.00038	0.12156	0.09630	0.00043
D. lablab		*		0.00388	0.00567	0.00044	0.00777	0.01382	0.00053	0.01118	0.02171	0.00058
C. maxima		**		0.00205	0.00542	0.00053	0.00355	0.01066	0.00060	0.00609	0.01888	0.00062
B. rubra		***		0.00510	0.00323	0.00022	0.01081	0.00790	0.00026	0.01347	0.01119	0.00029
Mixed	0.02358	0.01388	0.00029	0.03966	0.02339	0.00030	0.08027	0.08312	0.00053	0.11295	0.12473	0.00057

*, **, *** : The snails could not survive beyond 13 (*), 8 (**) and 7 (***) weeks.

TABLE 9. Net amount of protein gained by *Achatina fulica* following the consumption of plant-foods and the rate of conversion under different temperature grades.

Plant species	Protein (g)											
	20°C			25°C			30°C			Room (24.5-32.8°C)		
	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue
T. anguina	1.58119	0.21649	0.00515	2.45290	0.33567	0.00514	4.44043	0.76620	0.00649	7.77775	1.46128	0.00706
L. sativa	0.07463	0.01062	0.00179	1.07771	0.13577	0.00158	2.08420	0.48809	0.00294	2.82526	0.75474	0.00335
D. lablab		*		0.62408	0.05493	0.00424	1.24825	0.12534	0.00484	1.79655	0.19023	0.00510
C. maxima		**		0.51393	0.05247	0.00512	0.88906	0.09454	0.00533	1.52726	0.16661	0.00547
B. rubra		***		0.32165	0.03194	0.00219	0.68157	0.07307	0.00237	0.84928	0.10064	0.00262
Mixed	1.11447	0.11884	0.00252	1.70824	0.19484	0.00248	3.06752	0.64623	0.00414	4.21764	0.98315	0.00449

*, **, *** : The snails could not survive beyond 13 (*), 8 (**) and 7 (***) weeks.

TABLE 10. Rate of water gain by *Achatina fulica* from plant-food source under different temperature grades.

Plant species	Water (g)											
	20°C			25°C			30°C			Room (24.5-32.8°C)		
	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue	Total amount present in the plant tissues consumed	Total amount gained by animal tissues	Rate of gain(g) in animal tissue/ g plant tissue
T. anguina	34.81637	1.94763	0.04630	54.01073	2.72136	0.04170	97.77454	5.61995	0.04757	171.25940	9.98349	0.04825
L. sativa	5.58602	0.11522	0.01937	80.66051	1.21863	0.01419	155.99142	3.85398	0.02321	211.45521	5.68542	0.02525
D. lablab		*		10.37412	0.57685	0.04456	20.74985	1.17275	0.04529	29.86417	1.68678	0.04526
C. maxima		**		8.50506	0.55775	0.05440	14.71296	0.93239	0.05257	25.27459	1.52444	0.05004
B. rubra		***		13.16324	0.34957	0.02399	27.89262	0.76515	0.02478	34.75604	1.00076	0.02601
Mixed	41.92302	1.10823	0.02355	70.73821	1.67193	0.02124	141.93319	4.90694	0.03141	199.27458	7.15837	0.03269

*, **, *** : The snails could not survive beyond 13 (*), 8 (**) and 7 (***) weeks.

TABLE 11. Total amount of carbohydrate received by *Achatina fulica* following the consumption of five different plant-foods when supplied together, under different temperatures, during the period of 24 weeks.

Temperature (°C)	Amount of carbohydrate received (g)					
	L. sativa	*T. anguina*	*B. rubra*	*D. lablab*	*C. maxima*	Total
20	0.21339	0.29184	0.00943	0.00705	0.00816	0.52987
25	0.40663	0.37694	0.01986	0.01625	0.01558	0.83526
30	0.91462	0.59347	0.02546	0.02254	0.01917	1.57526
Room (24.5-32.8)	1.30761	0.80323	0.03125	0.02740	0.01984	2.18933

TABLE 12. Total amount of fat received by *Achatina fulica* following the consumption of five different plant-foods when supplied together, under different temperatures, during the period of 24 weeks.

Temperature (°C)	Amount of fat received (g)					
	L. sativa	*T. anguina*	*B. rubra*	*D. lablab*	*C. maxima*	Total
20	0.01412	0.00883	0.00031	0.00022	0.00010	0.02358
25	0.02691	0.01140	0.00066	0.00050	0.00019	0.03966
30	0.06053	0.01795	0.00085	0.00070	0.00024	0.08027
Room (24.5-32.8)	0.08653	0.02429	0.00104	0.00084	0.00025	0.11295

TABLE 13. Total amount of protein received by *Achatina fulica* following the consumption of five different plant-foods when supplied together, under different temperatures, during the period of 24 weeks.

Temperature (°C)	Amount of protein received (g)					
	L. sativa	*T. anguina*	*B. rubra*	*D. lablab*	*C. maxima*	Total
20	0.32819	0.70594	0.01982	0.03495	0.02557	1.11447
25	0.62539	0.91178	0.04173	0.08051	0.04883	1.70824
30	1.40668	1.43556	0.05352	0.11170	0.06006	3.06752
Room (24.5-32.8)	2.01109	1.94295	0.06568	0.13576	0.06216	4.21764

TABLE 14. Total amount of water received by *Achatina fulica* following the consumption of five different plant-foods when supplied together, under different temperatures, during the period of 24 weeks.

Temperature (°C)	Amount of water received (g)					
	L. sativa	*T. anguina*	*B. rubra*	*D. lablab*	*C. maxima*	Total
20	24.56363	15.54421	0.81107	0.58101	0.42310	41.92302
25	46.80720	20.07669	1.70795	1.33834	0.80803	70.73821
30	105.28237	31.60986	2.19026	1.85684	0.99386	141.93319
Room (24.5-32.8)	150.51906	42.78216	2.68792	2.25674	1.02870	199.27458

old and none survived beyond the 7th week when fed with *Basella rubra* at 20°C, data collected on the rates of food consumption and the growth of the individuals in respect to temperatures during the period of first seven weeks (Table 15; Figs. 2-4) were taken into consideration for statistical analysis. RBD (Randomised Block Design) random effect model was used for analysis of the data (see below).

Let y_{ijk} be the gain in body weight on the kth week observations corresponding to ith temperature and jth food-plant.

The linear model is

$$y_{ijk} = \mu + a_i + b_j + c_{ij} + e_{ijk};$$
$$i = 1,2,3,4;$$
$$j = 1,2,3,4,5;$$
$$k = 1(1)7;$$

where μ = additive constant,
a_i = effect due to ith temperature,
b_j = effect due to jth food-plant,
c_{ij} = interaction effect due to (a_i, b_j),
e_{ijk} = random error in y_{ijk}.

Assumptions:

(1) $[a_i]$ follows $N(o,\sigma_a^2)$.

(2) $[b_j]$ follows $N(o,\sigma_b^2)$.

(3) $[c_{ij}]$ follows $N(o,\sigma_c^2)$.

(4) $[e_{ijk}]$ follows $N(o,\sigma^2)$.

(5) $[a_i]$, $[b_j]$, $[c_{ij}]$, $[e_{ijk}]$ are independent.

To test the Hypotheses -

(i) H_{01}: there are no interactions between (a_i,b_j)

i.e., H_{01}: $\sigma_c^2 = o$ Vs $H_{11}: \sigma_c^2 > o$.

(ii) H_{02}: there are no food-plants effects $H_{02}: \sigma_b^2 = o$ Vs $H_{12}: \sigma_b^2 > o$.

TABLE 15. Average ± SE weekly growth rates in shell length and body weight of *Achatina fulica* in relation to the consumption of food-plant species during the first seven weeks under different temperatures.

	Amount consumed (g)				Shell length (mm)				Body weight (g)			
Temperature (°C) Plant species	20°	25°	30°	Room (24.5°-32.8°)	20°	25°	30°	Room (24.5°-32.8°)	20°	25°	30°	Room (24.5°-32.8°)
L. sativa	0.317 ± 0.047	1.332 ± 0.124	3.434 ± 0.551	6.256 ± 1.335	0.7 ± 0.08	1.8 ± 0.26	2.9 ± 0.22	3.7 ± 0.27	0.021 ± 0.004	0.099 ± 0.007	0.313 ± 0.058	0.540 ± 0.094
T. anguina	0.903 ± 0.164	1.508 ± 0.267	2.408 ± 0.386	4.522 ± 0.909	1.8 ± 0.07	2.8 ± 0.14	3.5 ± 0.34	4.6 ± 0.61	0.113 ± 0.020	0.252 ± 0.043	0.452 ± 0.065	0.855 ± 0.160
B. rubra	0.055 ± 0.014	0.371 ± 0.046	0.738 ± 0.121	0.999 ± 0.152	0.1 ± 0.04	0.9 ± 0.10	1.5 ± 0.13	1.6 ± 0.14	0.003 ± 0.001	0.029 ± 0.002	0.059± 0.006	0.089 ± 0.009
D. lablab	0.126 ± 0.011	0.333 ± 0.025	0.692 ± 0.090	1.128 ± 0.156	0.5 ± 0.05	1.5 ± 0.17	2.1 ± 0.31	2.7 ± 0.41	0.012 ± 0.001	0.068 ± 0.005	0.169 ± 0.020	0.266 ± 0.031
C. maxima	0.028 ± 0.006	0.317 ± 0.026	0.536 ± 0.049	1.390 ± 0.245	0.2 ± 0.06	1.4 ± 0.20	2.2 ± 0.27	2.8 ± 0.37	0.003 ± 0.001	0.067 ± 0.005	0.148 ± 0.014	0.249 ± 0.032

(iii) H_{o3}: there is no temperature effects $\equiv H_{o3}: \sigma_a^2 = o$ Vs $H_{13}: \sigma_a^2 > o$.

Sum of squares due to H_{o1},

$$SS(TXP) = \sum_i \sum_j \frac{T^2_{ij}}{7} - CF - SST - SSP$$

Sum of squares due to H_{o2},

$$SSP = \sum_j \frac{T^2_j}{28} - CF$$

Sum of squares due to H_{o3},

$$SST = \sum_i \frac{T^2_i}{35} - CF$$

Sum of squares due to total,

$$SS(T) = \sum_i \sum_j \sum_k y^2_{ijk} - CF$$

Sum of squares due to error, SSE = SS(T) - SST - SSP - SS(TXP)

Where T_{ij} =, T_i = =,
T_j = =, G =,
$CF = G^2/4x5x7 = G^2/140$.

Test statistics for

(1) H_{o1} is $F_{TxP} = (SS(TxP)/12)/(SSE/\gamma_e)$ follows F_{12}, γ_e under H_{o1}.
(2) H_{o2} is $F_p = (SSP/4)/(SSE/\gamma_e)$ follows F_4, γ_e under H_{o2}.
(3) H_{o3} is $F_T = (SST/3)/(SSE/\gamma_e)$ follows $F_3, \gamma e$ under H_{o3}

H_o is rejected if $F_{Calculated} > F_{Observed}$, γ_e = df of error = 120.

$$\text{Where } T_{ij} = \sum_k y_{ijk}, \quad T_i = \sum_j T_{ij} = \sum_j \sum_k y_{ijk},$$

$$T_j = \sum_i T_{ij} = \sum_j \sum_k y_{ijk}, \quad G = \sum_i T_i,$$

$$CF = G^2/4x5x7 = G^2/140$$

Test statistics for

$$(1)\ H_{o1} \text{ is } F_{TxP} = \frac{SS(TxP)/12}{SSE/\gamma_e} \text{ follows}$$

$$F_{12}\ ,\ \gamma_e \text{ under } H_{o1}$$

$$(2)\ H_{o2} \text{ is } F_P = \frac{SSP/4}{SSE/\gamma_e} \text{ follows}$$

$$F_4\ ,\ \gamma_e \text{ under } H_{o2}$$

$$(3)\ H_{o3} \text{ is } F_T = \frac{SST/3}{SSE/\gamma_e} \text{ follows}$$

$$F_3\ ,\ \gamma_e \text{ under } H_{o3}$$

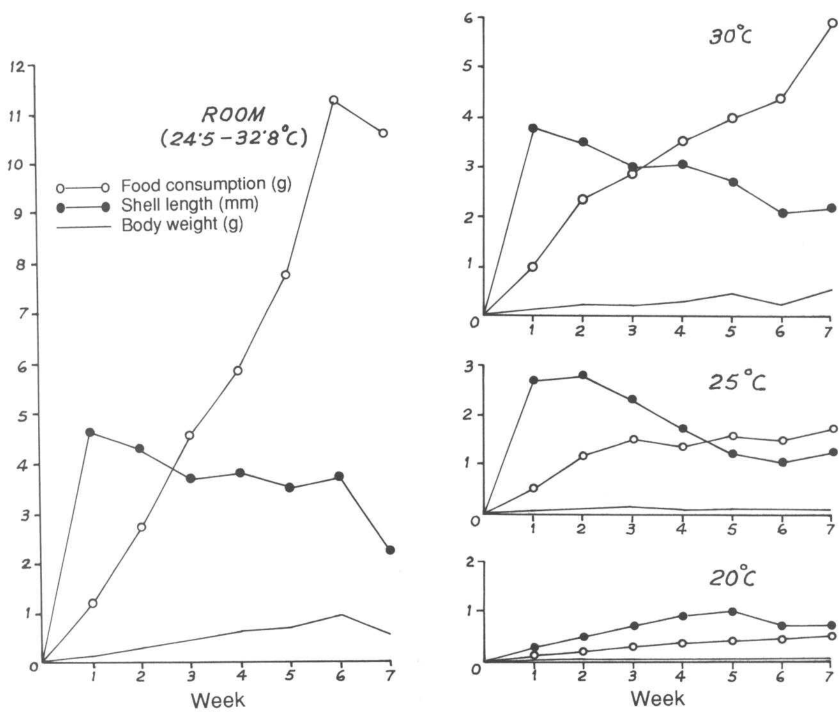

FIG. 2. Weekly growth rates in shell length and body weight of *Achatina fulica* under different temperatures during the period of first seven weeks since hatching following the consumption of *Lactuca sativa*.

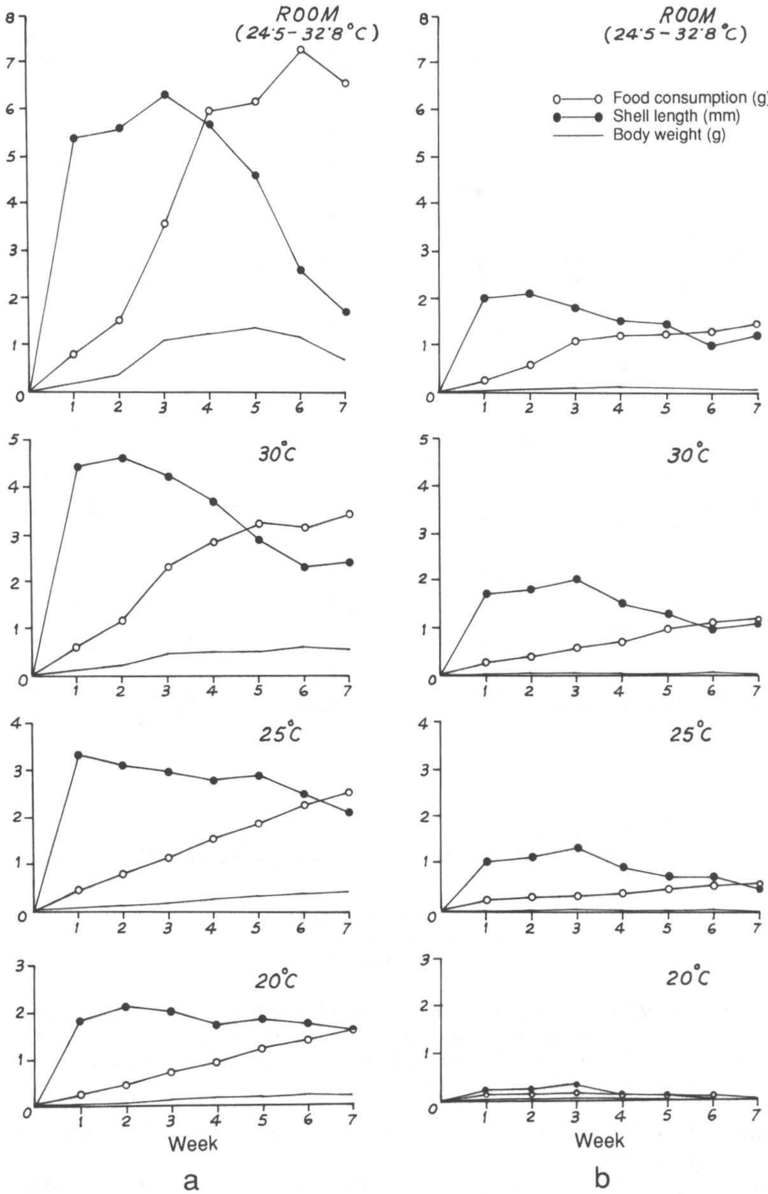

FIG. 3. Weekly growth rates in shell length and body weight of *Achatina fulica* under different temperatures during the period of first seven weeks since hatching following the consumption of *Trichosanthes anguina* (a) and *Basella rubra* (b).

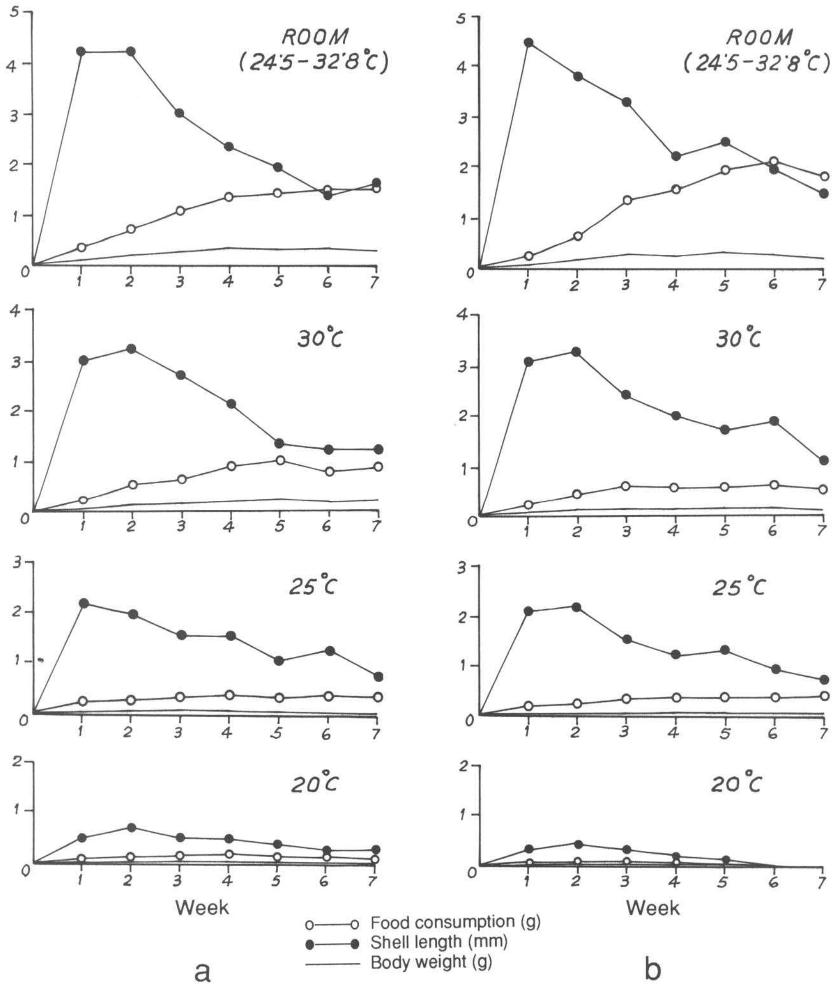

FIG. 4. Weekly growth rates in shell length and body weight of *Achatina fulica* under different temperatures during the period of first seven weeks since hatching following the consumption of *Dolichos lablab* (a) and *Cucurbita maxima* (b).

For temperature, l.s.d. = 0.1943 (at 5% level) and * (1,3), (1,4), (2,4) pairs differ significantly.

On the basis of observed data it appears that there exists a significant difference among the different interactions of temperatures and food-plants.

---

*1 ≡ Room temperature; 2 ≡ 30°C; 3 ≡ 25°C; 4 ≡20°C.

Now to study the best pair responding to the significant gain in body weight at different levels of temperature or among different types of food-plants or both least significance difference (l.s.d.) was calculated.

ANOVA Table 1. Analysis of variance to justify the role of temperatures and plant foods on the rate of gain in body weight of *Achatina fulica.*

Sources of variation	df	SS	$F_{calculated}$	$F_{observed}$ at 5% level
Temperatures (T)	3	2.7511	46.7280	2.68
Food-plants (P)	4	2.3828	30.3550	2.45
TxP	12	1.1139	4.8189	1.83
Error	120	2.3115	–	–
Total	139	8.5593	–	–

For food-plants, l.s.d. = 0.1738 (at 5% level) and ** (1,3), (1,4), (1,5), (2,5) pairs are significantly different.

To compare the effects of temperature and different types of food-plants on the growth in shell length of *Achatina fulica* RBD random effect model was used.

Let l_{ijk} be the gain in shell length on kth week corresponding to ith temperature and jth food-plant.

The linear model is $l_{ijk} = \mu + a_i + b_j + c_{ij} + e_{ijk}$; $i = 1(1)4$; $j = 1(1)5$; $k = 1(1)7$.

On the basis of the experimental data it may conclude that there is no significance interaction effect of temperature and food-plants on the shell length. But there is significant difference among different levels of temperature, and also among different types of food-plants on the basis of gain in shell length.

ANOVA Table 2. Analysis of variance to justify the role of temperatures and plant foods on the rate of gain in shell length of *Achatina fulica.*

Sources of variation	df	SS	$F_{calculated}$	$F_{observed}$ at 5% level
Temperatures (T)	3	108.3968	63.2710	2.68
Food-plants (P)	4	74.5703	32.6449	2.45
TxP	12	7.1932	1.0496	1.83
Error	120	68.5286	–	–
Total	139	258.6889	–	–

For temperatures, l.s.d. = 1.058 (at 5% level) and *(1,3), (1,4), (2,4) pairs are significantly different.

For food-plants, l.s.d. = 0.9463 (at 5% level) and **(1,3), (1,4), (1,5), (2,5), (4,5) pairs are significantly different.

** 1 ≡ *T. anguina;* 2 ≡ *L. sativa;* 3 ≡ *D. lablab;* 4 ≡ *C. maxima;* 5 ≡ *B. rubra*

Predictions on the best influencing food and the optimal temperature with respect to shell length and gain in body weight have already been made. Here the idea is to develop the linear or curvilinear relationship among the variables, if they are correlated, studied through the least square technique based on the data of 24 consecutive weeks when the experiments were conducted under room temperatures (24.5 - 32.8°C).

Denote, x = consumption of plant-food
y = gain in body weight;
z = gain in shell length.

Correlation Study

Food-plant	Correlation between (x,y)	Remarks
T. anguina	-0.0229476 [t = 0.1076621; p = 0.025]	not s.d.
L. sativa	0.3690198 [t = 1.862294; p = 0.025]	s.d.
D. lablab	0.3690198 [t = 1.862294; p = 0.025]	s.d.
C. maxima	0.4176544 [t = 2.156024; p = 0.025]	s.d.
B. rubra	-0.2647256 [t = 1.2876101; p = 0.05]	not s.d.

Food-plant	Correlation between (x,z)	Remarks
T. anguina	-0.8646469 [t=8.0726792] [p=0.025]	s.d.
L. sativa	-0.6896407 [t=4.4668839] [p=0.025]	s.d.
D. lablab	-0.2233667 [t=1.0748395] [p=0.025]	s.d.
C. maxima	0.0327644 [t=0.1537613] [p=0.025]	not s.d.
B. rubra	-0.8950616 [t=9.4142408] [p=0.05]	s.d.

Let the linear relationship between x and y be y = a + bx for a food-plant, when a, b are estimated by least square method. The normal equations are:

$$\sum y = na + b\sum x \quad \text{and} \quad \sum yx = a\sum x + b\sum x^2.$$

Food-plant	Estimated relationship
T. anguina	y=0.6978836-0.0021718x
L. sativa	y=0.2407685+0.0223772x
D. lablab	y=0.1053325+0.0397697x
C. maxima	y=0.0844113+0.0505523x
B. rubra	y=0.0729553+0.0139567x

Let X_{jk} be the amount of consumption of jth food-plant on kth week and Y_{jk} be the gain in body weight due to consumption of jth food-plant on kth week. Table 16 represents the data on the gain in shell length and body weight following the consumption of five types of food-plants for a period of 24 consecutive weeks since hatching in *A. fulica* maintained at room temperatures. Since in experiments the snails were not given the chance of feeding on any other plant-food except the supplied one, it is assumed that the correlations between food-plants (x_j and $x_{j'}$) are zero (for all $j \neq j'$). To fit a hypothetical model under the assumption of orthogonality to estimate the gain in body weight of the snail due to consumption of different food-plants at varying rates.

The model is,

$$y^{*} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5$$

Where a_j is the proportion by which jth food-plant will be consumed. Since x_j, $x_{j'}$ are orthogonal, on the basis of (X_{jk}, Y_{jk}); j = 1,2,3,4,5 and k = 1,2,3, ..., 24;

$$\sum yx_j = a_j \sum x_j^2$$

$$\Rightarrow \hat{a}_j = \sum yx_j \Big/ \sum x_j^2 \text{ , } j = 1,2,3,4,5$$

From the data, $\hat{a}_1 = 140.02993/2012.4679 = 0.0695811$
$\hat{a}_2 = 106.22455/2324.8097 = 0.0456917$
$\hat{a}_3 = 6.790979/72.0589 = 0.094242$
$\hat{a}_4 = 5.052446/49.0733 = 0.1029571$
$\hat{a}_5 = 3.745203/67.1936 = 0.0557374$

So, the estimated model equation is,

$y = -0.0695811\, x_1^{\dagger} + 0.0456917\, x_2 + 0.094242\, x_3 + 0.1029571\, x_4 + 0.0557374\, x_5$

This would prove helpful in predicting the gain in body weight of an individual if it is supplied with known proportion of plant-foods.

The model for shell length is, $z^{\S} = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$

Where b_j is the proportion by which jth food-plant will be consumed. Since x_j, $x_{j'}$ are orthogonal, on the basis of (X_{jk}, Z_{jk}); j = 1,2,3,4,5 and k = 1,2,3, ...,24;

$$\sum zx_j = b_j \sum x_j^2 \Rightarrow \hat{b}_j = \sum zx_j \Big/ \sum x_j^2 \text{ , } j = 1,2,3,4,5.$$

From the data, $\hat{b}_1 = 280.8036/2012.4679 = 0.1395319$
$\hat{b}_2 = 289.9084/2324.8097 = 0.1247019$
$\hat{b}_3 = 35.6299/72.0589 = 0.4944552$
$\hat{b}_4 = 32.5188/49.0733 = 0.6626577$
$\hat{b}_5 = 24.6582/67.1936 = 0.3669724$

So the estimated model equation is,

$z = -0.1395319\, x_1 - 0.1247019\, x_2 - 0.4944552\, x_3 + 0.6626577\, x_4 - 0.3669724\, x_5.$

This would prove helpful in predicting the gain in shell length of an individual if it is supplied with known proportion of plant-foods.

$^{*}1_y = Y(x_1, x_2, x_3, x_4, x_5)$, *i.e.*, at $X_1 = x_1$, Y_1, etc.; †–ve since correlation is negative; $^{\S}1_z = Z(x_1, x_2, x_3, x_4, x_5)$, *i.e.*, at $X_1 = x_1$, Z_1, etc.

TABLE 16 Average ± SE weekly growth rates in shell length and body weight of *Achatina fulica* in relation to consumption of food plant species during the period of 24 weeks under room temperatures (24.5-32.8°C).

Plant species	Amount consumed (g)	Shell length (mm)	Body weight (g)
L. sativa	9.380 ± 0.608	1.6 ± 0.29	0.451 ± 0.037
T. anguina	8.621 ± 0.630	1.9 ± 0.39	0.679 ± 0.060
B. rubra	1.603 ± 0.098	0.8 ± 0.12	0.095 ± 0.005
D. lablab	1.553 ± 0.157	1.1 ± 0.25	0.167 ± 0.020
C. maxima	1.269 ± 0.134	1.0 ± 0.26	0.149 ± 0.016

DISCUSSION

Our experimental studies show that growth rate in *Achatina fulica* is significantly influenced by temperature. Of the seven temperature grades considered, constant temperatures of 10°, 15° and 35°C were unfavourable for the *A. fulica*'s activity and thereby growth. In the remaining three constant temperatures, *viz.*, 20°, 25° and 30°C, the snails exhibited a gradually higher rate of growth with each incremental increase of 5°C. This indicates that increased temperatures were responsible for the successively higher growth rates. Although growth rates were gradually higher with the increase of temperature from 20°C to 30°C, maximum growth, irrespective of parameters, was noted in individuals maintained under room temperatures (24.5°-32.8°C). It should be mentioned here that although the room temperatures ranged from 24.5°-32.8°C, on the whole the snails were exposed to a mean temperature 28.6°C. It is assumed that the growth rate in these snails is between the rates noted for the snails maintained at 25°C and 30°C. But, in fact, the recorded net average growth in these snails, irrespective of parameters, was higher than that recorded for snails maintained at 30°C. This suggests that a fluctuating but favourable range of temperature is ideal for optimum growth of the snails.

Although temperature regulates the activity of *A. fulica* (Chock & Nakao, 1951; Mead, 1961; Raut, 1979; Raut & Ghose, 1984), reports on precise role of the said factor are still wanting. Since the food consumption rate varied with the temperatures, even after the supply of similar type of foods – it is evident that temperature regulates the rate of food consumption in *A. fulica*. Since all the experiments were conducted under similar conditions, *e.g.*, relative humidity and soil moisture, and the snails consumed gradually higher amounts of food with the gradual increase of temperature from 20°C to 30°C – it is certain that increased temperatures induced snails to swallow more foods. This phenomenon is also true irrespective of the plant-foods the snails consumed. Unlike growth rate, significantly higher consumption rate has been noted also in individuals maintained under room temperatures. It appears that in *A. fulica* temperature controls food consumption rate, and the growth rate is controlled by the food consumption rate.

From the foregoing accounts it is apparent that the entire phenomenon involved in feeding and growth in *Achatina fulica* is governed by the degree of temperature and the quality of food. This can be seen from the failure of the snails to survive more than 24 weeks while fed on *Basella rubra, Dolichos lablab* and *Cucurbita maxima* at 20°C. (Snails fed with only *B. rubra* did not survive beyond seven weeks; those fed with only *C. maxima* did not live longer than eight weeks; and those fed only on *D. lablab* died after 13 weeks). Since the snails fed with *Lactuca sativa, Trichosanthes anguina* and 'mixed food' thrived beyond 24 weeks and those fed with *B. rubra, C. maxima* and *D. lablab* did not, it seems that the rate of ingestion and digestion of food are also guided by the temperature. Of course, the physiological processes involved in digestion and assimilation of food in *A. fulica* are very much dependent on the efficiency for conversion of the proximate constituents (carbohydrate, fat, protein and water) of the ingested food materials into its own proximate constituents under a given temperature. It seems that such efficiency of an individual varied with the temperatures.

The results of biochemical experiments clearly indicate that the amount of carbohydrate, fat, protein and water per gram wet tissue of the plant-food varied with the plant species. Of the five food-plant species, *Lactuca sativa* contains 0.94g; *Basella rubra,* 0.9g; *Cucurbita maxima* and *Trichosanthes anguina,* 0.83g each; and Dolichos lablab, 0.8g water per gram wet tissue. If 0.94g water per gram wet plant tissue were essential for optimal growth, and as the snails have maintained their body water from the plant-food source, then the snails had to consume more *T. anguina, D. lablab* and *C. maxima* so as to maintain the level of the water demand as with *L. sativa.* But the situation is reverse, as the snails consumed these plant-foods less in quantity. In other words, if the amount of water present in *L. sativa* tissues is higher than the amount required by the snails, then the consumed amount would have been same both in *T. anguina* and *C. maxima.* But this was not the case. These anomalies suggest that it is not the amount of water taken in through the consumption of plant tissues but the amount of water gained by the tissues of the snails concerned. However, answers to such questions by no means satisfy the query for higher growth rate in *Achatina fulica* in relation to food-plants. This leads to the consideration of other factors like carbohydrate, fat and protein contents of the plant-foods consumed by the snails.

Of the five types of plant-foods, *Cucurbita maxima* contains both carbohydrate and protein in highest amount per gram wet tissue, but contains fat lowest in amount and *Lactuca sativa* contains the lowest amount carbohydrate and protein but the highest amount of fat. But, the snails fed with these plant-foods exhibited growth rates fourth and second in order. *Trichosanthes anguina*-fed snails showed the maximum growth rate in spite of the less amount of protein content than *Dolichos lablab* and *C. maxima.* The carbohydrate content of *T. anguina* is also less than the amount noted in *C. maxima.* The fat content is also less than the amount noted in *L. sativa,* but higher than those recorded from *D. lablab* and *C. maxima.* Thus, it appears that, like water, the amount of protein, carbohydrate and fat in the plant-foods, although playing an important role in regulating growth rate in *Achatina fulica,* does not *per se* explain the role of food-plant on snail growth.

During the 24-week experimental period, the snails consumed a varying amount of food in respect to temperatures and plant species. But, the data on the weekly total consumption of different plant-foods clearly indicate the variations in the rate of consumption of food at different ages of the snails concerned. Whatever may be the composition of food-plant tissues, if the plant is acceptable, the snails will swallow it. As a rule, at the initial stage, the rate of consumption would be low and at the same time the amount would be different depending upon the nutrient values or palatability of the plant species concerned. As is shown by our study, it is clear that under room temperatures the snails consumed *Trichosanthes anguina* at an increasing rate up to the 14th week, and thereafter, a steady state of consumption was maintained. Thus, at a particular per consumption rate, the snails must have received the carbohydrate, fat and protein accordingly per gram availability from the plant-food. This explains the faster growth observed in the first 14 weeks, and the steady state of growth in the remaining 10 weeks. This can also be seen from the snails' consumption of *Lactuca sativa, Dolichos lablab, Cucurbita maxima* and *Basella rubra.* Although the snails consumed foods gradually at a greater amount, the total weekly consumption declined on and after the 17th week, while it was maintained with *L. sativa* and *D. lablab*, and the 16th week while fed with *C. maxima.* The growth rate was also influenced accordingly with the rate of gain in carbohydrate, fat and protein from the plant-food source. Since the snails consumed *L. sativa* almost at an equal rate on and after the 5th week, the consumption was greatest in contrast to *T. anguina.* But, the growth was not as with *T. anguina*-fed snails, probably for two reasons. Firstly, *L. sativa* contains water in maximum quantity (94%), but carbohydrate (0.008%) and protein (0.01%) in minimum quantity. If carbohydrate, fat and protein were the determining factors for growth in *Achatina fulica,* then the snails had to consume a greater amount of *L. sativa* to maintain the growth rate shown by *T. anguina-fed* snails. As there is a limitation of ingestion of food materials in all animals in a given time, these snails were unable to engulf more *L. sativa* within a 24-hour period than they had consumed. Since the initial growth rate in the snails fed with *T. anguina* was higher than the snails fed with *L. sativa,* and the rate of feeding on *L. sativa* in the last few weeks was slightly low, the snails received less carbohydrate and protein and the snails exhibited slower growth rate.

The snails maintained with *Dolichos lablab* as their food showed a gradually reduced rate of consumption on and after the 12th week. The growth rate slowed down even when the net gain in shell length and body weight was very similar to *Lactuca sativa*-fed snails during the first two weeks. This was also true of the snails fed with *Cucurbita maxima* since the consumption was at a reduced rate on and after the 13th week. The snails' growth, although a steady state of consumption was maintained on and after the third week, was not as expected due to the low consumption rate. This phenomenon is also true of the growth rates in snails maintained under different temperature grades. As the rate of consumption was gradually less with the fall of temperature, the snails received the proximate components like carbohydrate, fat and protein lower in quantity and the growth rates varied accordingly. The failure of the snails to survive beyond the 7th, 8th and 13th weeks, respectively, when maintained on *Basella rubra, C. maxima* and *D. lablab* at 20°C may be due to their inability to add growth after some weeks of being fed *B. rubra, C. maxima,* and *D. lablab.* In some cases, a gradual loss in body weight had to occur, and consequently some individuals died within few days. It was observed that snails fed with *L. sativa* at 20°C failed to add to the respective growth parameters after the 15th week, although they continued feeding up to the 24th week. Of course, they also consumed gradually less amounts of food. That was why a gradual loss in body weight was noted in the following weeks.

Since seven snails died between the 15th and 24th weeks, it is most likely that the death was induced by malnutrition. This idea is strengthened by the death of all the individuals that were fed with *Dolichos lablab, Cucurbita maxima* and *Basella rubra* at 20°C between 7th and 13th weeks. The malnutrition may be due to the deficiency of essential components like carbohydrate, fat and protein or may have been due to the lack of minerals and vitamins (which have not been considered in the present study), or may be the joint effect of both.

The results of ANOVA and lsd tests indicate that there is a significant difference in the rates of growth both in body weight and in shell length in respect to temperatures and the types of food-plants. It is also clear from the study of pair tests that the snails would exhibit almost similar trend of growth under ecologically similar conditions at room temperatures (24.5-32.8°C) and constant 25°C; at room temperatures and constant 20°C; and at constant 30 and 20°C. Similarly, the snails, if fed with *Trichosanthes anguina* or *Dolichos lablab;* with *T. anguina* or *Cucurbita maxima;* with *T. anguina* or *Basella rubra;* and with *Lactuca sativa* or *B. rubra* would have shown a significant trend of growth at least in shell length and body weight. However, *C. maxima* and *B. rubra*-fed snails followed the expected only in gain of shell length. Thus, it appears that *Achatina fulica* would grow faster under low temperatures between 20-25°C in any part of the globe, while a similar rate of growth would be seen if they are maintained under room temperatures (24.5-32.8°C) in tropical and sub-tropical countries, at least in India. Whether it may be a temperate or a tropical country, it is at least evident from the findings of Daguzan (1985) on *Helix aspersa* that those snails prefer temperatures around 20°C for optimum growth.

Achatina fulica exhibited maximum growth in all parameters only when fed with *Trichosanthes anguina.* But from a statistical point of view, the rate of consumption of *T. anguina* and the rate of growth in body weight exhibited by a snail are negatively correlated and not statistically significant. Although a positive correlation between the rate of food consumption and the rate of growth in body weight has been noted in snails fed with *Lactuca sativa, Dolichos lablab, Cucurbita maxima* and *Basella rubra* separately, it is certain that these food-plants would not be utilized in the farming of *A. fulica.* Because, the rate of growth is always dependent on the habit of consumption of foods, at least to a level that would enable the snail to retain its body weight. This is, of course, dependent on the availability of preferred food-plants by the snail. Since the snails were compelled to feed on less preferred plant-foods, they had to consume a certain amount of food at least to keep them alive. The rate of consumption of *B. rubra, C.*

maxima and *D. lablab* by the snails, although less, was still enough to keep growth at an increasing rate. This explains why significant growth rates were noted in spite of the smaller food consumption, and less total growth at the end of 24 weeks.

Whatever may be the factors, either known or unknown, that promote the growth rate of *Achatina fulica*, our study clearly indicates that faster growth rate is associated not only with the feeding of food-plants having the necessary amount of carbohydrate, fat and protein (may be true of minerals and vitamins) in their tissues, but also on the fact of 'minimum growth level' by the particular food-plant. If the 'minimum growth level' falls below the level that would allow an individual to grow more; and, if such a reduced level continues for a few weeks, the body weight will gradually start to fall. This was shown by the death following gradual reduction in body weight in the snails fed with *Basella rubra* and *Cucurbita maxima*. From the linear relationship between the food consumption rate and the gain in body weight it is clear that *A. fulica* exhibits the 'minimum growth level' 0.072 and 0.084 for *B. rubra* and *C. maxima*, respectively. To the contrary, the 'minimum growth level' estimated for *Dolichos lablab*, *Lactuca sativa* and *Trichosanthes anguina* was 0.105, 0.24 and 0.697, respectively. In fact, the average total growth irrespective of parameters as have been recorded in the present study supports the idea because the snails fed with the food-plants having highest level of minimum growth rate (*e.g.*, *T. anguina*) added the maximum to all the growth parameters. As the levels of minimum growth rate of *L. sativa*, *D. lablab*, *C. maxima* and *B. rubra* were next in order, the snails fed with these food-plants showed the mean total addition to the growth parameters gradually less in respect to food-plants. Although an increased growth rate was noted with the rise of temperature, it is evident that the same is dependent upon the 'minimum growth level' of the individuals concerned following the consumption of a particular type of plant-food. It is estimated that the snails would gain in body weight 0.022g from *L. sativa*, 0.039g from *D. lablab*, 0.05g from *C. maxima* and 0.013g from *B. rubra* , and would lose 0.002g following the consumption of *T. anguina* for increase of every 5°C in temperature. If the calculated growth rate to be gained by the snails in respect to increase of 5°C temperature is added to the calculated minimum level of growth by each food-plant species, then the total amount would be 0.695g for *T. anguina*, 0.262g for *L. sativa*, 0.144g for *D. lablab*, 0.134g for *C. maxima* and 0.085g for *B. rubra*. This indicates that the snails fed with *T. anguina*, *L. sativa*, *D. lablab*, *C. maxima* and *B. rubra* would exhibit the same order of growth as the previous in respect to the food-plants even after adding 5°C temperature. Since the data recorded on the growth rates of *A. fulica* fed with these five plant species are in complete agreement with the idea, it can safely be concluded that the growth in *A. fulica* is determined by the level of minimum growth rate caused by the plant-foods available to them.

As *Achatina fulica* is a serious agri-horticultural pest, attempts are being made to control it, either through ecological management policies or through the utilization of its flesh as protein-rich diet. Our findings would prove helpful in both the cases. Since *A. fulica* has a wide range of food-plant acceptability (Mead, 1961; Raut, 1979), the infested areas can be kept free from cultivation of those food-plants, at least for few years, which enable the snails to continue living by maintaining its minimum level of growth. This would compel the snails to feed on the food-plants which do not favour the snails to maintain the lowest level of growth rate. The snails would gradually lose their body weight and finally would die. In the long run, population decline would be noticed. On the other hand, for mass rearing with a view to getting more flesh (for edible species), the snails must be supplied with the food-plants which favour the snails in maintaining their minimum growth rate at the highest level. These findings may be applied to management and culture of any terrestrial herbivore mollusc.

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RECENT COLLECTIONS OF FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) FROM WESTERN NEW YORK

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ABSTRACT - We surveyed the unionid faunas of 52 sites in western New York between 1987 and 1990. We found living populations of 23 species, including *Villosa fabalis* and *Lampsilis fasciola*. A subfossil shell of *Obovaria subrotunda* from the Allegheny River basin represents the first record of this species from New York. Many of the unionid communities of the Allegheny River basin are intact, whereas many communities of the Great Lakes basin in the Buffalo metropolitan area have been destroyed. Between six and 17 species have apparently been lost from the formerly rich fauna of the Niagara-Erie basin. We review geological evidence to support the idea that the Niagara River may have held some rare Ohioan unionid species until recently.

KEY WORDS - Unionidae, New York, Niagara River, Allegheny River, ecology, distribution, endangered species.

INTRODUCTION

Western New York forms the northeastern boundary of the Ohioan unionacean province. While some Ohioan species are found in central and eastern New York (Clarke & Berg, 1959; Harman, 1970; Strayer, 1987), the representation of Ohioan species drops sharply from Buffalo to Albany and farther east. Western New York, therefore, represents both the gateway of postglacial faunal exchange between the Ohioan and Atlantic Slope unionid faunas and a potential refuge for increasingly scarce Ohioan species (cf. Stansbery, 1970).

The only major work on the molluscan fauna of western New York was done by Robertson & Blakeslee (1948), although a number of important records were published by Lewis (1874), Marshall (1895), Letson (1909) and Baker (1928). We surveyed the waters of western New York to determine the present status of unionid populations, especially for several rare species known historically from the region, and to gather distributional records from areas (chiefly the Allegheny basin) that were overlooked by previous authors.

THE STUDY AREA

This paper is concerned with the area west of the Genesee River basin in New York, encompassing parts of the Allegheny River, Lake Erie, Niagara River, and Lake Ontario basins (Fig. 1). Almost all of this area was

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so the various sedimentary rocks of the region are mantled by a wide variety of glacial deposits (Richard & Fisher, 1970; Cadwell, 1988). The land is rolling, and supports agricultural fields and forests as well as urban and suburban areas. Metropolitan Buffalo (roughly bounded by stations 28, 36, 44, and 30 on Fig. 1) is the only large city in the region. Streams in the area range in size from headwater streams to the Allegheny and Niagara Rivers, with mean annual discharges of 79 and 5,777 m^3/sec, respectively (Hood *et al.*, 1983). Stream water in the study area typically is hard and nutrient-rich (*e.g.*, Hood *et al.*, 1983).

METHODS

We visited 52 sites in the study area (Fig. 1; Table 1) during the summers of 1987, 1989, and 1990, chiefly during periods of low, clear water. We collected mussels by handpicking while wading or snorkeling, sometimes with the aid of glass-bottom buckets. At a few very turbid sites, we searched for mussels with our hands, which greatly reduced the efficiency of our survey. Most specimens were identified and returned immediately to the sediments. Voucher specimens from this work have been deposited in the New York State Museum (NYSM) in Albany. In addition, we searched the collections of the Museum of Comparative Zoology (MCZ), the American Museum of Natural History (AMNH), the New York State Museum (NYSM), and the Buffalo Science Museum (BSM) for relevant lots. Mussel nomenclature follows Turgeon *et al.* (1988).

RESULTS AND DISCUSSION

The upper Allegheny drainage in New York (stations 1-26) now contains a typical Ohioan headwater assemblage of 15 species, plus two species known only from old, empty valves (Table 2). All 17 of these species were reported from the Allegheny drainage in Pennsylvania (Ortmann, 1919). An additional 20 species are known historically from the lower Allegheny drainage in Pennsylvania (Ortmann, 1919), but most of these are large-river species that would not be expected to occur as far upstream as New York. A few species found by Ortmann but not by us *(e.g., Pleurobema clava, Quadrula cylindrica, Villosa iris)* do occur in small streams and may yet turn up in New York.

All but two of the 15 species now found in the New York waters of the Allegheny drainage are common and widespread. *Villosa fabalis*, recently listed as a Category Two species (possibly endangered or threatened) under the Federal Endangered Species Act, lives in a short stretch of Olean Creek (stations 17-19). The population probably is small. All shells and the living animal we found were on shallow, gravelly riffles among *Myriophyllum*, apparently the typical habitat for this species (Ortmann, 1919; van der Schalie, 1938). The only other records of *V. fabalis* from New York are from Chautauqua Lake and its outlet (Ortmann, 1919). *Lampsilis fasciola* is found in small numbers at several sites in the upper Allegheny drainage in New York. This Ohioan species is rare throughout much of its former range (van der Schalie, 1975; Cummings & Berlocher, 1990). Previous records of *L. fasciola* from New York include a few historical records from the Great Lakes basin in western New York (Marshall, 1895; Robertson & Blakeslee, 1948).

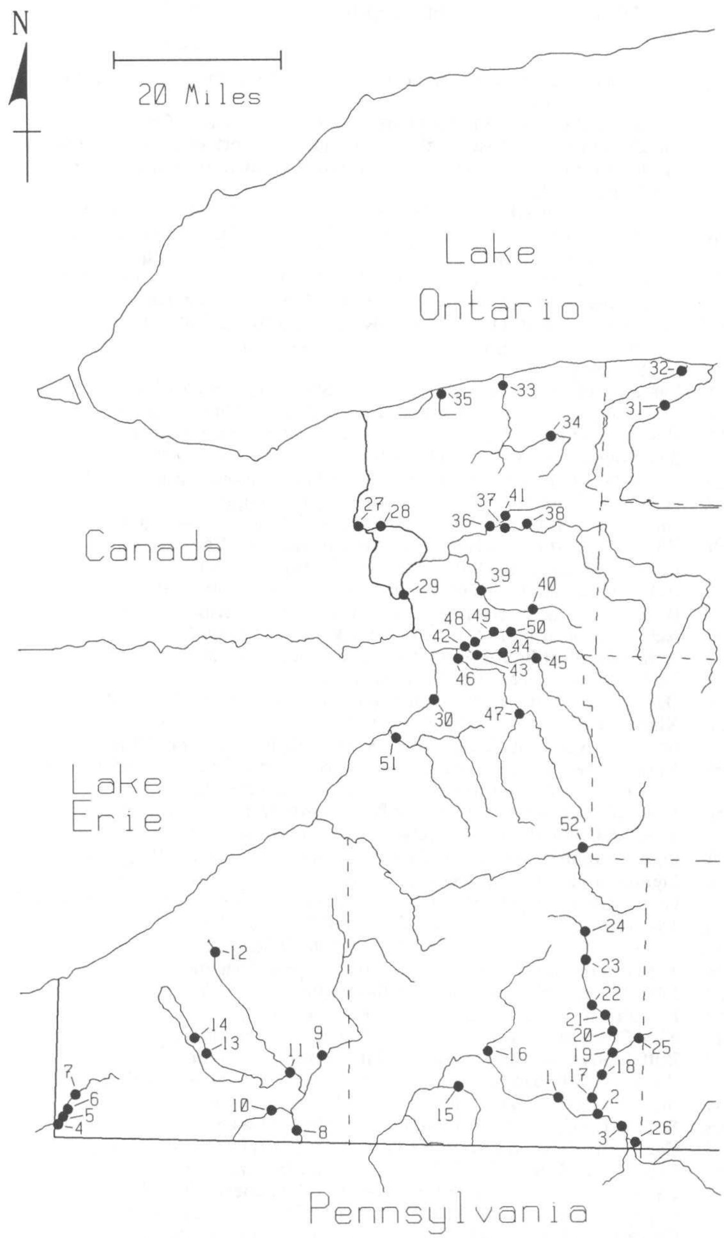

FIG. 1. Collecting sites in western New York. Dashed lines show county boundaries. See Table 1 for precise locations of sampling sites.

TABLE 1. Location of sampling sites shown in Fig. 1.

1. Allegheny River at Route 17 downstream of Allegany, town of Allegany, Cattaraugus Co.
2. Allegheny River at Route 16, town of Olean, Cattaraugus Co.
3. Allegheny River at Steam Valley Road, town of Portville, Cattaraugus Co.
4. French Creek at New York-Pennsylvania line, town of French Creek, Chautauqua Co.
5. French Creek at White Hill Road, town of French Creek, Chautauqua Co.
6. French Creek at Marvin Road, town of French Creek, Chautauqua Co.
7. French Creek at King Road, town of French Creek, Chautauqua Co.
8. Conewango Creek at Riverside Road, town of Kiantone, Chautauqua Co.
9. Conewango Creek at Route 62, town of Poland, Chautauqua Co.
10. Stillwater Creek at Bacon Road, town of Kiantone, Chautauqua Co.
11. Junction of Conewango Creek and Chadakoin River, town of Ellicott, Chautauqua Co.
12. Cassadaga Creek at Luce Road, town of Stockton, Chautauqua Co.
13. Chautauqua Lake at Bemus Point, town of Ellery, Chautauqua Co.
14. Chautauqua Lake at Long Point, town of Ellery, Chautauqua Co.
15. Red House Brook at Route 17, town of Red House, Cattaraugus Co.
16. Great Valley Creek at Route 219, town of Great Valley, Cattaraugus Co.
17. Olean Creek at Route 16, town of Olean, Cattaraugus Co.
18. Olean Creek at Union Valley Road, town of Olean, Cattaraugus Co.
19. Olean Creek at Dutch Hill Road, town of Hinsdale, Cattaraugus Co.
20. Ischua Creek at Farwell Road, town of Ischua, Cattaraugus Co.
21. Ischua Creek at Dutch Hill Road, town of Ischua, Cattaraugus Co.
22. Ischua Creek at Pierce Hill Road, town of Franklinville, Cattaraugus Co.
23. Ischua Creek at Main Street, Franklinville, Cattaraugus Co.
24. Ischua Creek at Route 16/98, town of Farmersville, Cattaraugus Co.
25. Oil Creek at Cattaraugus-Allegany Co. line
26. Oswayo Creek at North Carroll Road, town of Portville, Cattaraugus Co.
27. Niagara River at Goat Island, town of Niagara, Niagara Co.
28. Niagara River at Buckhorn Island State Park, town of Grand Island, Erie Co.
29. Niagara River at Beaver Island State Park, town of Grand Island, Erie Co.
30. Lake Erie at Athol Springs, town of Hamburg, Erie Co.
31. Oak Orchard Creek at Townline Road, town of Ridgeway, Orleans Co.
32. Johnson Creek at Route 18, town of Carlton, Orleans Co.
33. Eighteenmile Creek at Burt Dam Park, town of Newfane, Niagara Co.
34. Eighteenmile Creek at Hartland Road, town of Hartland, Niagara Co.
35. East Branch of Twelvemile Creek at Route 18, town of Wilson, Niagara Co.
36. Tonawanda Creek at New Road, town of Amherst, Erie Co.
37. Tonawanda Creek at Transit Road, town of Pendleton, Niagara Co.
38. Tonawanda Creek at Rapids, town of Lockport, Niagara Co.
39. Ellicott Creek at Glen Road, Williamsville, town of Amherst, Erie Co.
40. Ellicott Creek at Stony Road, town of Lancaster, Erie Co.
41. Mud Creek at Transit Road, town of Pendleton, Niagara Co.
42. Buffalo River at Harlem Road, town of West Seneca, Erie Co.
43. Buffalo Creek 1 km below Route 277, town of West Seneca, Erie Co.
44. Buffalo Creek at Transit Road, town of Elma, Erie Co.
45. Buffalo Creek at Girdle Road, town of Elma, Erie Co.
46. Cazenovia Creek at Cazenovia Park, town of Lackawanna, Erie Co.
47. Cazenovia Creek at Route 20A, town of Aurora, Erie Co.
48. Cayuga Creek at Clinton Street, town of West Seneca, Erie Co.
49. Cayuga Creek at Como Park Road, town of Cheektowaga, Erie Co.
50. Cayuga Creek at Transit Road, town of Cheektowaga, Erie Co.
51. Eighteenmile Creek at Route 5, town of Hamburg, Erie Co.
52. Cattaraugus Creek at Route 16, town of Sardinia, Erie Co.

TABLE 2. Collection records of unionids from the Allegheny River basin in western New York. Site locations are given in Table 1 and Fig. 1. Numbers show the numbers of living animals found at each site. D = recently dead shells found, d = subfossil shells found, L = living animals found but not counted.

Site Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Actinonaias ligamentina	D	1	69		L	L		d	7								31									18
Alasmidonta marginata	D	D	d				d		1						13		D		L							
Amblema plicata								d																		
Anodonta grandis								d	4		D								D							D
Anodontoides ferussacianus							d																			1
Elliptio dilatata	D	1	27		L	L			D				D	L			62	1	L							44
Lampsilis cardium	D	1	59		L									L	4		9		d							18
Lampsilis fasciola		1	5		D												2									1
Lampsilis siliquoidea			3		L	L		d	16		1		D	L					d				d			2
Lasmigona compressa												1			3											
Lasmigona costata	D	D	21		L	L			1						3		34	5	L							8
Ligumia recta		D	4																							
Obovaria subrotunda								d																		
Pleurobema coccineum	D	1	8			D		d									3									2
Ptychobranchus fasciolaris					L	L							D	L												
Strophitus undulatus		D			L				3					D	18		D	D	L				D			
Villosa fabalis																	1	d	d							
Number of species	6	9	9	0	8	6	2	6	7	0	2	1	3	5	5	0	9	4	8	0	0	0	2	0	0	9
Person-hours	2	3	4.5	1.8	2.8	2.7	1.2	2.2	2	1	2	1	0.3	1	0.3	1	4	0.7	3.3	0.5	0.6	0.5	1.5	1.5	1	1.7

The widely quoted record of *L. fasciola* from Butternut Creek in Otsego County (*e.g.*, Marshall, 1895) is based on a malformed specimen of *Lampsilis radiata* (ANSP 32391).

Most of the streams in the Allegheny basin in New York still support healthy mussel communities. Notable exceptions include the lower Conewango Creek (stations 8, 11), which probably has suffered from wastes from Jamestown and local agriculture, Oil Creek (station 25), which has been straightened and channelized, and two stations on French Creek (stations, 4, 7) that inexplicably lacked unionids. The area of the Allegheny River impounded by Kinzua Dam (below station 1) almost certainly does not now contain its original mussel fauna, but we did not survey this area.

In contrast, mussel communities at many sites in the Great Lakes basin in western New York have been badly degraded by human activities in metropolitan Buffalo. The Buffalo River drainage (stations 42-50), which flows through suburban areas, has been particularly badly affected. We found sparse, species-poor mussel communities in the Buffalo River drainage (Table 3) in contrast to the rich communities (17 species, including *Simpsonaias ambigua)* reported by Letson (1909) and others. Many streams outside the immediate metropolitan Buffalo area (*e.g.*, stations 31-41) still contain healthy communities of mussels. For example, Tonawanda Creek in Erie County (stations 37, 38) supported 12 species of unionids both in the 1930's and 1940's (Robertson & Blakeslee, 1948) and in 1987 and 1990 (this study), although the lists of species found in these two periods were not identical.

We found living representatives of 19 species of unionids plus dead shells of two others that probably still live in the Great Lakes basin in western New York (Table 3). None of these species is rare globally. Apparently, many species of mussels have disappeared from the Great Lakes basin in western New York over the last century or so. It is difficult to place an exact figure on the number of these local extinctions, because the historical record of mussel collections is of such mixed quality. Historical records from the Great Lakes basin in western New York (Table 4) contain species records that are well supported by photographs or museum lots (group A in Table 4), species records that are almost certainly spurious (probably based on misidentifications or switched museum labels) (group C in Table 4), and a large number of species records that are poorly supported by museum lots or photographs, but which are not implausible enough to reject outright (group B in Table 4). Many of these latter records are based on very old collections (early to mid-19th century) or represent species that are easily confused with other, more common species (*e.g.*, *Actinonaias ligamentina* with *Lampsilis* spp.; *Potamilus ohiensis* with *Leptodea fragilis*, etc.). Nevertheless, between six and 17 mussel species probably have been eliminated from the Great Lakes basin in western New York. Many of these species now are rare or endangered throughout their ranges (*e.g.*, *Epioblasma* spp., *Simpsonaias ambigua, Lampsilis abrupta, Leptodea leptodon, and Potamilus capax).*

The existence of several big-river mussels *(Epioblasma obliquata, Lampsilis abrupta, Lampsilis teres, Leptodea leptodon,* and *Potamilus capax)* in the Niagara River has been largely ignored or dismissed by most

TABLE 3. Collection records of unionids from the Great Lakes basin in western New York. Site locations are given in Table 1 and Fig. 1. Numbers show the numbers of living animals found at each site. D = recently dead shells found, d = subfossil shells found, L = living animals found but not counted.

Site Number	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Alasmidonta marginata					1																					
Alasmidonta viridis																		D								
Amblema plicata											14	23			1											
Anodonta grandis		D	D			D				D	D			1	3											
Anodontoides ferussacianus			1					1						8	5											
Elliptio complanata					34	4		115																		
Elliptio dilatata	d	d	D	D							6	3														
Fusconaia flava		D	6					8			2	2											d			
Lampsilis cardium			d	D							D									D						
Lampsilis siliquoidea	d	D	8	D	18	32		8			20	47		21	17											
Lasmigona compressa					D										1	D		3								
Lasmigona costata					10	4		4		D	9	19														
Leptodea fragilis		D	D	D		2				D	2					1	D					1				
Ligumia nasuta		1	3																							
Ligumia recta											1	D														
Obovaria olivaria	d																									
Pleurobema coccineum			1																							
Potamilus alatus			D	D		1					1											1				
Ptychobranchus fasciolaris			2	D							2	D														
Strophitus undulatus	d	D	D								1					D	8	31		D				D		
Villosa iris	d	1	D			D		L			D															
Number of species	5	8	13	6	5	7	0	6	0	3	13	7	0	3	5	3	2	3	0	2	0	2	1	1	0	0
Person-hours	0.5	1.5	5	0.7	1.3	1.7	0.7	1.3	0.4	0.1	3.2	–	1	1.5	0.7	1.5	2.6	2.5	0.3	1.5	1.5	0.7	1.5	1	1	1

TABLE 4. Species of freshwater mussels recorded from the Great Lakes basin in western New York, but not found in the present survey.

	Source[a]	Location[b]
A. Well supported records		
Epioblasma triquetra (Rafinesque)	2, 4	N, E
Lampsilis fasciola Rafinesque	4, 5	N
Quadrula quadrula (Rafinesque)	4	N
Simpsonaias ambigua (Say)	1, 2, 3, 6	B, E
Toxolasma parvus (Barnes)	4, 6	T
Truncilla truncata Rafinesque	2, 4	T
B. Poorly supported records		
Actinonaias ligamentina (Lamarck)	4, 5	N, T
Cyclonaias tuberculata (Rafinesque)	3	E
Epioblasma obliquata (Rafinesque)	7	N
Lampsilis abrupta (Say)	4, 10	N
Lampsilis teres (Rafinesque)	2, 5, 8	N
Lasmigona complanata (Barnes)	2, 9	?
Leptodea leptodon (Rafinesque)	3	?
Obovaria subrotunda (Rafinesque)	3	E
Potamilus capax (Green)	4, 10	N, O
Potamilus ohiensis (Rafinesque)	4, 5	B, E
Quadrula pustulosa (Lea)	4, 5	N
C. Spurious records		
Anodonta cataracta Say	5	B
Leptodea ochracea (Say)	5	B
Ligumia subrostrata (Say)	5	N
Margaritifera margaritifera (Linnaeus)	3	E
Venustaconcha ellipsiformis (Conrad)	2	?

[a]Sources: 1 = Lewis (1874), 2 = Marshall (1895), 3 = Letson (1905), 4 = Robertson & Blakeslee (1948), 5 = Letson (1909), 6 = AMNH collections, 7 = Johnson (1978), 8 = NYSM collections, 9 = ANSP (Academy of Natural Sciences of Philadelphia) collections, 10 = Johnson (1980).

[b]B = Buffalo River or its tributaries, E = Lake Erie, N = Niagara River, O = Lake Ontario or its tributaries east of the Niagara River, T = Tonawanda Creek or its tributaries, ? = specific locality not specified (*e.g.*, "near Buffalo" or "western New York").

malacologists, because the Niagara River is so far from any other known populations of these species. Indeed, as we have just noted, historical evidence for these records is equivocal, so some or all of these records may be spurious. Nevertheless, there are close zoogeographical connections between the Niagara River and the nearest known populations of these five species (the Wabash or Maumee Rivers), as already noted by Ortmann (1924). About 13,300 B.P., the present basin of Lake Erie was nearly dry (due to the low elevation of the sill at Niagara Falls). The Maumee and Detroit Rivers formed the headwaters of a large river that ran across the dry bed of Lake Erie to the Niagara River (Coleman, 1922; Calkin & Feenstra, 1985). The course of this river was interrupted only by a small lake in the deepest parts of present-day Lake Erie. Any big-river mussels that crossed the Maumee-Wabash divide 1100 years earlier presumably would have found suitable habitat in this river and could have dispersed eastward to Niagara Falls. As the Niagara outlet rose through isostatic rebound, this river was drowned, leaving the Niagara River (and in the headwaters, the Detroit River) as the only large-river habitat in the region. There is thus every reason to believe that the Niagara River might have supported, at least until recently, a rich mussel fauna containing some outlying populations of Wabash-Maumee species. The Detroit River held 25 species of unionids as late as 1983, including some fairly large-river species such as *Epioblasma torulosa, Obovaria olivaria, Truncilla* spp., and *Obliquaria reflexa* (W. Kovalak, pers. comm.). Unfortunately, we did not have the resources to do a proper survey of the swift, very large Niagara River. Such a survey would be very desirable, to verify the existence of rare or relict mussel species in the Niagara River.

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TWENTIETH CENTURY CHANGES IN THE FRESHWATER MUSSEL FAUNA OF THE CLINCH RIVER (TENNESSEE AND VIRGINIA)

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ABSTRACT – This study investigated the current status of freshwater mussel populations in the Clinch River since first being reported by Ortmann (1918). Four mussel species are new to the Clinch River fauna since Ortmann. Three of these *(Anodonta grandis, Anodonta suborbiculata* and *Lasmigona complanata)* have colonized the lower river since impoundment. *Quadrula sparsa* was also found and occurs only in the upper Clinch. Freshwater mussel species have declined from a reported 60 species to the 47 species identified in this study. Impoundments have drastically reduced the mussel fauna in the lower Clinch and are largely responsible for the extirpation of eight species previously reported. Mussels have failed to recolonize a portion of the upper Clinch below Carbo, Virginia, following two major toxic spills in 1967 and 1970.

There was a distinct longitudinal distribution of mussel species in the upper Clinch with an increase in the number of species downstream with increasing stream size. Abrupt changes in stream gradient were effective physical barriers for mussel distributions in the upper Clinch.

KEY WORDS – Freshwater mussels, Clinch River, Tennessee, Virginia, distribution.

CONTENTS

INTRODUCTION

The Clinch River of Tennessee and Virginia is one of several major tributary streams forming the headwaters of the upper Tennessee River above Chattanooga. These tributary streams have developed highly diverse aquatic faunas, especially among the freshwater mussels. Ortmann

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(1918) referred to the upper Tennessee River region as one of the major centers for freshwater mussel diversity and perhaps the most prolific region in the world for this particular group. Particularly interesting among freshwater mussels are those species endemic to this region, referred to by Ortmann as the Cumberlandian faunal group because they are found only in the southern Appalachian Mountains and the Cumberland Plateau region. Ortmann (1924, 1925) later defined the Cumberlandian region as including only the drainages of the Tennessee River system from the headwaters to the vicinity of Muscle Shoals in Colbert and Lauderdale counties, Alabama; and the Cumberland River system extending from the headwaters to the vicinity of Clarksville, Montgomery County, Tennessee. The Cumberlandian region is one of six major areas with distinct endemic species of freshwater mussels. The other five regions include: (l) Atlantic, (2) Pacific, (3) Mississippi (Interior basin or Ohioan of some authors), (4) Ozarks, (5) West Floridian or Appalachicolan (van der Schalie & van der Schalie 1950).

Over the past 85 years, a rich freshwater mussel fauna has been reported from the Clinch River. Prior to the lower sections of the river being impounded by Norris Dam in the mid-1930s, studies made by Charles C. Adams and Arnold E. Ortmann (both reported in Ortmann, 1918) documented the richness of this fauna at 26 collecting sites traversing almost the entire length of the Clinch River, a distance of approximately 563 stream kilometers (350 miles). At this time, collecting efforts were primarily limited to those sites accessible by railroad; however, their studies represent the only complete documentation of the original mussel fauna in the river prior to impoundment and environmental changes caused by humans. Since the completion of Norris Dam on the Clinch River at 128-km (CRM 79.8) by the Tennessee Valley Authority (TVA) in 1936, the lower reaches of the Clinch have been further impounded by Melton Hill Dam at 37-km (CRM 23), completed by TVA in 1963 and approximately 96-km (60 miles) downstream from Norris Dam. Further, the lowermost portion of the river below Melton Hill Dam is inundated by the backwaters of Watts Bar Reservoir (filled in 1942), a mainstream impoundment on the Tennessee River. Thus, approximately 241-km (150 miles) of the lower Clinch River in Tennessee are impounded. These impounded waters cover some of the richest mussel-containing riffle and shoal habitats once found in the Clinch. Although some mussels still survive in the more riverine reaches of the river below Norris and Melton Hill dams, the communities are very depauperate and are limited to a few old individuals probably present before construction of the dams. A few young specimens (evidence of reproduction) have been observed; this suggests that there are some environmentally tolerant species or individuals produced in or recruited from tributary streams, possibly by way of their fish hosts.

The upper free-flowing reaches of the Clinch above Norris Reservoir are situated in remote areas somewhat removed from human population centers. The mountainous terrain and inaccessibility have been a major hindrance for large scale development in this region. Except for a few isolated areas where toxic spills have occurred and strip-mining is in progress, the upper Clinch today contains the richest faunal assemblage of freshwater mussels remaining in the Tennessee River system. This fauna is not without change, however. Certain species of mussels, especially those belonging to the genus *Epioblasma (= Dysnomia)*, have been nearly eliminated, while others maintain apparently healthy populations. Some of these mussel species may be considered as extirpated from the Clinch River fauna, extinct, or still surviving but reduced to such low numbers that they would be found only by chance while sampling. In any case, documented impacts have already occurred that reduced the mussel fauna in certain portions of the river and future changes or declines can be expected because of current developments related to oil and gas exploration and the proposed funding of a coal slurry pipeline. Any major finds of oil and gas deposits or the construction and operation of a coal slurry pipeline would open previously isolated portions of the river watershed to additional development, thus increasing water demands that would result in additional pollution of the river.

This study was initiated to:

1. assess the current status of freshwater mussels in the upper free-flowing reaches of the Clinch including observations on the fauna below Norris and Melton Hill dams; and
2. determine what changes have occurred in the faunal assemblage since being surveyed by Adams and Ortmann (Ortmann 1918).

During the course of this study, from 1978 to 1983, mussel data were accumulated at 204 collecting sites from both the upper free-flowing reaches of the Clinch and the lower impounded portion. The largest of these projects was the Cumberlandian Mollusk Conservation Program (CMCP). This program was designed to improve conditions for the survival of endangered and other stream dwelling mollusks that exist only in the headwaters of the Tennessee and Cumberland rivers (Jenkinson 1981). As one part of this program, float surveys of several rivers including the upper Clinch River were completed in order to update distribution records for Cumberlandian mussel species. Additional records from other TVA mussel studies on the Clinch have been compiled for this study. These records include mussel surveys at proposed bridge sites, barge terminals, waste treatment plants, and an industrial site. Further, an intensive mussel study was also completed on the Clinch River at the proposed Breeder Reactor site and at a mussel relocation project at St. Paul, Virginia. The author participated at each of these projects as a biologist/mussel taxonomist except for studies conducted at the proposed barge terminals.

LITERATURE REVIEW

Many species of freshwater mussels originally were described from streams in the upper Tennessee River drainage which includes the Clinch River. Pilsbry & Rhoads (1897) first reported 16 species of freshwater mussels from one site on the lower Clinch River in Roane County, Tennessee (now impounded). In 1899, Charles C. Adams, while conducting his studies of the pleurocerid river snail *Io*, made extensive collections of mussels at 11 sites throughout the Clinch River. From 1912 to 1915, Arnold E. Ortmann made additional mussel collections in the Clinch River, including some sites previously sampled by Adams. Ortmann (1918) later compiled his information with that of Adams and reported it with other mussel studies from the upper Tennessee River drainage. This report was to become the most important study of that region's freshwater mussel fauna known prior to impoundment and pollution of these streams. While studying snails, Goodrich (1913) published records of 30 species of freshwater mussels from five sites in the upper Clinch in southwest Virginia collected during a field trip with Ortmann. In 1909, Boepple & Coker (1912) investigated the market value of shells left by pearl fishermen in the lower reaches of the Clinch downstream from Clinton, Tennessee (now impounded). Thousands of shells representing 16 mussel species were observed. During the period 1935 to 1937, Hickman (1937) made extensive collections in the Clinch downstream from the Norris Dam construction site prior to closure of the dam in 1936. Thirty-nine species of mussels were reported. Cahn (1936) made similar collections of the Clinch downstream from Norris Dam upon closure of the structure. Forty-five species of mussels were found in the dewatered riverbed below the dam.

More recently, extensive freshwater mussel collections of the upper Clinch River upstream from Norris Reservoir were reported by Stansbery (1973). From 1963 to 1971, an undetermined number of sites were sampled for mussels by Stansbery who reported 53 species of mussels. This represents the largest number of mussel species ever reported from the upper free-flowing reaches of the Clinch above Norris Reservoir. An excellent account of the mussel fauna in the upper Clinch was also reported by Bates & Dennis (1978), who sampled the river from 1972 to 1975; 38 species were reported from 33 collecting sites. Included with this survey are limited data on the mussel fauna in the downstream impounded reaches of the lower Clinch. Seven species of mussels were reported from the impounded portions of the lower Clinch (Bates 1975; Bates & Dennis 1978). Neves *et al.* (1980) surveyed the endangered freshwater mussels of Virginia. This study included only the Virginia portion of the upper Clinch and included 32 species of mussels at 6 collecting sites.

DESCRIPTION OF THE STUDY AREA

The Clinch River originates in a mountainous region near Bluefield, Tazewell County, Virginia, and flows in a southwesterly direction 563 stream kilometers (350 miles) to its confluence with the Tennessee River at 913-km (Tennessee River Mile (TRM) 567.8) in Watts Bar Reservoir near Kingston, Tennessee. Of its total length, only 322-km (200 miles) of the Clinch River remains free-flowing.

The Clinch River basin has an area of 5,180 km^2 (4,413 square miles) and includes two major physiographic regions; the Ridge and Valley and the Cumberland Plateau. This drainage area represents 10.8% of the Tennessee River basin.

The Ridge and Valley Province is characterized by long, subparallel ridges separated by narrow valleys consisting of folded shale, limestone, and dolomites interspersed by numerous sinkholes and extensive underground drainage (Masnik 1974). The Clinch River drainage in the Cumberland Plateau have horizontally bedded sedimentary strata dominated by shales, sandstone, and coal seams, and are considerably more recent (carboniferous) than Ridge and Valley strata (Silurian or earlier).

The climate for the Clinch River basin is temperate, with an average annual temperature of 12°C (53°F) and precipitation of 117 cm (46 inches) annually. Because of the steep mountainous terrain, approximately 41% of the annual precipitation leaves the watershed as surface runoff (Crossman et al. 1973). The mean average discharge for the unregulated flows of the Clinch above Tazewell, Tennessee, is 58 m^3/sec (2,048 CFS) with a maximum flow of 2,778 m^3/sec (98,100 CFS) recorded during the April 1977 flood (TVA 1978). Low flows generally average 3 m^3/sec (103 CFS) during late summer and early fall.

Approximately 50% of the Clinch River watershed is forested, with farming accounting for most of the remaining land use. Other land use practices include strip-mining for coal and rock quarrying. Coal mining is largely restricted to the northern portion of the Clinch River basin (Cumberland Plateau Province) and appears to have had little effect on water quality because of the buffering capacity of limestone and dolomite formations which neutralize acid mine wastes (Crossman *et al.*, 1973; Masnik, 1974).

Two major toxic spills in the upper Clinch River in Virginia have had significant effects on the river's fauna. In 1967, a dike surrounding a fly ash settling lagoon collapsed at the Appalachian Power Company coal fired steam-electric plant near Carbo, Virginia, releasing a highly caustic alkaline slurry (pH = 12) into the river. During this period an estimated 162,000 fish were killed in the Virginia portion of the Clinch (106-km); an additional 54,000 fish were killed in the Tennessee portion (38-km) where the polluted mass was diluted (Anonymous 1967; Cairns et al. 1971). In June 1970, a second spill involving an undetermined amount of sulfuric acid was released into the river from the same steam-electric plant. As a result of this spill, approximately 5,300 fish were killed in a 35-km reach downstream from the plant (Cairns *et al.*, 1971). In addition to these short term, catastrophic events, high levels of suspended solids are delivered by tributary streams such as Dump's Creek near Carbo, Guest River below St. Paul (Crossman *et al.*, 1973), and Lick Creek above St. Paul. In 1979, Lick Creek was observed by the author to be running black with coal fines.

COLLECTION TECHNIQUES AND DATA ANALYSIS

Sampling Procedures

Mussel surveys were conducted either at river points accessible by road or float-surveyed between access points using canoes and flatbottom boats (Figs. 1 and 2). During float surveys, each riffle or shoal encountered was sampled for mussels as were the pool areas at the head of each shoal. Each set of locality data was taken from 1:24000 topographic maps and consisted of the following: name of the river, landmark, date, river mile, county, and state. In general, each site was sampled using wading, snorkeling, and scubadiving sampling techniques. All mussel specimens observed were removed from the substrate by hand and placed in nylon mesh collecting bags for sorting and identification. Occasionally a garden rake was used to dislodge mussels buried in the substrate. Approximately four to five divers were utilized for most aspects of these surveys and average time spent for each person per site is estimated at between 60 and 90 minutes. In addition to instream sampling, stream banks were searched for muskrat shell middens. Shell middens were a prime source for locating fresh-dead specimens of mussel species which may be rare or overlooked while sampling. All fresh-dead shells (*i.e.*, evidence of flesh inside the shell and shiny nacre with hinge ligament intact) were identified in the field,
recorded on field data sheets, and placed in cloth collecting bags with an appropriate field identification label. Specimens were returned to the TVA fisheries laboratory at Norris, Tennessee, for cleaning, verification, cataloging, and storage. All live mussels found were identified in the field, recorded on field data sheets, and immediately returned to the river substrate. Specimens of federally-listed endangered mussels were photographed before being returned to the river substrate.

Quantitative sampling for mussels was conducted in areas which contained endangered freshwater mussels or dense mussel concentrations. A quadrat sampler, consisting of a metal frame with a sampling area of 0.5 m^2, was randomly placed on top of the substrate and sampled to a depth of five to 10 cm. All living mussels found within the sampler were removed, identified, counted, and recorded on field data sheets. The number of quadrats taken per site depended upon the size of the habitat containing mussel concentrations. The following table was developed for field use to standardize the relationship between the mussels' habitat area and the number of quantitative samples required to adequately access population densities.

Mussels Habitat Area (m^2)	Number of Quadrat Samples (0.5 m^2)
100–300	12
400	16
500	20
600	24
700	28
800	32
900	36
1,000	40
1,000 or larger	40

Treatment of Data

In order to examine the similarity between collecting sites in the Clinch River, a similarity coefficient was computed for each 32-km (20 mile) reach of the river. Separate cluster analysis was performed on all recent mussel data and Ortmann's (1918) survey data. The coefficient of association used is the Jaccard Coefficient (Sj) (Sneath and Sokal 1973):

$$Sj = a / (a + b + c)$$

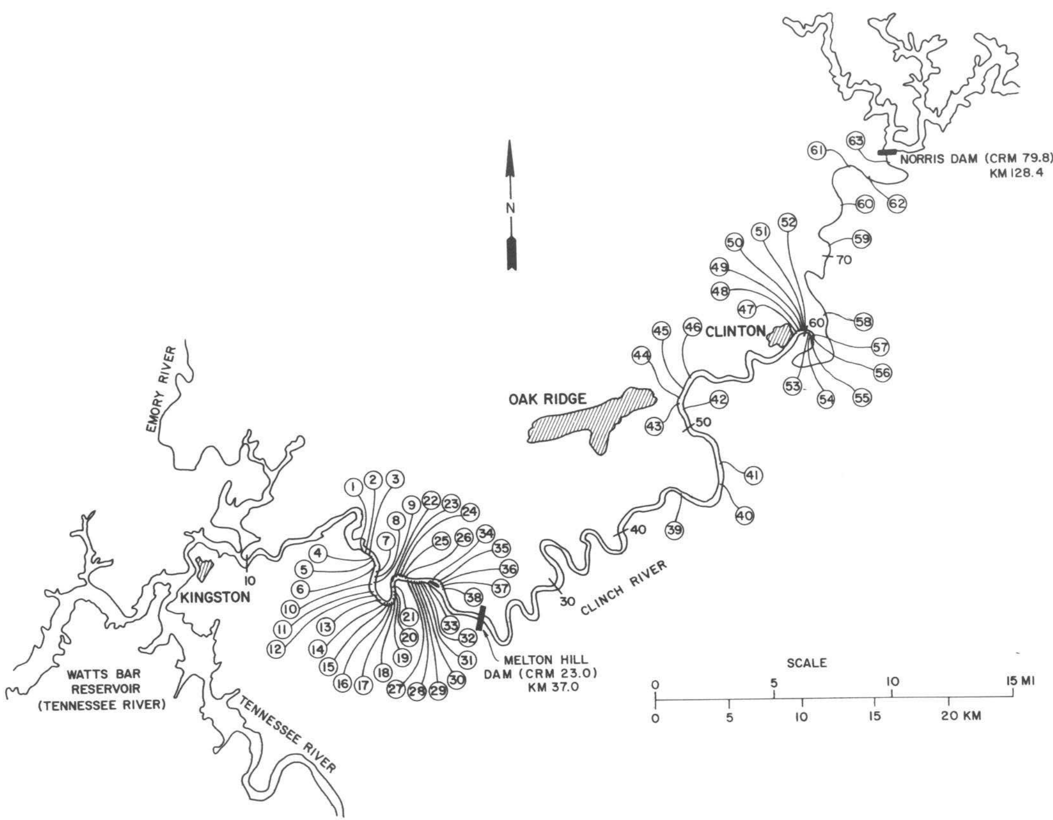

FIG. 1. Lower Clinch River mussel collecting sites.

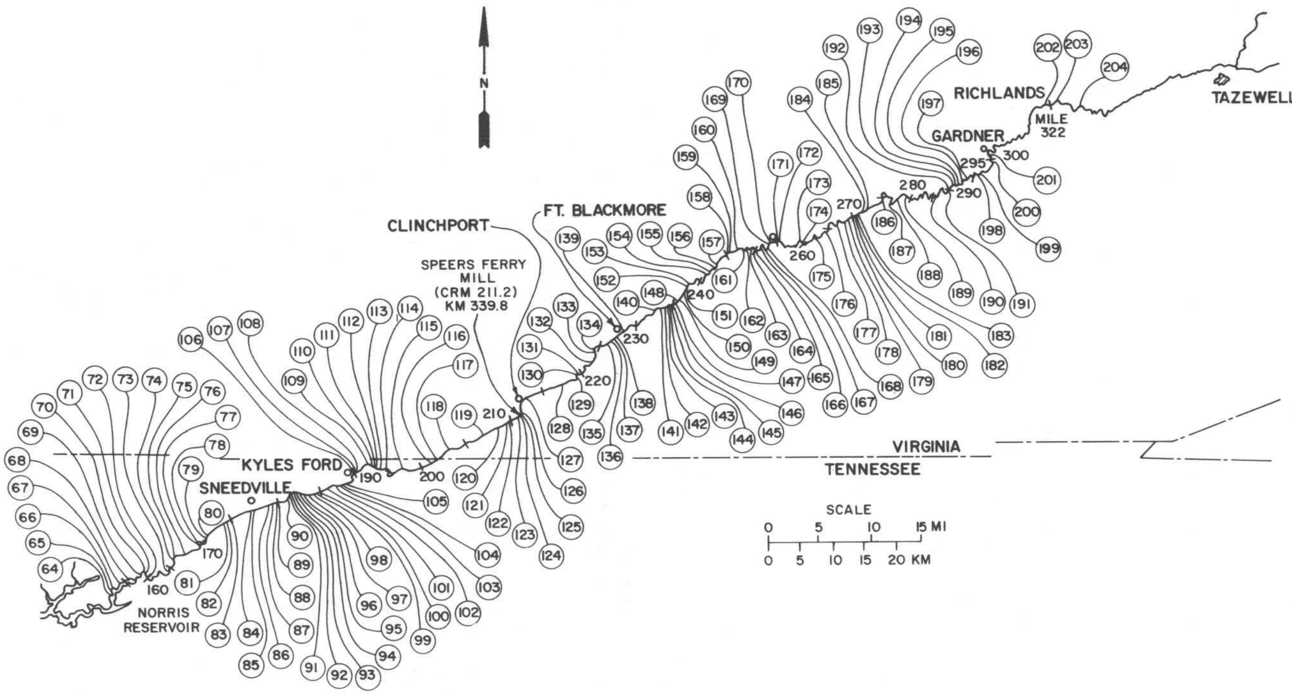

FIG. 2. Upper Clinch River mussel collecting sites.

where a is the number of species in both of two reaches, b is the number of species occurring in the first reach but not the second, and c is the number of species occurring in the second reach, but not the first.

The method used in this analysis was the unweighted pair group method using arithmetic means (UPGMA). This is the most frequently used clustering method.

Correlations were computed between the number of mussel species found in each 32-km reach of the Clinch, and elevation, gradient, and river kilometer. Correlations were computed separately for both survey collections.

ABUNDANCE AND DISTRIBUTION OF MUSSELS

The taxonomic nomenclature used in this report follows Ortmann's (1918) species records from the Clinch with recent synonyms and name changes according to Turgeon *et al.* (1988) (Table 1).

The Clinch River mussel survey was divided into two river sections: the lower and upper Clinch (Table 2, Figs. 1 and 2). The lower Clinch refers to sampling sites 1 through 63 located in the impounded reaches of the river downstream from Norris and Melton Hill dams. The upper Clinch refers to sampling sites 64 through 204 which occurs in the free-flowing portion of the river upstream from Norris Reservoir.

Lower Clinch

Twenty species of freshwater mussels were found at 63 collecting sites in the lower Clinch (Tables 2 and 3; Fig. 1). Three species *(Anodonta grandis, A. suborbiculata,* and *Lasmigona complanata)* are new to the river fauna. One federally listed endangered species *(Lampsilis abrupta)* was also reported from the lower Clinch.

Freshwater mussels were found at practically every site in the lower Clinch; however, species diversity and abundance were extremely low in comparison to the 53 species reported by Ortmann (1918) from this area (Table 4). Generally, from one to four species were present at each site with the largest numbers observed at sites 42 (12 species), 1 (six species), and 4 (five species). The low number of species collected probably reflects the impact caused by impoundment and stream channelization. Stream channelization is the deepening of the river channel by dredging for navigation and barge traffic. Numerous dead specimens were found imbedded in the substrate only in areas that had not been channelized and, with few exceptions, most live mussels were found along the backside of islands or in the overbanks of the channelized stream bed.

Quadrula pustulosa, Amblema plicata and *Anodonta grandis* were the most common species found in the lower Clinch with *Q. pustulosa* being the most numerous of the three. An unusually large number of species were found at site 42; 12 species were encountered and six of these occur nowhere else in the lower river. Most of the 20 species found in the lower Clinch were old, eroded individuals, barely surviving; however, at least four species *(Q. pustulosa, A. plicata, A. grandis* and *C. tuberculata)* were reproducing and are often common components of impoundments.

Three species *(Anodonta grandis, A. suborbiculata* and *Lasmigona complanata)* were found to occur only in the lower Clinch. These species are typical of post-impoundment situations; they have probably invaded the

TABLE 1. Clinch River mussel species collected by Ortmann (1918) with recent nomenclatural changes according to Turgeon *et al.* (1988).

Ortmann 1918		Recent
Margaritanidae		
Cumberlandia monodonta	=	*Cumberlandia monodonta*
Unionidae		
Unionidae		
Amblema plicata costata	=	*Amblema plicata*
Rotundaria tuberculata	=	*Cyclonaias tuberculata*
Elliptio niger	=	*Elliptio crassidens*
Elliptio dilatata	=	*Elliptio dilatata*
Fusconaia barnesiana		
Fusconaia barnesiana bigbyensis	=	*Fusconaia barnesiana*
Fusconaia barnesiana tumescens		
Fusconaia cor	=	*Fusconaia cor*
Fusconaia cor analoga		
Fusconaia cuneolus	=	*Fusconaia cuneolus*
Fusconaia cuneolus appressa		
Fusconaia pilaris		
Fusconaia pilaris bursa-pastoris	=	*Fusconaia subrotunda*
Fusconaia pilaris lesueriana		
Lastena lata	=	*Hemistena lata*
Lexingtonia dolabelloides	=	*Lexingtonia dolabelloides*
Lexingtonia dolabelloides conradi		
Plethobasus cooperianus	=	*Plethobasus cooperianus*
Plethobasus cyphyus	=	*Plethobasus cyphyus*
Pleurobema obliquum	=	*Pleurobema cordatum*
Pleurobema obliquum catillus	=	*Pleurobema coccineum*
Pleurobema obliquum coccineum		
Pleurobema obliquum cordatum	=	*Pleurobema plenum*
Pleurobema obliquum rubrum	=	*Pleurobema rubrum* (= *P. pyramidatum)*
Pleurobema oviforme		
Pleurobema oviforme argenteum	=	*Pleurobema oviforme*
Pleurobema oviforme holstonense		
Quadrula cylindrica	=	*Quadrula cylindrica*
Quadrula cylindrica strigillata		
Quadrula intermedia	=	*Quadrula intermedia*
Quadrula pustulosa	=	*Quadrula pustulosa*
Anodontinae		
Alasmidonta marginata	=	*Alasmidonta marginata*
Alasmidonta minor	=	*Alasmidonta viridis*
Lasmigona badia	=	*Lasmigona holstonia*
Lasmigona costata	=	*Lasmigona costata*
Strophitus edentulus	=	*Strophitus undulatus*
Lampsilinae		
Nephronaias ligamentina gibba	=	*Actinonaias ligamentina*

TABLE 1 (cont.)

Ortmann 1918		Recent
Nephronaias pectorosa	=	*Actinonaias pectorosa*
Toxolasma lividum	=	*Toxolasma lividus*
Lemiox rimosus	=	*Lemiox rimosus*
Cyprogenia stegaria	=	*Cyprogenia stegaria*
Dromus dromas caperatus	=	*Dromus dromas*
Truncilla arcaeformis	=	*Epioblasma arcaeformis*
Truncilla capaeformis	=	*Epioblasma capsaeformis*
Truncilla interrupta	=	*Epioblasma brevidens*
Truncilla haysiana	=	*Epioblasma haysiana*
Truncilla lenior	=	*Epioblasma lenior*
Truncilla propinqua	=	*Epioblasma propinqua*
Truncilla stewardsoni	=	*Epioblasma stewardsoni*
Truncilla torulosa gubernaculum	=	*Epioblasma torulosa gubernaculum*
Truncilla triquetra	=	*Epioblasma triquetra*
Lampsilis fasciola	=	*Lampsilis fasciola*
Lampsilis orbiculata	=	*Lampsilis abrupta*
Lampsilis ovata	=	*Lampsilis ovata*
Lampsilis ovata ventricosa		
Medionidus plateolus	=	*Medionidus conradicus*
Eurynia recta	=	*Ligumia recta*
Eurynia fabalis	=	*Villosa fabalis*
Eurynia nebulosa	=	*Villosa nebulosa*
Eurynia perpurpurea	=	*Villosa perpurpurea*
Eurynia trabalis	=	*Villosa trabalis*
Eurynia vanuxemensis	=	*Villosa vanuxemensis*
Obliquaria reflexa	=	*Obliquaria reflexa*
Obovaria retusa	=	*Obovaria retusa*
Paraptera fragilis	=	*Leptodea fragilis*
Paraptera leptodon	=	*Leptodea leptodon*
Plagiola lineolata	=	*Ellipsaria lineolata*
Proptera alata	=	*Potamilus alatus*
Ellipsaria fasciolaris	=	*Ptychobranchus fasciolaris*
Ellipsaria subtenta	=	*Ptychobranchus subtentum*
Amygdalonaias truncata	=	*Truncilla truncata*

lower river from populations in the upper Tennessee River. All three species were first reported from the lower Clinch in the early 1970's (Bates, 1975; Bates & Dennis, 1978). *Lampsilis abrupta,* a federally listed endangered species, was found at one site (site 27) downstream from Melton Hill Dam. *Lampsilis abrupta* is extremely rare in the Clinch but appears to be doing fairly well in larger river impoundments with flow-through, river-lake conditions (Ahlstedt ,1983h).

Upper Clinch

Forty-three species of freshwater mussels including 16 Cumberlandian forms are reported from 141 collecting sites in the upper Clinch River (Ta-

TABLE 2. Location of all Clinch River collecting sites in kilometers (km) and miles (CRM). TN = Tennessee; VA = Virginia.

Site	km	(CRM)	Location
1	22.5	(14.0)	Gallaher Bridge, Roane Co., Tennessee
2	22.8	(14.2)	Above Gallaher Bridge, Roane Co., Tennessee
3	23.2	(14.4)	Above Gallaher Bridge, Roane Co., Tennessee
4	23.5	(14.6)	Gauging Station, Roane Co., Tennessee
5	23.8	(14.8)	Roane Co., Tennessee
6	24.1	(15.0)	Roane Co., Tennessee
7	24.5	(15.2)	Roane Co., Tennessee
8	24.8	(15.4)	Roane Co., Tennessee
9	25.1	(15.6)	Roane Co., Tennessee
10	25.4	(15.8)	Roane Co., Tennessee
11	25.7	(16.0)	Below Poplar Springs Creek, Roane Co., Tennessee
12	26.1	(16.2)	Above Poplar Springs Creek, Roane Co., Tennessee
13	26.4	(16.4)	Roane Co., Tennessee
14	26.7	(16.6)	Dug Ridge, Roane Co., Tennessee
15	27.0	(16.8)	Below Caney Creek, Roane Co., Tennessee
16	27.4	(17.0)	Mouth Caney Creek, Roane Co., Tennessee
17	27.7	(17.2)	Above Caney Creek, Roane Co., Tennessee
18	28.0	(17.4)	Above Caney Creek, Roane Co., Tennessee
19	28.3	(17.6)	Above Caney Creek, Roane Co., Tennessee
20	28.6	(17.8)	Above Caney Creek, Roane Co., Tennessee
21	29.0	(18.0)	Below Grubb Islands, Roane Co., Tennessee
22	29.3	(18.2)	Below Grubb Islands, Roane Co., Tennessee
23	29.6	(18.4)	Grubb Islands, Roane Co., Tennessee
24	29.9	(18.6)	Grubb Islands, Roane Co., Tennessee
25	30.2	(18.8)	Above Grubb Islands, Roane Co., Tennessee
26	30.6	(19.0)	Roane Co., Tennessee
27	30.7	(19.1)	Roane Co., Tennessee
28	30.9	(19.2)	Roane Co., Tennessee
29	31.2	(19.4)	Below Raccoon Creek, Roane Co., Tennessee
30	31.4	(19.5)	Below Jones Island, Roane Co., Tennessee
31	31.5	(19.6)	Below Jones Island, Roane Co., Tennessee
32	31.9	(19.8)	Jones Island, Roane Co., Tennessee
33	32.2	(20.0)	Jones Island, Roane Co., Tennessee
34	32.5	(20.2)	Jones Island, Roane Co., Tennessee
35	32.8	(20.4)	Jones Island, Roane Co., Tennessee
36	33.1	(20.6)	Below Jones Island, Roane Co., Tennessee
37	33.5	(20.8)	Mouth Whiteoak Lake, Roane Co., Tennessee
38	33.8	(21.0)	Above Whiteoak Lake, Roane Co., Tennessee
39	72.1	(44.8)	Above Solway Bridge, Knox/Anderson Co., Tennessee
40	75.8	(47.1)	Across Bull Run Steam Plant, Anderson Co., Tennessee
41	77.2	(48.0)	Below Edgemoor Bridge, Anderson Co., Tennessee
42	81.6	(50.7)	Above Braden Branch, Anderson Co., Tennessee
43	82.1	(51.0)	Below Oak Ridge Daymark, Anderson Co., Tennessee
44	82.5	(51.3)	Below Elza Daymark, Anderson Co., Tennessee
45	83.3	(51.8)	Above Elza Daymark, Anderson Co., Tennessee
46	84.3	(52.4)	Below Lost Bottoms Daymark, Anderson Co., Tennessee
47	95.7	(59.5)	Above Southern Railroad Tressel, Anderson Co., Tennessee
48	95.9	(59.6)	Anderson Co., Tennessee

TABLE 2 (cont.)

Site	km	(CRM)	Location
49	96.1	(59.7)	Anderson Co., Tennessee
50	96.2	(59.8)	Anderson Co., Tennessee
51	96.4	(59.9)	Anderson Co., Tennessee
52	96.5	(60.0)	Below Clinton Island, Anderson Co., Tennessee
53	96.7	(60.1)	Clinton Island, Anderson Co., Tennessee
54	96.9	(60.2)	Clinton Island, Anderson Co., Tennessee
55	97.0	(60.3)	Clinton Island, Anderson Co., Tennessee
56	97.2	(60.4)	Clinton Island, Anderson Co., Tennessee
57	97.3	(60.5)	Head of Clinton Island, Anderson Co., Tennessee
58	107.2	(66.6)	Hwy. 61 Bridge, Anderson Co., Tennessee
59	113.4	(70.5)	Fish Trap, Anderson Co., Tennessee
60	117.1	(72.8)	Above River Bridge, Anderson Co., Tennessee
61	122.0	(75.8)	Massengill Bridge, Anderson Co., Tennessee
62	124.1	(77.1)	Above Millers Island, Anderson Co., Tennessee
63	128.0	(79.5)	Below Norris Dam, Anderson Co., Tennessee
64	242.6	(150.8)	Below Hwy. 25E Bridge, Claiborne/Grainger Co., Tn.
65	243.8	(151.5)	Below Hwy. 25E Bridge, Claiborne/Grainger Co., Tn.
66	244.4	(151.9)	Hwy. 25E Bridge, Claiborne/Grainger Co., Tennessee
67	247.5	(153.8)	Claiborne/Grainger Co., Tennessee
68	250.5	(155.7)	Kelly Branch, Claiborne/Grainger Co., Tennessee
69	254.4	(158.1)	Hancock Co., Tennessee
70	256.2	(159.2)	Grissom Island, Hancock Co., Tennessee
71	256.3	(159.3)	Grissom Island, Hancock Co., Tennessee
72	257.4	(160.0)	The Narrows, Hancock Co., Tennessee
73	265.2	(164.8)	Hancock Co., Tennessee
74	266.8	(165.8)	Above Evans Knob, Hancock Co., Tennessee
75	267.7	(166.4)	Manning Ferry, Hancock Co., Tennessee
76	270.3	(168.0)	Hancock Co., Tennessee
77	273.2	(169.8)	Hancock Co., Tennessee
78	274.3	(170.5)	Lawson Mill, Hancock Co., Tennessee
79	277.1	(172.2)	Swan Island, Hancock Co., Tennessee
80	277.2	(172.3)	Swan Island, Hancock Co., Tennessee
81	280.3	(174.2)	Between River Knobs, Hancock Co., Tennessee
82	280.8	(174.5)	Hancock Co., Tennessee
83	281.3	(174.8)	Hancock Co., Tennessee
84	285.3	(177.3)	Hwy. 33 Sneedville Bridge, Hancock Co., Tennessee
85	285.4	(177.4)	Hwy. 33 Sneedville Bridge, Hancock Co., Tennessee
86	287.5	(178.7)	Fall Branch, Hancock Co., Tennessee
87	288.7	(179.4)	Hancock Co., Tennessee
88	289.3	(179.8)	Farmers Branch, Hancock Co., Tennessee
89	289.5	(179.9)	Above Farmers Branch, Hancock Co., Tennessee
90	291.6	(181.2)	Frost Ford, Hancock Co., Tennessee
91	291.7	(181.3)	Frost Ford, Hancock Co., Tennessee
92	292.5	(181.8)	Hancock Co., Tennessee
93	293.2	(182.2)	Hancock Co., Tennessee
94	293.8	(182.6)	Hancock Co., Tennessee
95	294.3	(182.9)	Alder Hollow, Hancock Co., Tennessee
96	294.9	(183.3)	Brooks Island, Hancock Co., Tennessee
97	295.3	(183.5)	Brooks Island, Hancock Co., Tennessee

TABLE 2 (cont.)

Site	km	(CRM)	Location
98	295.6	(183.7)	Above Brooks Island, Hancock Co., Tennessee
99	296.1	(184.0)	Davis Branch, Hancock Co., Tennessee
100	296.9	(184.5)	Above Davis Branch, Hancock Co., Tennessee
101	299.3	(186.0)	Hancock Co., Tennessee
102	300.9	(187.0)	Hancock Co., Tennessee
103	301.4	(187.3)	Below Webb Island, Hancock Co., Tennessee
104	301.7	(187.5)	Webb Island, Hancock Co., Tennessee
105	301.8	(187.6)	Above Webb Island, Hancock Co., Tennessee
106	304.6	(189.3)	Above Livesay Mill, Hancock Co., Tennessee
107	305.1	(189.6)	Kyles Ford, Hancock Co., Tennessee
108	305.2	(189.7)	Kyles Ford, Hancock Co., Tennessee
109	308.9	(192.0)	Mouth of N.F. Clinch River, Hancock Co., Tennessee
110	309.6	(192.4)	Wallens Bend, Hancock Co., Tennessee
111	310.1	(192.7)	Hancock Co., Tennessee
112	310.5	(193.0)	Hancock Co., Tennessee
113	311.0	(193.3)	Hancock Co., Tennessee
114	312.1	(194.0)	Walnut Grove Church, Hancock Co., Tennessee
115	318.6	(198.0)	Hancock Co., Tennessee
116	323.7	(201.2)	Hancock Co., Tennessee
117	325.0	(202.0)	Shelby Creek, Hancock Co., Tennessee
118	327.3	(203.4)	Scott Co., Virginia
119	332.9	(206.9)	Unnamed Island, Scott Co., Virginia
120	335.3	(208.4)	Above Watts Branch, Scott Co., Virginia
121	337.1	(209.5)	Bobs Branch, Scott Co., Virginia
122	337.9	(210.0)	Scott Co., Virginia
123	339.2	(210.8)	Scott Co., Virginia
124	339.7	(211.1)	Gauging Station, Scott Co., Virginia
125	340.0	(211.3)	Speers Ferry, Scott Co., Virginia
126	340.8	(211.8)	Above Mouth of Copper Creek, Scott Co., Virginia
127	343.4	(213.4)	Above Stock Creek, Scott Co., Virginia
128	349.2	(217.0)	Scott Co., Virginia
129	352.5	(219.1)	Below Hwy. Bridge at Hill, Scott Co., Virginia
130	352.7	(219.2)	Below Craft Mill, Scott Co., Virginia
131	352.9	(219.3)	Below Craft Mill, Scott Co., Virginia
132	359.3	(223.3)	Below Swinging Bridge at Slant, Scott Co., Virginia
133	360.6	(224.1)	McDowell Branch, Scott Co., Virginia
134	360.7	(224.2)	Above McDowell Branch, Scott Co., Virginia
135	363.3	(225.8)	The Suck, Scott Co., Virginia
136	364.1	(226.3)	Pendleton Island, Scott Co., Virginia
137	364.3	(226.4)	Pendleton Island, Scott Co., Virginia
138	364.6	(226.6)	Pendleton Island, Scott Co., Virginia
139	365.9	(227.4)	Fort Blackmore Bridge, Scott Co., Virginia
140	374.3	(232.6)	Island at Staunton Creek, Scott Co., Virginia
141	376.0	(233.7)	Grays Island, Scott Co., Virginia
142	376.5	(234.0)	Grays Island, Scott Co., Virginia
143	377.3	(234.5)	Grays Island, Scott Co., Virginia
144	377.6	(234.7)	Grays Island, Scott Co., Virginia
145	378.0	(234.9)	Below Benges Creek at Unnamed Island, Scott Co., Va.
146	378.2	(235.1)	Above Benges Creek at Unnamed Island, Scott Co., Va.

TABLE 2 (cont.)

Site	km	(CRM)	Location
147	378.4	(235.2)	Above Benges Creek at Unnamed Island, Scott Co., Virginia
148	378.9	(235.5)	Scott Co., Virginia
149	380.2	(236.3)	Below Wolf Run Creek, Scott Co., Virginia
150	381.3	(237.0)	Above Bridge at Dungannon, Scott Co., Virginia
151	381.7	(237.2)	Dungannon, Scott Co., Virginia
152	382.5	(237.7)	Unnamed Island Below Mill Island, Scott Co., Virginia
153	383.4	(238.3)	Mill Island, Scott Co., Virginia
154	388.6	(241.5)	Island Above Townes Tunnel, Scott Co., Virginia
155	389.1	(241.8)	Scott Co., Virginia
156	391.0	(243.0)	Miller Yard, Scott Co., Virginia
157	391.1	(243.1)	Miller Yard, Scott Co., Virginia
158	394.2	(245.0)	Above Bangor, Wise/Russell Co., Virginia
159	394.8	(245.4)	Above Bangor, Wise/Russell Co., Virginia
160	397.3	(246.9)	Wise/Russell Co., Virginia
161	398.2	(247.5)	Hale Hollow, Wise/Russell Co., Virginia
162	399.0	(248.0)	Below Tributary at Hasn Hollow, Wise/Russell Co., Va.
163	401.6	(249.6)	Burtons Ford, Wise/Russell Co., Virginia
164	401.8	(249.7)	Above Burtons Ford, Wise/Russell Co., Virginia
165	401.9	(249.8)	Above Burtons Ford, Wise/Russell Co., Virginia
166	403.7	(250.9)	Wise/Russell Co., Virginia
167	405.6	(252.1)	Below Castle Run Creek, Wise/Russell Co., Virginia
168	406.4	(252.6)	Above Castle Run Creek, Wise/Russell Co., Virginia
169	407.1	(253.0)	Wise/Russell Co., Virginia
170	408.4	(253.8)	Below Robinette Branch, Wise/Russell Co., Virginia
171	410.9	(255.4)	Island Above St. Paul, Wise/Russell Co., Virginia
172	411.3	(255.6)	Below Lick Creek, Russell Co., Virginia
173	417.2	(259.3)	Russell Co., Virginia
174	418.3	(260.0)	Russell Co., Virginia
175	421.2	(261.8)	Dry Run Bend, Russell Co., Virginia
176	425.1	(264.2)	Carterton Bridge, Russell Co., Virginia
177	431.5	(268.2)	Above Carbo, Russell Co., Virginia
178	433.5	(269.4)	Above Carbo, Russell Co., Virginia
179	433.8	(269.6)	Above Carbo at Mill Creek, Russell Co., Virginia
180	434.8	(270.2)	Russell Co., Virginia
181	435.7	(270.8)	At Island Below Cleveland, Russell Co., Virginia
182	435.9	(270.9)	At Island Below Cleveland, Russell Co., Virginia
183	436.0	(271.0)	At Island Below Cleveland, Russell Co., Virginia
184	436.7	(271.4)	Hwy. Bridge Below Cleveland, Russell Co., Virginia
185	437.6	(272.0)	Above Cleveland, Russell Co., Virginia
186	441.7	(274.5)	Hwy. Bridge Below Artrip, Russell Co., Virginia
187	445.0	(276.6)	Russell Co., Virginia
188	447.3	(278.0)	Unnamed Island, Russell Co., Virginia
189	449.6	(279.4)	Hwy. Bridge at Nash Ford, Russell Co., Virginia
190	459.9	(285.8)	Above Dilly Branch, Russell Co., Virginia
191	466.3	(289.8)	Russell Co., Virginia
192	467.1	(290.3)	Russell Co., Virginia
193	467.9	(290.8)	Russell Co., Virginia
194	468.7	(291.3)	Below Thompson Branch, Russell Co., Virginia

TABLE 2 (cont.)

Site	km	(CRM)	Location
195	469.8	(292.0)	Russell Co., Virginia
196	471.4	(293.0)	Above Hubbard Hole, Russell Co., Virginia
197	473.0	(294.0)	Above Lewis Creek, Russell Co., Virginia
198	475.6	(295.6)	Russell Co., Virginia
199	476.7	(296.3)	Russell Co., Virginia
200	482.1	(299.6)	Mouth of Little River, Russell Co., Virginia
201	484.3	(301.0)	Russell Co., Virginia
202	517.6	(321.7)	At Railroad Bridge, Russell Co., Virginia
203	519.1	(322.6)	Below Bridge at Cedar Bluff, Tazewell Co., Virginia
204	521.0	(323.8)	Above Cedar Bluff, Tazewell Co., Virginia

bles 2 and 3). Five of the 16 Cumberlandian species *(Lemiox rimosus, Dromus dromas, Fusconaia cuneolus, F. cor,* and *Quadrula sparsa)* are federally listed endangered species. Two additional endangered species *(Lampsilis abrupta* and *Pleurobema plenum)* are also reported from the upper Clinch (Table 3).

Ortmann (1918) reported 42 species of freshwater mussels from 14 sites in this reach of the Clinch and included 10 species not present during this study (Table 4). Those 10 species reported by Ortmann are, with few exceptions, now believed extirpated from the river or considered extinct. Eleven additional species not reported by Ortmann from the upper Clinch were found during this study (Table 3). These 11 species, with the exception of *Quadrula sparsa,* were reported by Ortmann only from the lower (now impounded) portion of the Clinch.

Mussels were both diverse and abundant throughout the upper Clinch. At least 30 collecting sites contained 18 or more species of freshwater mussels. A noted decline or total absence of mussels were found primarily in the headwaters of the river above site 150. Nineteen sites above site 150 had fewer than three species of mussels (Table 3). This reach of the Clinch contains numerous alternating bedrock shelves and boulder substrate. Freshwater mussels were noticeably absent in areas with abrupt changes in stream gradient. Habitats essential for the colonization of freshwater mussels were practically non-existent at some of these sites. However, mussels were generally present but somewhat localized in pockets at sites containing rubble, gravel, and sand substrates.

Mussels were noticeably absent in a 14-km reach of the Clinch between sites 172 and 176. This river section was impacted by 198 million m^3 of caustic alkaline slurry (pH = 12) in June 1967 when a fly ash spill from Appalachian Power Company's steam-electric generating plant at Carbo, Virginia, killed fish for 105 km downstream and eliminated the mussel fauna for at least 28-km below Carbo (Cairns *et al.,* 1971). In June 1970, a sulphuric acid spill from the same generating plant impacted this same river reach for 24 km downstream to St. Paul and killed most mollusks for 18-km (Cairns *et al.,* 1971). Between sites 172 and 176, the mussel fauna was devastated by these toxic spills. Only six live mussels representing four species

TABLE 3. Number of each naiad species found during qualitative sampling of the Clinch River between 1978 and 1983.

Mussel Species	Collecting Sites[1]																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Actinonaias ligamentina	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Actinonaias pectorosa[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alasmidonta marginata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata	2	3	4	1	–	–	–	–	–	–	–	–	–	1	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta grandis	2	–	–	1	–	–	–	–	–	1	–	2	–	–	–	1	–	–	1	–	–	2	2	4	1	1	–	–	–	2	1	2	3	1
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata	1	–	2	2	–	–	1	2	–	–	–	–	–	3	–	–	2	–	–	–	–	–	1	–	1	–	–	–	–	2	–	–	–	–
Cyprogenia stegaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dromus dromas[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
Elliptio dilatata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma brevidens[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma capsaeformis[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia cor[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia cuneolus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia subrotunda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hemistena lata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Lampsilis fasciola	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis ovata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata	–	–	–	–	–	–	1	–	–	2	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–
Lasmigona costata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lemiox rimosus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lexingtonia dolabelloides[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Medionidus conradicus[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plethobasus cyphyus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum	1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	1	1	1	–	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptychobranchus subtentum[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula metanevra	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Quadrula pustulosa	3	1	9	3	6	1	5	2	2	14	4	10	2	14	4	6	1	3	–	–	–	–	4	1	4	2	–	–	1	7	–	1	–	–
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa nebulosa[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemensis[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total number of species	6	2	3	5	1	1	3	2	1	3	2	4	1	3	1	4	3	1	1	0	1	2	4	3	4	3	1	0	2	4	2	2	–	–

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 3 (cont.)

Mussel Species	Collecting Sites [1]																																	
	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
Actinonaias ligamentina	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	1	2	1	1
Actinonaias pectorosa[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–
Alasmidonta marginata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Amblema plicata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–
Anodonta grandis	1	–	1	3	–	1	–	9	1	2	–	2	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	–	–	–	–	1	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	2	–	–	–	1	1	–	–	–
Cyclonaias tuberculata	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Cyprogenia stegaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dromus dromas[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–
Elliptio dilatata	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	2	1	1
Epioblasma brevidens[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma capsaeformis[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Fusconaia cor[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia cuneolus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Fusconaia subrotunda	–	–	–	–	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hemistena lata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Lampsilis ovata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–
Lasmigona complanata	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1
Lemiox rimosus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Lexingtonia dolabelloides[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Medionidus conradicus[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
Plethobasus cyphyus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum	–	–	–	–	–	–	–	12	1	1	–	3	–	–	–	1	–	–	–	–	–	3	–	1	–	–	–	–	–	–	–	–	–	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	–	–	–	–	–	1	–	7	–	–	–	–	1	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	1	–
Ptychobranchus fasciolaris	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Ptychobranchus subtentum[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–
Quadrula cylindrica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula metanevra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	–	–	–	2	5	–	–	2	–	3	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa nebulosa[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemensis[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total number of species	1	0	2	2	2	2	0	12	·2	3	1	3	1	0	0	1	0	1	1	1	1	1	1	4	1	4	1	0	0	2	7	8	9	9

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 3 (cont.)

Mussel Species	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
	Collecting Sites[1]																																	
Actinonaias ligamentina	1	27	5	1	1	10	1	1	1	–	52	2	17	6	10	9	4	31	2	2	22	8	2	24	25	6	8	20	7	4	4	320	13	80
Actinonaias pectorosa[2]	1	2	1	–	–	1	–	–	–	–	6	1	2	–	1	1	3	9	–	–	9	–	–	10	2	–	2	7	4	–	1	9	–	10
Alasmidonta marginata	–	–	1	–	–	1	–	–	–	–	–	–	11	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	1	–	1	–	6	–
Amblema plicata	–	1	1	–	1	–	1	1	1	–	1	–	–	–	–	–	–	1	2	–	–	1	–	–	–	–	3	–	1	–	2	4	1	4
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	1	–	7	1	1	12	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Cyclonaias tuberculata	1	5	1	1	1	–	–	1	1	–	1	–	4	2	1	3	6	4	13	1	5	1	–	–	2	4	–	–	4	–	1	72	2	4
Cyprogenia stegaria	–	–	–	–	–	–	–	–	1	–	–	–	8	–	1	–	–	3	7	1	9	–	3	–	1	1	–	1	1	3	4	62	1	–
Dromus dromas[2,3]	–	–	–	–	–	–	–	–	1	–	1	1	1	5	7	–	1	8	1	–	5	–	5	1	–		–	–	1	–	–	–	–	1
Elliptio crassidens	–	–	1	–	–	1	–	–	–	–	–	1	1	–	–	–	1	1	–	–	–	–	–	–	–		–		1	–	1	–	–	–
Elliptio dilatata	1	1	1	1	1	3	1	1	–	–	–	–	–	–	–	1	–	1	1	1	1	–	1	–	2		2	–	4	–	–	–	–	1
Epioblasma brevidens[2]	–	–	–	–	–	–	–	–	–	–	–	1	2	1	1	–	–	1	–	–	2	–	–	–	1	–	–	–	1	–	2	20	–	1
Epioblasma capsaeformis[2]	–	–	–	–	–	3	–	–	–	–	–	1	3	–	2	–	–	3	–	1	16	1	4	2	–	2	–	1	11	–	–	1	–	2
Epioblasma triquetra	–	–	–	–	–	–	–	–	1	–	1	–	8	1	1	–	–	1	1	2	1	–	–	1	9	1	1	1	1	1	1	33	–	–
Fusconaia barnesiana[2]	1	1	–	–	–	–	–	–	1	–	1	–	1	–	1	–	–	12	1	–	3	–	1	–	3	1	1	–	4	1	3	16	–	1
Fusconaia cor[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–
Fusconaia cuneolus[2,3]	–	1	–	–	–	1	–	–	–	–	–	–	3	–	–	–	–	1	1	–	2	–	–	–	–	–	–	–	7	–	2	5	–	–
Fusconaia subrotunda	–	–	–	–	–	–	–	1	–	–	1	–	–	–	1	–	–	–	–	–	–	1	–	6	–	–	–	1	–	–	–	3	1	2
Hemistena lata	–	–	–	–	–	5	–	–	–	–	1	–	1	1	1	–	–	16	–	1	11	–	11	–	1	–	–	–	–	–	–	4	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Lampsilis fasciola	1	1	1	–	–	1	–	–	–	–	–	1	1	–	1	–	1	3	–	–	5	–	1	–	2	–	–	–	2	1	2	6	–	–
Lampsilis ovata	–	–	1	–	–	2	–	–	–	1	3	1	2	–	–	–	2	1	–	–	–	1	–	2	3	2	–	1	1	–	–	10	–	4
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	1	5	6	1	1	7	1	–	–	1	2	1	1	–	–	–	2	4	–	–	–	1	–	3	3	4	1	1	1	1	–	8	1	5
Lemiox rimosus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	2	–	–
Leptodea fragilis	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	5	–	1
Lexingtonia dolabelloides[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	–	2	–	–	–	–	–	–	–	–	–	1	–	–	1	1	–	–	–	–	–	–	–	4	2	1	–	1	–	1	4	–	1
Medionidus conradicus[2]	1	–	2	1	–	5	–	–	–	–	1	–	3	–	–	1	–	5	–	–	19	–	–	2	–	–	–	5	2	–	1	–	–	–
Plethobasus cyphyus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	–	2	1	–	–	2	–	1	2	1	1	1	25	–	1
Pleurobema cordatum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	1	–	–	1	–	1	12	1	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	1	5	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	14	–	–
Pleurobema oviforme[2]	–	–	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	1	–	1	8	–	4
Potamilus alatus	–	1	2	1	1	–	–	1	1	–	–	1	1	1	1	–	–	1	–	1	1	1	–	1	2	1	–	–	1	–	1	32	3	4
Ptychobranchus fasciolaris	–	–	–	–	–	–	1	–	–	–	–	–	1	–	1	–	–	–	1	1	2	–	–	1	1	–	2	–	1	–	–	3	–	3
Ptychobranchus subtentum[2]	1	5	4	–	–	1	–	–	–	–	2	1	2	1	1	1	–	15	–	–	13	1	7	–	1	1	6	2	3	1	3	1	–	3
Quadrula cylindrica	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	3	–	–	–	4	–	–	–	–	–	–	1	–	–	1	–	–
Quadrula metanevra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	–	1	1	–	–	–	–	1	1	–	1	–	7	–	1	–	–	6	20	7	4	–	1	–	1	4	1	–	2	–	5	219	–	–
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	–	–
Truncilla truncata	–	–	–	–	–	2	–	–	–	–	–	1	8	1	1	–	–	2	2	–	7	–	–	–	1	1	–	–	1	–	2	109	–	–
Villosa nebulosa[2]	–	–	3	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemensis[2]	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–
Total number of species	10	12	19	7	8	17	6	7	11	3	14	14	25	9	17	7	9	29	14	10	21	11	11	14	19	15	12	11	34	8	22	32	9	19

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 3 (cont.)

Mussel Species	Collecting Sites[1]																																
	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136
Actinonaias ligamentina	1	28	4	10	496	6	6	28	16	2	4	16	1	10	1	13	23	1	1	1	1	18	1	–	1	1	26	22	30	99	75	15	15	219
Actinonaias pectorosa[2]	1	3	1	3	225	4	1	7	9	–	7	9	–	10	1	3	12	–	1	1	1	21	1	–	1	–	4	4	32	85	51	4	41	183
Alasmidonta marginata	1	–	1	1	1	3	–	1	–	–	–	–	–	–	1	–	–	1	–	1	–	–	–	–	–	–	1	1	–	–	–	–	–	4
Amblema plicata	–	10	1	17	18	–	3	3	–	–	–	1	1	6	1	2	1	1	–	–	1	–	1	–	1	1	7	4	17	8	–	–	2	68
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	1	1	1	2	24	–	3	–	–	–	–	7	1	–	1	7	1	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–
Cyclonaias tuberculata	1	6	1	7	31	–	4	1	–	–	2	4	1	5	1	2	3	1	1	–	1	2	1	–	1	–	4	3	3	5	2	1	5	30
Cyprogenia stegaria	–	–	–	6	8	–	–	1	–	–	–	–	–	1	1	–	1	1	1	1	–	1	–	–	–	–	2	–	–	–	–	–	–	3
Dromus dromas[2,3]	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens	1	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio dilatata	–	–	–	4	46	2	–	2	–	–	6	4	1	4	1	10	2	1	1	–	1	1	–	–	–	1	11	4	7	26	2	–	4	132
Epioblasma brevidens[2]	–	–	–	–	3	1	–	1	–	–	–	–	1	–	1	–	2	1	1	1	1	–	–	1	1	1	1	2	–	1	–	–	1	8
Epioblasma capsaeformis[2]	1	1	1	4	12	5	2	4	4	–	2	–	–	–	1	–	9	1	1	1	1	2	1	2	–	–	1	5	–	1	–	–	–	39
Epioblasma triquetra	–	–	–	1	4	–	–	1	–	–	–	–	–	–	1	–	2	1	–	–	–	–	–	–	–	–	1	1	–	–	1	–	–	3
Fusconaia barnesiana[2]	1	2	1	17	32	1	–	6	1	–	2	–	1	–	1	1	1	–	1	1	–	–	–	–	1	1	4	4	1	–	–	–	–	22
Fusconaia cor[2,3]	–	–	–	11	4	–	–	–	–	–	–	–	1	1	1	1	1	–	1	–	1	–	–	–	1	–	1	1	–	–	–	–	–	16
Fusconaia cuneolus[2,3]	–	–	–	–	27	21	–	–	–	–	2	–	1	4	1	2	1	–	1	1	1	–	1	–	–	–	2	2	4	3	–	–	–	78
Fusconaia subrotunda	–	2	–	5	46	–	3	–	1	–	4	1	1	7	1	3	2	1	1	–	1	1	1	–	1	–	11	11	25	81	19	2	14	77
Hemistena lata	–	–	–	1	6	–	–	1	–	–	–	–	–	–	1	1	1	1	–	–	1	–	–	–	–	–	3	–	–	–	–	–	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola	1	–	2	–	17	1	–	2	–	–	1	–	1	–	1	–	1	1	1	–	1	–	1	–	–	–	–	1	2	1	–	–	–	9
Lampsilis ovata	1	2	1	2	15	–	6	–	–	–	1	–	–	–	1	–	1	–	–	–	1	3	1	–	–	–	1	1	1	6	1	–	1	17
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	1	4	1	3	23	–	–	7	14	–	10	13	1	10	1	5	5	1	1	–	1	12	1	–	1	–	12	4	3	4	–	1	2	82
Lemiox rimosus[2,3]	–	–	–	1	3	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	5
Leptodea fragilis	1	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	1	–	–	–	–	–	1	1	–	–	–	–	–	6
Lexingtonia dolabelloides[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	2	1	1	2	–	1	–	–	–	–	–	–	–	1	–	1	–	–	–	1	–	–	–	–	–	–	–	–	2	–	–	–	6
Medionidus conradicus[2]	1	1	–	4	88	5	–	4	7	–	3	1	1	–	1	3	11	–	1	1	1	–	–	–	–	1	–	2	1	1	–	–	–	5
Plethobasus cyphyus	–	1	1	1	2	–	–	–	–	–	–	–	–	–	1	–	1	–	–	1	1	–	–	–	1	–	–	–	2	2	–	–	–	2
Pleurobema cordatum	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[2]	–	–	–	1	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	4
Potamilus alatus	1	6	1	4	2	–	9	2	3	1	–	2	1	3	1	–	–	–	–	–	1	–	–	–	1	–	1	–	–	2	–	–	–	14
Ptychobranchus fasciolaris	–	2	–	–	16	–	–	2	–	–	2	–	1	7	1	4	2	1	1	–	1	1	1	–	1	–	2	1	1	4	1	–	–	17
Ptychobranchus subtentum[2]	1	–	–	3	125	17	1	14	15	–	14	10	1	1	1	1	9	1	1	1	1	5	1	–	1	1	2	1	1	6	3	–	2	25
Quadrula cylindrica	1	–	1	24	20	–	2	–	–	–	1	–	–	–	1	–	2	1	1	–	1	–	–	–	–	1	–	–	1	6	–	1	–	70
Quadrula metanevra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	1	1	1	5	8	–	–	–	–	–	–	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	1	–	–	17	–	–	–	2
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	2
Truncilla truncata	–	–	–	10	7	–	2	–	1	–	–	–	1	1	1	–	2	–	–	1	–	–	–	–	–	–	1	3	–	–	–	–	–	7
Villosa nebulosa[2]	–	–	–	–	11	8	–	–	1	–	–	–	1	2	1	–	–	–	1	1	1	–	–	1	1	1	1	–	–	2	–	–	–	17
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Villosa vanuxemensis[2]	–	–	–	1	1	–	–	1	–	–	–	1	1	–	1	–	–	–	–	1	1	–	–	–	–	–	1	–	–	–	–	–	–	7
Total number of species	17	16	16	28	34	13	13	19	11	2	15	13	21	16	31	15	27	16	18	14	25	11	12	3	14	9	27	21	16	23	9	7	10	33

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 3 (cont.)

Mussel Species	Collecting Sites[1]																																		
	137	2138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170
Actinonaias ligamentina	126	115	6	52	28	89	175	188	112	150	16	23	3	–	–	–	–	16	–	1	2	–	–	–	–	8	–	1	8	17	–	1	18	24
Actinonaias pectorosa[2]	113	93	4	25	3	129	173	63	82	235	7	78	82	–	–	–	–	33	–	3	5	–	–	2	–	17	–	–	3	23	–	–	43	78
Alasmidonta marginata	1	2	–	–	–	1	–	–	1	2	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	1	–	–	1	6
Amblema plicata	15	61	1	14	12	14	16	31	14	65	15	1	–	–	–	–	–	1	1	1	–	–	1	1	1	2	–	1	9	14	1	–	29	162
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata	15	17	–	10	–	67	15	8	13	64	6	4	–	–	–	–	–	2	2	–	1	–	–	–	1	2	–	–	3	6	–	–	3	8
Cyprogenia stegaria	–	1	–	–	–	–	–	–	–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dromus dromas[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Elliptio dilatata	27	70	1	–	5	6	14	16	17	17	5	2	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	2	–	–	–	–	33	96
Epioblasma brevidens[2]	–	1	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma capsaeformis[2]	–	3	–	–	–	1	–	–	3	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra	–	–	–	1	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana[2]	3	–	1	–	–	5	–	–	1	2	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	3	–	1	8	1	–	–	73	65
Fusconaia cor[2,3]	–	–	–	–	1	1	–	–	–	3	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	–	1	–	–	2	37
Fusconaia cuneolus[2,3]	8	55	–	3	–	21	3	3	6	31	7	31	1	–	–	–	–	2	–	2	3	–	–	–	1	–	–	1	4	2	–	–	73	188
Fusconaia subrotunda	151	33	–	56	–	18	96	37	188	135	6	3	1	–	–	–	–	2	1	2	–	–	–	1	–	–	–	–	1	6	–	–	–	6
Hemistena lata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola	1	8	–	4	–	3	1	1	7	4	3	14	5	–	–	–	–	2	–	4	11	–	–	1	1	2	–	3	–	2	–	–	10	54
Lampsilis ovata	2	7	1	–	1	6	7	8	23	15	9	23	7	–	–	–	–	8	1	2	1	–	–	–	2	2	1	–	1	4	–	–	7	45
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	17	54	4	35	22	114	23	18	18	48	55	33	6	–	–	–	–	8	8	1	3	1	–	2	4	8	–	–	12	17	–	–	16	53
Lemiox rimosus[2,3]	2	3	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Leptodea fragilis	–	1	–	–	–	–	1	–	–	1	–	1	–	–	–	–	–	–	2	–	–	–	–	–	–	1	–	–	3	5	1	–	7	31
Lexingtonia dolabelloides[2]	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	4	2	–	1	–	1	–	1	2	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	3
Medionidus conradicus[2]	1	1	–	–	–	–	–	–	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Plethobasus cyphyus	1	1	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus	1	5	2	5	4	3	4	3	11	9	5	7	2	–	–	–	–	–	1	–	1	–	–	3	–	5	–	–	6	12	–	–	2	64
Ptychobranchus fasciolaris	8	35	–	7	1	2	6	7	6	23	2	5	2	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	3	3	–	–	1	3
Ptychobranchus subtentum[2]	8	10	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	2	1	–	–	–	–
Quadrula cylindrica	3	13	1	8	1	1	4	3	–	15	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula metanevra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	1	–	–	–	1	–	2	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Villosa nebulosa[2]	–	3	–	–	–	–	–	–	1	1	3	1	–	–	–	–	–	–	–	7	8	–	–	–	–	–	–	1	4	–	–	–	62	653
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemensis[2]	–	2	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	4	161
Total number of species	21	28	13	12	11	18	15	16	22	30	18	15	11	0	0	0	0	10	7	12	10	1	1	6	6	11	1	10	17	16	2	1	19	22

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 3 (cont.)

Mussel Species	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204
	Collecting Sites [1]																																	
Actinonaias ligamentina	14	–	–	–	–	–	3	–	2	–	1	5	6	2	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–
Actinonaias pectorosa[2]	12	–	–	–	–	–	16	1	9	1	37	13	96	13	4	10	28	120	21	49	60	2	2	2	109	85	4	12	29	10	2	1	–	–
Alasmidonta marginata	–	1	–	–	–	–	3	1	–	–	1	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata	4	1	–	–	–	–	–	–	–	–	2	4	9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta grandis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyprogenia stegaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dromus dromas[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio dilatata	–	–	–	–	–	–	1	–	1	–	3	14	5	2	–	1	4	2	1	7	1	1	–	–	5	4	–	1	1	1	–	–	–	–
Epioblasma brevidens[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma capsaeformis[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia barnesiana[2]	–	–	–	–	–	–	2	–	–	1	–	4	1	–	–	–	–	–	1	1	3	–	–	–	1	–	–	–	–	2	–	7	–	–
Fusconaia cor[2,3]	–	–	–	–	–	–	1	–	2	–	2	1	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia cuneolus[2,3]	–	–	–	–	–	–	3	–	–	–	4	3	1	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	3	–	3	1	–
Fusconaia subrotunda	6	–	–	–	–	–	4	–	1	–	5	1	12	2	–	–	–	2	–	7	–	–	–	–	3	–	–	–	4	–	2	13	–	–
Hemistena lata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis abrupta[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola	–	–	–	–	–	–	–	1	2	–	1	–	2	2	1	1	1	2	4	2	–	–	1	–	3	1	2	–	2	–	–	1	–	–
Lampsilis ovata	1	–	–	–	–	–	–	–	1	–	2	–	6	–	–	–	1	3	–	1	–	–	–	–	–	–	–	1	1	–	–	–	–	–
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	3	–	–	–	–	–	18	–	14	–	70	44	77	45	6	8	19	62	12	12	3	1	–	–	9	12	1	2	16	1	1	–	–	–
Lemiox rimosus[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lexingtonia dolabelloides[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Medionidus conradicus[2]	–	–	–	–	–	–	1	–	5	–	3	24	8	3	2	–	8	1	3	1	3	–	1	1	4	3	–	3	–	3	–	–	–	–
Plethobasus cyphyus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema plenum[3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[2]	–	–	–	–	–	–	–	–	1	–	1	–	3	–	–	1	–	1	3	4	–	–	1	–	5	9	–	2	–	3	–	1	–	–
Potamilus alatus	3	–	–	2	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris	1	–	–	–	–	–	1	–	1	–	2	1	12	2	–	–	1	3	1	3	1	–	–	–	12	2	2	6	2	5	1	1	–	–
Ptychobranchus subtentum[2]	1	–	–	–	–	–	–	–	1	–	2	1	5	–	–	2	3	6	3	2	2	–	–	–	2	9	2	1	–	1	1	2	–	–
Quadrula cylindrica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula metanevra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula sparsa[2,3]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa nebulosa[2]	–	–	–	–	–	–	3	–	–	–	2	–	1	1	1	2	12	3	5	4	1	–	–	–	1	11	1	1	6	10	–	8	5	–
Villosa perpurpurea[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Villosa vanuxemensis[2]	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Total number of species	10	2	1	1	0	1	12	4	12	2	17	13	18	9	7	9	10	14	11	12	8	3	4	2	11	9	6	9	10	10	5	10	2	0

[1] Collecting sites (1-63 lower Clinch, 64-204 upper Clinch); [2] Cumberland form; [3] Endangered species.

TABLE 4. Longitudinal distribution of freshwater mussel species in 32-km (20-mile) reaches of the Clinch River with historical records reported by Ortmann (O) (1918) and recent collections from 1978 to 1983 by Ahlstedt (A).

	Collecting Sites (kilometer/mile reach)																	
		Lower Clinch River						Upper Clinch River										
Mussel Species	km 16 mi. 10	48 30	80 50	113 70	145 90	177 110	209 130	241 150	273 170	306 190	338 210	370 230	402 250	434 270	466 290	499 310	531 330	563 350
Actinonaias ligamentina	O	–	O,A	O,A	O	–	O	A	A	O,A	O,A	A	O,A	A	A	–	A	–
Actinonaias pectorosa	–	–	–	–	–	–	O	A	A	O,A	O,A	A	O,A	O,A	A	A	A	–
Alasmidonta marginata	O	–	O	O	–	–	O	A	A	A	O,A	A	O,A	O,A	–	O	–	–
Alasmidonta viridis	–	–	–	–	–	–	–	–	–	–	O	–	O	O	–	O	O	–
Amblema plicata	O,A	–	OA	O,A	–	–	O	A	A	A	O,A	O,A	O,A	O,A	–	–	–	–
Anodonta grandis	A	A	A	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anodonta suborbiculata	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cumberlandia monodonta	–	–	O,A	O,A	O	O	O	A	A	A	A	–	–	–	–	–	–	–
Cyclonaias tuberculata	A	–	O,A	O	O	–	O	A	A	O,A	O,A	A	A	–	–	–	–	–
Cyprogenia stegaria	–	–	O	O	O	–	O	–	A	A	A	A	–	–	–	–	–	–
Dromus dromas	–	–	O	O	O	—	O	–	A	A	–	–	–	–	–	–	–	–
Elliptio crassidens	O,A	–	O,A	O,A	–	–	O	A	A	A	O	A	A	–	–	–	–	–
Elliptio dilatata	O	–	O,A	O,A	O	—	O	A	O,A	O,A	O,A	A	O,A	O,A	A	O	O	–
Epioblasma arcaeformis	–	–	–	–	–	–	O	–	–	–	–	–	–	–	–	–	–	–
Epioblasma brevidens	–	–	O	–	–	–	O	–	A	A	O,A	A	–	–	–	–	–	–
Epioblasma capsaeformis	–	–	O	O	–	–	O	–	A	O,A	O,A	A	O	O	–	O	O	–
Epioblasma haysiana	–	–	O	O	–	–	O	–	–	–	–	–	–	–	–	O	–	–
Epioblasma lenior	–	–	–	–	–	–	–	–	–	–	O	–	–	–	–	–	–	–
Epioblasma propinqua	O	–	O	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma stewardsoni	–	–	–	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma torulosa gubernaculum	–	–	–	–	–	O	O	–	–	O	O	O	–	–	–	–	–	–
Epioblasma triquetra	–	–	O	O	–	–	O	–	A	O,A	O,A	A	–	–	–	–	–	–
Fusconaia barnesiana	O	–	O	O	O	–	O	A	A	O,A	O,A	A	O,A	A	A	O	O,A	O
Fusconaia cor	O	–	O	–	–	–	O	–	O,A	A	O,A	A	O,A	O,A	–	–	–	–
Fusconaia cuneolus	–	–	O	O	–	–	O	A	A	O,A	O,A	A	A	A	A	–	A	–
Fusconaia subrotunda	O	–	O,A	O,A	O	–	O	–	O,A	O,A	O,A	A	O,A	O,A	A	O,A	O,A	–
Hemistena lata	–	–	O	O	–	–	O	–	A	A	O,A	–	O	O	–	–	–	–
Lampsilis abrupta	A	–	O	O	–	–	–	–	–	A	–	–	–	–	–	–	–	–
Lampsilis fasciola	O	–	O	O	–	–	O	A	A	A	O,A	A	O,A	O,A	A	O	O,A	–
Lampsilis ovata	–	–	O	O	–	–	O	A	A	A	O,A	A	O,A	O,A	A	O	O	–
Lasmigona complanata	A	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	–	–	O	O	–	–	O	A	A	O,A	O,A	A	O,A	O,A	A	O,A	O	–

TABLE 4. (cont.)

		Collecting Sites (kilometer/mile reach)																
		Lower Clinch River						Upper Clinch River										
Mussel Species	km 16 mi. 10	48 30	80 50	113 70	145 90	177 110	209 130	241 150	273 170	306 190	338 210	370 230	402 250	434 270	466 290	499 310	531 330	563 350
Lasmigona holstonia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	O	O	O
Lemiox rimosus	–	–	–	O	–	–	–	–	–	A	A	A	O,A	–	–	–	–	–
Leptodea fragilis	–	–	O	–	–	–	O	A	A	A	A	A	A	A	–	–	–	–
Leptodea leptodon	–	–	O	–	–	–	O	–	–	–	–	–	–	–	–	–	–	–
Lexingtonia dolabelloides	–	–	O	O,A	O	–	O	–	–	–	O	A	O	O	–	O	O	–
Ligumia recta	–	–	O,A	O	O	–	O	A	A	A	O,A	A	O,A	–	–	–	–	–
Medionidus conradicus	–	–	–	–	–	–	O	A	A	O,A	O,A	A	O,A	O,A	A	O	O	–
Obliquaria reflexa	O	–	O	O	O	–	–	–	–	–	–	–	–	–	–	–	–	–
Obovaria retusa	–	–	–	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ellipsaria lineolata	O	–	–	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plethobasus cooperianus	O	–	O	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Plethobasus cyphyus	–	–	O	O	O	–	O	–	O,A	A	O,A	A	A	–	–	–	–	–
Pleurobema coccineum	–	–	O	–	–	–	O	–	–	–	O	–	–	O	–	–	–	–
Pleurobema cordatum	A	–	O,A	O,A	O	–	O	–	A	A	–	A	–	–	–	–	–	–
Pleurobema oviforme	–	–	O	O,A	–	–	–	A	A	O,A	O,A	A	O	O,A	A	O	O,A	–
Pleurobema plenum	–	–	O	O	–	–	–	–	–	A	–	–	–	–	–	–	–	–
Pleurobema rubrum	O,A	–	O,A	O,A	O	–	O	–	A	A	–	A	–	–	–	–	–	–
Potamilus alatus	A	–	O	O	–	–	O	A	A	A	O,A	A	A	A	–	–	–	–
Ptychobranchus fasciolaris	–	–	O,A	O	O	–	O	A	A	A	O,A	A	O,A	O,A	A	A	A	–
Ptychobranchus subtentum	–	–	–	O	–	–	O	A	O,A	O,A	O,A	A	O,A	O,A	A	O,A	O,A	–
Quadrula cylindrica	–	–	O	O	O	–	O	A	A	A	O,A	A	O	O,A	–	O	O	–
Quadrula intermedia	–	–	–	–	–	–	–	–	–	–	O	–	–	O	–	–	–	–
Quadrula metanevra	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa	O,A	A	O,A	O	–	–	–	A	A	A	A	A	–	–	–	–	–	–
Quadrula sparsa	–	–	–	–	–	–	–	–	–	–	–	A	–	–	–	–	–	–
Strophitus undulatus	–	–	O	O	–	–	O	–	–	A	A	A	O	O	–	O	O	–
Toxolasma lividis	–	–	–	–	–	–	–	–	–	–	O	–	–	–	–	–	–	–
Truncilla truncata	–	–	O	O	–	–	O	–	A	A	A	A	A	A	–	–	–	–
Villosa fabalis	–	–	–	–	–	–	O	–	–	–	O	–	O	O	–	–	–	–
Villosa nebulosa	–	–	O	–	–	–	O	A	A	A	O,A	A	O,A	O,A	A	O	O,A	–
Villosa perpurpurea	–	–	–	–	–	–	–	–	–	–	O,A	A	O	O,A	–	O	O	–
Villosa trabalis	–	–	–	–	–	–	–	–	–	–	O	–	–	–	–	–	–	–
Villosa vanuxemensis	O	–	–	O	–	–	O	–	A	A	O,A	A	A	A	A	–	–	–

were found; however, 12 mussel species were reported immediately above the steam plant at site 177 and gradual faunal recovery was apparently occurring downstream from the steam plant at site 171. Freshwater mussels have probably been unable to recolonize this reach of the Clinch because of continued discharges of effluents from the steam plant and silt and coal fines from Dump's and Lick creeks.

The largest concentration of mussel species found in the Clinch occurred between sites 86 and 146 (Table 3; Fig. 2). Over 27 species of mussels were reported from 11 sites in this reach. Thirty-four species were found at sites 97 and 107, and 33 occurred at site 136. Large concentrations of mussels were reported from a series of islands and island by-passes at Pendleton Island between sites 136 and 138. A total of 36 species have been identified from these three sites. This reach of the river between sites 86 and 146 contains alternating bedrock shelves interspersed by long pools and numerous islands and riffles. Sites below site 86 were also found to contain large species diversity and an abundance of individuals, especially at sites 71 and 81 where 19 and 25 species were reported. This reach of the Clinch has deep pools containing large populations of *Amblema plicata, Actinonaias ligamentina, Actinonaias pectorosa* and *Potamilus alatus.* Beginning below site 67, mussels gradually became sparse, primarily because of less suitable habitat, numerous bedrock shelves, and the effects of impoundment from Norris Reservoir.

Mussel population densities were quantified at 12 sites on the Clinch (Table 5). A total of 385 quadrat samples were taken. Ten of the twelve sites averaged five or more mussels per square meter. Four sites between sites 100 (CRM 184.5) and 136 (CRM 226.3) had densities averaging 10 or more mussels per square meter with the highest number reported at site 107 (CRM 189.6), 30.9 specimens, and at site 136 (CRM 226.3), 24.6 specimens. *Actinonaias ligamentina* and *Actinonaias pectorosa* were the most abundant species found during quantitative sampling.

The Clinch River provides habitat for a number of endangered freshwater mussels. Most of the seven endangered species found during this survey occur only in the middle to lower reaches of the river below site 169 (CRM 253) with the exception of *Fusconaia cuneolus* and *Fusconaia cor* which occur throughout the Clinch River. *Fusconaia cuneolus* was the most common of seven endangered species found.

Lemiox rimosus was found both alive and fresh dead at 12 sites between sites 169 (CRM 253) and 97 (CRM 183.5). Quantitative sampling produced only one live specimen (0.10 per square meter) at site 107 (CRM 189.6).

Specimens of *Dromus dromas* were found alive and fresh dead at 16 sites in the lower reaches of the Clinch between sites 108 (CRM 189.7) and 77 (CRM 169.8). Quantitative sampling produced only one live specimen (0.10 per square meter) at site 79 (CRM 172.2).

Quadrula sparsa was found alive at only two sites in the middle reaches of the Clinch. One specimen each was found at sites 146 (CRM 235.1) and 145 (CRM 234.9). None was found in any of the quantitative samples and the species is considered extremely rare in the Clinch.

One fresh dead specimen of *Lampsilis abrupta* was found at site 100 (CRM 184.5). This species is also extremely rare in the Clinch and is more

TABLE 5. Number of mussels per square meter in Clinch River quantitative samples.

Mussel Species	Site / River Mile	7 159.2	16 172,2	37 184.5	44 189.6	56 206.9	61 211.1	66 219.1	67 219.2	73 226.3	83 235.1	119 270.9	139 321.7
Actinonaias ligamentina		5.20	5.10	6.62	7.41	5.50	0.80	2.50	3.36	3.40	1.90	0.20	–
Actinonaias pectorosa[1]		0.20	0.60	0.31	6.05	2.75	1.10	0.30	0.48	3.60	2.50	–	0.11
Amblema plicata		–	–	0.15	0.39	–	–	0.60	0.48	0.80	0.20	0.60	–
Cumberlandia monodonta		–	–	–	0.78	–	–	–	–	–	–	–	–
Cyclonaias tuberculata		0.80	–	1.08	0.39	0.50	0.20	0.30	0.32	1.10	0.20	–	–
Cyprogenia stegaria		–	–	–	0.10	–	0.10	0.10	–	–	–	–	–
Dromus dromas[1, 2]		–	0.10	–	–	–	–	–	–	–	–	–	–
Elliptio dilatata		0.20	–	–	2.15	0.25	0.10	1.00	0.48	6.30	0.10	0.20	–
Epioblasma brevidens[1]		–	–	–	0.10	0.25	–	–	0.16	–	–	–	–
Epioblasma capsaeformis[1]		–	–	–	0.39	2.00	0.20	–	0.64	0.80	0.10	–	–
Epioblasma triquetra		–	0.10	0.15	0.10	0.25	–	–	–	–	–	–	–
Fusconaia barnesiana[1]		0.20	0.10	–	2.15	–	–	0.40	0.48	0.10	0.10	0.20	0.32
Fusconaia cor[1, 2]		–	–	–	0.20	–	–	–	–	0.30	0.30	–	–
Fusconaia cuneolus[1, 2]		–	–	–	0.29	–	–	0.10	0.16	1.10	–	0.40	0.22
Fusconaia subrotunda		–	0.30	0.46	0.78	0.25	0.10	1.10	1.60	1.70	1.00	–	0.43
Hemistena lata		–	0.10	0.15	0.10	–	–	0.20	–	–	–	–	–
Lampsilis fasciola		–	–	–	0.20	0.25	–	–	–	0.20	0.30	–	0.11
Lampsilis ovata		–	0.20	0.92	0.10	0.25	0.30	0.10	–	0.50	0.10	–	–
Lasmigona costata		0.80	0.20	–	1.27	1.00	0.20	1.10	0.48	1.30	0.10	2.20	–
Lemiox rimosus[1, 2]		–	–	–	0.10	–	–	–	–	–	–	–	–
Leptodea fragilis		–	–	–	–	–	–	–	–	0.10	–	–	–
Ligumia recta		–	–	0.31	–	0.25	–	–	–	0.10	–	–	–
Medionidus conradicus[1]		–	0.10	–	2.44	2.50	–	–	0.16	0.20	–	1.40	–
Plethobasus cyphyus		–	–	0.15	–	–	–	–	–	–	–	–	–
Pleurobema cordatum		–	–	0.15	–	–	–	–	–	–	–	–	–
Pleurobema oviforme[1]		–	–	–	0.29	–	–	–	–	–	–	–	0.11
Potamilus alatus		–	–	0.31	–	–	–	0.10	–	0.10	0.10	–	–
Ptychobranchus fasciolaris		–	–	0.15	0.29	0.25	0.10	0.10	–	0.40	0.70	–	0.11
Ptychobranchus subtentum[1]		0.80	0.10	0.15	4.20	2.00	0.50	0.10	–	1.10	–	0.20	0.11
Quadrula cylindrica		–	–	–	0.10	0.25	–	–	–	1.30	–	–	–
Quadrula pustulosa		–	–	0.31	0.10	–	–	–	–	–	–	–	–
Truncilla truncata		–	–	–	0.10	0.25	–	–	0.32	–	–	–	–
Villosa nebulosa[1]		–	–	–	0.39	–	–	–	–	0.10	–	–	0.54
Villosa perpurpurea[1]		–	–	–	–	–	–	–	–	–	–	–	–
Total		8.20	7.00	11.38	30.93	18.75	3.70	8.10	9.12	24.60	7.70	5.40	2.05
Total number quadrats		20	40	26	41	16	40	40	25	40	40	20	37
Total number mussels		41	70	74	317	75	37	81	57	246	77	27	19

[1] Cumberland form; [2] Endangered species.

often found in larger rivers rather than smaller streams like the upper Clinch.

Pleurobema plenum was found alive and fresh dead only in the lower reaches of the Clinch at sites 100 (CRM 184.5), 99 (CRM 184), and 97 (CRM 183.5). This species is also extremely rare in the Clinch and is typically a larger river species not usually found in smaller streams. *Pleurobema plenum* was not found in any of the quantitative samples.

Live and fresh dead specimens of *Fusconaia cuneolus* and *Fusconaia cor* occur throughout the upper Clinch. *Fusconaia cuneolus* was found at 56 sites between sites 203 (CRM 322.6) and 68 (CRM 155.7). Quantitative sampling produced density estimates ranging from 0.10 to 1.10 specimens per square meter at six sites (sites 107, 129, 130, 136, 182 and 202) with the greatest densities (1.10 specimens) reported from Pendleton Island at site 136 (CRM 226.3).

Fusconaia cor was found both alive and fresh dead at 29 sites throughout the river. This species is the second most abundant endangered species in the Clinch. Quantitative sampling produced density estimates of 0.30 specimens per square meter at sites 136 (CRM 226.3) and 146 (CRM 235.1) and, 0.20 at site 107 (CRM 189.6).

Distribution of Mussels

Since the mid-1970's, several papers by Bates (1975), TVA (1976, 1979, 1983), Harker *et al.* (1980), Parmalee *et al.* (1980, 1982), Pardue (1981), and Sickel (1982) have updated species distributions in the Tennessee and Cumberland rivers. Additional studies included in this report by Bates & Dennis (1978), Ahlstedt & Brown (1979), Ahlstedt (1980, 1981, 1983i), Neves *et al.* (1980), TVA (1980b, 1980c, 1982), Dennis (1981), Hatcher & Ahlstedt (1982), Schmidt (1982), and Starnes & Bogan (1982) also provided excellent current mussel distributions for many of the larger tributary streams of the Tennessee and Cumberland river systems. Results of these studies have been incorporated into the following comments concerning current distribution and abundance in the Tennessee and Cumberland drainages.

In general, most mussel species found in the Clinch River occurred in a variety of habitats with no apparent preferences. Only those species with noticeable habitat preference or unusual observations and comments were included in this section.

Cumberlandia monodonta is a relatively rare species in the upper Clinch in Tennessee and Virginia, and the lower Clinch. It was reported from 22 sites between sites 64 and 132 in the upper river and at four sites (sites 39, 42, 59, and 60) in the lower impounded stretches (Table 3; Figs. 1 and 2). Ortmann (1918) reported it from seven sites only in the lower (now impounded) portions of the Clinch, where he considered it locally abundant. *Cumberlandia monodonta* was rare in the Virginia portion of the river with the largest concentrations occurring in the Tennessee portion of the upper Clinch; however, a small but viable population still occurs at one site (site 60) in the lower Clinch. Currently, *C. monodonta* is a widespread, Interior Basin species now considered rare in the Tennessee, Cumberland, and upper Mississippi rivers (Bogan & Parmalee 1983; Nelson & Freitag 1980), but common in the lower Meramec River (Buchanan 1980). It is also found in the Powell and Nolichucky rivers, both tributaries to the Tennessee River. *Cumberlandia monodonta* has a preference for shallow areas, particularly along stream banks near water willow beds where it buries itself firmly into the sand and mud substrates and between bedrock ledges in fast-flowing current.

Amblema plicata is a fairly common species in the upper Clinch in Tennessee and Virginia, and the lower Clinch. It was reported from 69 sites between sites 70 and 183 in the upper Clinch and at nine sites between sites 1 and 60 in the lower impounded stretches (Table 3; Figs. 1 and 2). Ortmann (1918) found it at 13 sites throughout the river and commented that it was generally widespread in the upper Tennessee drainage. This species is more common in the Virginia portion of the upper Clinch where it extends into the headwaters near Cleveland (site 183).

Presently, *Amblema plicata* is a widespread, Ohioan species present throughout the Tennessee and Cumberland rivers. Unusually large numbers of old, heavier specimens dominate some of the pools of the upper Clinch.

Cyclonaias tuberculata is an extremely common species in the upper Clinch in Tennessee and Virginia, as well as in the lower Clinch. It was present at 75 sites between sites 67 and 171 in the upper Clinch and at 11 sites between sites 1 and 42 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported *C. tuberculata* from 12 sites throughout the river and mentioned that it was generally abundant in larger rivers where it extends far into the headwaters. This species was found to occur into the headwaters of the upper Clinch in Virginia where it disappears near St. Paul (site 171).

Cyclonaias tuberculata is a common, widespread, Ohioan species present throughout the Tennessee and Cumberland rivers and their tributary streams. Pardue (1981) reported it as very common in the upper Tennessee River. The author observed it to be common below Ft. Loudoun and Watts Bar dams. Unusually large, old specimens were observed in the deeper pools of the upper Clinch.

Ortmann (1918) reported two species of the genus *Elliptio (E. dilatata* and *E. crassidens)* from the Clinch River, with *E. dilatata* being the most common of the two. It occurs in the upper Clinch in Tennessee and Virginia, and in the lower Clinch. This species was present at 78 sites between sites 65 and 200 in the upper Clinch and 2 sites (42 and 60) in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported *E. dilatata* from 20 sites throughout the river and indicated that it was one of the most common, widely distributed species in the upper Tennessee region. As an extremely common Interior Basin species, *E. dilatata* is present throughout the Tennessee and Cumberland rivers and their tributary streams. It is very common in the majority of smaller, tributary streams and remains one of the most abundant species in the upper Clinch where it is present in all habitats.

Elliptio crassidens is a relatively rare species in the upper Clinch in Tennessee and Virginia, and in the lower Clinch. It was reported from 12 sites between sites 71 and 170 in the upper Clinch and at three sites (sites 31, 42, and 60) in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) found it at 10 sites throughout the river and commented that it was everywhere in the larger rivers. *Elliptio crassidens* is primarily a big river species and therefore, as expected, is very rare in the upper headwaters of the Clinch in Virginia.

As an extremely common, widespread, Interior Basin species, *Elliptio crassidens* is present throughout the Tennessee and Cumberland rivers but uncommon to rare in the smaller tributary streams. Pardue (1981) reported this mussel as the most common species in the upper Tennessee River. The author observed it to be extremely common below Ft. Loudoun and Watts Bar dams.

Four species of the genus *Fusconaia (F. subrotunda, F. barnesiana, F. cuneolus* and *F. edgariana)* were reported by Ortmann (1918) during his study of the Clinch. All four species were found in this study, primarily in the upper Clinch above Norris Reservoir. *Fusconaia subrotunda* is the most common of the four *Fusconaia* encountered. It was reported from 66 sites between sites 76 and 202 in the upper Clinch in Tennessee and Virginia, and at two sites (42 and 54) in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported *F. subrotunda* from 21 sites throughout the Clinch and commented it was more abundant in the headwaters, extending as far upstream as Cedar Bluff (site 202).

Fusconaia subrotunda is a widespread but uncommon Interior Basin species, present but rare in the Tennessee and Cumberland rivers. It becomes increasingly common in the tributary streams of the Tennessee River but is apparently absent or extirpated from the tributaries of the Cumberland. Unusually large specimens occur in some of the deeper pools of the upper Clinch.

Fusconaia barnesiana is a common species present only in the upper Clinch in Tennessee and Virginia. It was found at 63 sites between sites 67 and 202 (Table 3). Ortmann (1918) reported it from 13 sites throughout the river and commented that it was generally distributed over the upper Tennessee drainage, especially in the headwater sections of larger streams.

Recent records for *Fusconaia barnesiana* indicate it being a relatively common Cumberlandian species present only in the tributary streams of the Tennessee River. It is now apparently extirpated from the Tennessee River but remains a common species of the upper Clinch and many smaller tributaries. *Fusconaia barnesiana* typically occurs only in riffle and shoal areas in clean-swept substrates; it is rarely found in pools or slackwater areas.

Fusconaia cuneolus is a relatively common species present only in the upper Clinch in Tennessee and Virginia. It was reported from 56 sites between sites 68 and 203 (Table 3; Fig. 2). Ortmann (1918) reported *F. cuneolus* from nine sites throughout the river and indicated it to be widespread in the upper Tennessee drainage. No information is given by Ortmann as to how common this species was in the Clinch or the upper Tennessee drainage; however, it was found to be more abundant in the Virginia portion of the river, extending upstream as far as Cedar Bluff (site 203). Bates & Dennis (1978) found two specimens in the lower Clinch below Norris Dam. During this study none were found; it is now believed extirpated from the lower Clinch.

In June 1976, *Fusconaia cuneolus* was federally listed as an endangered species. This rare Cumberlandian species is presently found only in tributaries of the Tennessee River (Bogan & Parmalee, 1983; Neves 1983a). An unusually large concentration occurs in the upper Clinch River. Lesser known populations are found in the Powell, Little River, North Fork Holston, Elk, Sequatchie, and Paint Rock rivers (Neves 1983a). *Fusconaia cuneolus* is typically a riverine species found in moderate- to fast-flowing current in clean-swept rubble, gravel, and sand substrates. It is rarely found in pools or slackwater areas.

Fusconaia cor is the rarest of the four *Fusconaia* encountered. It was present in the upper Clinch in Tennessee and Virginia and occurred at 29 sites between sites 86 and 186 (Table 3; Fig. 2). Ortmann (1918) found it at 11 sites throughout the river and considered it abundant, especially in the Virginia portion.

In June 1976, *Fusconaia cor* was federally listed as an endangered species. This rare Cumberlandian species is presently found only in tributaries of the Tennessee River (Bogan & Parmalee 1980; Neves 1983b). The largest known concentrations are found in the upper Clinch and the North Fork Holston river above Saltville, Virginia. Lesser known populations occur in the Powell, Elk, and Paint Rock rivers (Neves 1983b). *Fusconaia cor* is typically a riverine species found in moderate- to fast-flowing current in clean-swept rubble, gravel, and sand substrates. It rarely occurs in deeper pools or slackwater areas.

Hemistena lata is a relatively rare species present only in the upper Clinch in Tennessee and Virginia. It was reported from 21 sites between sites 74 and 129 (Table 3; Fig. 2). Ortmann (1918) found it at only six sites in the Clinch and considered it rare. The largest concentrations were found in the Tennessee portion of the river, and it was not found above Craft Mill, Virginia (site 129). *Hemistena lata* is probably more widespread in the upper Clinch; however, it buries itself deeply into the substrate, making it a difficult mussel to find.

Considered a rare, but widespread, Ohioan species, *Hemistena lata* is now apparently extirpated from the Tennessee and Cumberland rivers. This species is presently known only from the upper Clinch, Powell, and Elk rivers, all tributaries to the Tennessee River. The largest known concentrations are probably found in the upper Clinch. This mussel is typically a shallow riffle or shoal species found in moderate- to fast-flowing current in rubble, gravel, and sand substrates. *Hemistena lata* is extremely difficult to locate because of its long foot, which enables it to burrow deeply into the substrate. Specimens are found only after a great deal of digging effort.

Lexingtonia dolabelloides is generally a rare species in the Clinch, present at one site in the upper Clinch at Pendleton Island (site 137) and at one site in the lower Clinch (Table 3; Figs. 1 and 20). Ortmann (1918) reported it from 10 sites throughout the river and found it to be abundant in the headwaters. It is rare today in the upper river and its survival is tenuous in the lower Clinch.

Currently, *Lexingtonia dolabelloides* is widespread, but a relatively rare Cumberlandian species now believed extirpated from the Tennessee River. This species continued survival in the Clinch and Powell rivers remains uncertain. The largest concentrations occur in the North Fork Holston, Duck, Elk, and Paint Rock rivers. It is typically a riverine species present only in shallow riffle and shoal areas with moderate- to fast-flowing current and clean-swept rubble, gravel, and sand substrates.

Ortmann (1918) reported two species of the genus *Plethobasus (P. cyphyus* and *P. cooperianus)* from the Clinch. Only *P. cyphyus* was found in this study. *Plethobasus cyphyus* is relatively common in the upper Clinch in Tennessee and Virginia. It was reported from 29 sites between sites 86 and 173 (Table 3; Fig. 2). Ortmann indicated *P. cyphyus* to be a larger river species and found it at 11 sites throughout the river. It occurs in the upper headwaters of the Clinch in Virginia, but is absent above St. Paul (site 173). It is now believed to be extirpated from the lower Clinch.

Plethobasus cyphyus is a widespread Interior Basin species present in the Cumberland River drainage and tributaries to the Tennessee River. Another closely related species, *Plethobasus cooperianus* is now believed extirpated from the Clinch River. *Plethobasus cooperianus* is a federally listed, endangered, Interior Basin species presently known only from the Tennessee, Cumberland, and lower Ohio rivers (Ahlstedt, 1983g).

Ortmann (1918) reported five species of the genus *Pleurobema (P. oviforme, P. cordatum, P. rubrum, P. plenum* and *P. coccineum)* from the Clinch. All but one *(P. coccineum)* were found during this study.

Pleurobema oviforme was an uncommon species in the upper Clinch in Tennessee and Virginia, and the lower Clinch. It was reported from 27 sites between sites 71 and 202 in the upper Clinch but only from site 55 in the impounded section (Table 3; Figs. 1 and 2). Ortmann (1918) found it at 11 sites throughout the river and indicated it to be widely distributed in rivers of eastern Tennessee where it extends into headwater tributaries. It is extremely rare in the lower Clinch with only two old specimens found during this study. Considered an uncommon Cumberlandian species, *P. oviforme* is extremely rare in the Tennessee River and believed extirpated from the Cumberland River. This species is reported from tributary streams to the Tennessee and Cumberland rivers, with probably the largest concentrations occurring in the upper Clinch and North Fork Holston river above Saltville, Virginia. It has a definite preference for smaller headwater streams.

Pleurobema cordatum is a rare species that was found in the upper and lower Clinch. It was reported from nine sites between sites 86 and 137 in the upper Clinch in Tennessee and Virginia, and at nine sites between sites 1 and 58 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) mentioned it to be a larger river species and found it at only six sites in the lower river. The occurrence of *P. cordatum* in the Virginia portion of the river (site 137) is the first record of this species this far upstream. Its occurrence in the upper Clinch is unusual and rare for this otherwise larger river species, although occasional specimens are still found in the lower Clinch.

Currently, *Pleurobema cordatum* is a common, widespread, Interior Basin species present throughout the Tennessee and Cumberland rivers and the larger tributary streams of the Tennessee River. The larger river habitat in the lower Clinch, especially below Melton Hill Dam, probably receives some recruitment from the upper Tennessee River, where *P. cordatum* is reported as common (Pardue, 1981). Specimens were found off the main river channel in the overbanks of the lower Clinch in slow- to moderately-flowing current.

Pleurobema rubrum is an extremely rare species in the upper Clinch in Tennessee and Virginia, and the lower Clinch. It was reported from three sites between sites 87 and 137 in the upper Clinch and from five sites between sites 1 and 57 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported it from 10 sites in the lower Clinch and mentioned that it was abundant. The occurrence of *P. rubrum* in the Virginia portion of the upper Clinch (site 137) is the first record of this species this far upstream. It is primarily a species of larger rivers.

As an uncommon, to rare, Interior Basin species, *Pleurobema rubrum* is often confused or lumped taxonomically with *P. cordatum* (Stansbery 1983). Fresh-dead specimens have been observed by the author from commercial mussel fishermen cull piles on the Tennessee and Cumberland rivers. A small reproducing population occurs in the upper Clinch near Brooks Island (site 97) and in the overbanks of the lower Clinch.

Pleurobema plenum is an extremely rare species present only in the upper Clinch in Tennessee. It was reported from three sites between sites 97 and 100 (Table 3; Fig. 2). Ortmann (1918) collected *P. plenum* from only three sites, all in the lower Clinch and considered this species scarce in the upper Tennessee region. In June 1976, *P. plenum* was federally listed as an endangered species. This rare Interior Basin species is presently found only in the Tennessee, Cumberland, Clinch, Green, and Barren rivers (Ahlstedt 1984). The largest concentrations probably occur in the Tennessee River. A small reproducing population occurs in the upper Clinch near Brooks Island (site 97). *Pleurobema plenum* is typically a big river shoal species and its presence in the upper Clinch is unusual.

Ortmann (1918) reported three species of the genus *Quadrula (Q. pustulosa, Q. cylindrica* and *Q. intermedia)* during his study of the Clinch. Only two of these species *(Q. pustulosa* and *Q. cylindrica)* were encountered during this study. Two additional species of *Quadrula (Q. sparsa* and *Q. metanevra)* not found by Ortmann were present in this study. Ortmann considered *Q. sparsa* synonymous with another closely related species, *Q. intermedia.* Any *Q. sparsa* specimens that may have been found by Ortmann were probably lumped with *Q. intermedia.* During recent sampling, *Q. sparsa* has been positively identified from the upper Clinch. *Quadrula metanevra* was not found by Ortmann, but was later listed by Cahn (1936) and Hickman (1937) from the lower Clinch prior to impoundment.

Quadrula pustulosa is the most common of the four *Quadrula* species found during this study. It was present at 31 sites between sites 67 and 146 in the upper Clinch in Tennessee and Virginia, and at 31 sites between sites 1 and 46 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported it from five sites in the lower (now impounded) river and commented that it rarely occurs in headwaters of the upper Clinch, being more common in the lower, big river section.

Recent collections indicate *Quadrula pustulosa* as a common, widespread, Interior Basin species present in the Tennessee and Cumberland rivers and their tributary streams. Pardue (1981) considered *Q. pustulosa* the most common *Quadrula* species in the upper Tennessee River.

Quadrula cylindrica is a relatively common species, but only in the upper Clinch in Tennessee and Virginia. It was found at 33 sites between sites 71 and 183 (Table 3; Fig. 2). Ortmann (1918) found it at 12 sites throughout the river and commented that it was a frequent species of larger rivers, often extending into headwater tributaries. *Quadrula cylindrica* is now believed extirpated from the lower Clinch.

Currently, *Quadrula cylindrica* is an uncommon, widespread, Interior Basin species now considered rare in the Tennessee and Cumberland rivers. Young specimens (five to seven years old) have been observed by the author at a commercial mussel fishermen's cook-out camp near Savannah, Tennessee. This represents the only recent record of it from the Tennessee River, but it remains widespread in tributary streams of the Tennessee and Cumberland rivers. Hundreds of live specimens have been observed in the upper Clinch at Pendleton Island, Virginia (site 137). *Quadrula cylindrica* has a definite preference for slackwater areas along stream banks and the transition zone between pools and riffles. Specimens were almost always observed lying on their side in silt, over rubble and gravel, with at least half of the shell exposed.

Quadrula sparsa is an extremely rare species present only in the upper Clinch in Virginia. One live specimen was found at site 145 and 146 (Table 3; Fig. 2). Ortmann (1918) never considered *Q. sparsa* separate from *Q. intermedia* because of the close similarities between the two. However, Stansbery (1973) considered both *Q. sparsa* and *Q. intermedia* as valid species and reported both from the upper Clinch in Virginia. *Quadrula intermedia* was not found during this study, but one fresh-dead specimen was collected in 1983 by Richard Neves (Virginia Polytechnic Institute, personal communication) from the upper Clinch at Pendleton Island (site 137). Ortmann (1918) reported it at two sites in the upper Clinch in Virginia and judged it to be rare. Both species are considered extremely rare in the upper Clinch.

In June 1976, *Quadrula sparsa* was federally listed as an endangered species. This rare Cumberlandian species is presently found only in the upper Clinch and Powell rivers (Ahlstedt 1983b). The largest populations known today occur in the upper Powell. *Quadrula sparsa* is typically a riverine species found only in shallow riffle and shoal areas in moderate- to fast-flowing current. It occurs in clean-swept rubble, gravel, and sand substrates, and is rarely found in standing pools or slackwater. Specimens remain buried in the substrate except during spawning. Live specimens have been observed in the upper Powell totally exposed on the substrate while spawning in early May and June.

Quadrula intermedia a federally listed, endangered, Cumberlandian species, is presently known only from the upper Clinch, Powell, Duck and Elk rivers (Ahlstedt 1983c). It is typically a riverine species found only in shallow riffle and shoal areas in moderate- to fast- flowing current. It occurs in clean-swept rubble, gravel, and sand substrates and is rarely found in standing pools or slackwater.

Quadrula intermedia is always buried in the substrate except during spawning. Live specimens were observed in the upper Powell partially or totally exposed on the substrate while spawning in early May and June.

This species was also observed to be sexually dimorphic, an observation previously unreported.

Quadrula metanevra is a rare species in the Clinch River, found only in the lower reaches at sites 4 and 29 (Table 3; Fig. 1). Ortmann (1918) did not find this species in the Clinch; however, *Quadrula metanevra* is a common, widespread, Interior Basin species present throughout the Tennessee and Cumberland rivers.

Two species of the genus *Alasmidonta (A. marginata* and *A. viridis)* were reported from the Clinch River. *Alasmidonta marginata* was the only species found in the Clinch. The closely related *A. viridis* was recently reported from Copper Creek, an upper Clinch River tributary (Ahlstedt 1981). Ortmann (1918) reported it from only four sites in the upper Clinch in Virginia, but noted it to be locally abundant in small streams throughout the upper Tennessee region.

Alasmidonta marginata is a relatively common species in the upper Clinch in Tennessee and Virginia. It was reported from 41 sites between sites 66 and 188 (Table 3; Fig. 2). Ortmann (1918) recorded it from 12 sites throughout the river and commented that it was generally distributed over the upper Tennessee region and becomes more abundant in the headwater tributaries. This mussel is now believed extirpated from the lower Clinch.

As a widespread, Interior Basin species, *Alasmidonta marginata* is now believed extirpated from the Tennessee and Cumberland rivers but relatively common in their tributary streams. It prefers fast-flowing currents in clean-swept rubble, gravel, and sand substrates.

Alasmidonta viridis was not found during the present study, but is believed to still occur in the Clinch. This species may have been overlooked while sampling. It was found in Copper Creek (Ahlstedt 1981), occurring in shallow riffle and shoal areas in moderate- to fast-flowing current.

Ortmann (1918) reported two species of the genus *Lasmigona (L. costata* and *L. holstonia)* from the Clinch. *Lasmigona costata* was the only species found in the upper Clinch; however, another species of *Lasmigona (L. complanata)* now occurs in the lower Clinch. *Lasmigona complanata* was not found by Ortmann in the Clinch, but was later reported by Bates (1975) and Bates & Dennis (1978). *Lasmigona holstonia* was not found during this study but may still occur in the extreme headwaters of the Clinch. Ortmann considered *L. holstonia* to be locally abundant in small streams and reported it from three sites only in the upper Clinch in Virginia.

Lasmigona costata is an extremely common species in the upper Clinch in Tennessee and Virginia. It occurred at 100 sites between sites 66 and 201 (Table 3; Fig. 2). Ortmann (1918) reported it from 16 sites throughout the river and commented that it was abundant in small- to medium-sized streams but rare in larger rivers. This mussel is now believed extirpated from the lower Clinch.

Currently, *Lasmigona costata* is an extremely common Interior Basin species occurring in the Tennessee and Cumberland rivers and their tributaries. It prefers the headwater portions of streams where it becomes locally abundant in all habitats.

Lasmigona complanata is an extremely rare species present at six sites between sites 7 and 37 in the lower Clinch (Table 3; Fig. 1). This species is not part of the original Clinch River mussel fauna but is often found to colonize the overbanks of rivers that have been impounded (Bates 1962, 1975). Since *L. complanata* was found only in the lower Clinch below Melton Hill Dam, it probably invaded that area from sources in the upper Tennessee River.

Recent surveys indicate *Lasmigona complanata* as a common, widespread, Interior Basin species occurring in the Tennessee and Cumberland rivers, and their tributaries. *Lasmigona complanata* prefers soft mud and sand substrates off the main river channel in the overbanks.

Strophitus undulatus is an extremely rare species in the upper Clinch in Tennessee and Virginia. Occasional specimens were found at seven sites between sites 92 and 144 (Table 3; Fig. 2). Ortmann (1918) reported it from 12 sites throughout the river and found it to be abundant both in the larger rivers and smaller tributaries.

Mussel surveys report *Strophitus undulatus* as an uncommon, widespread, Interior Basin species now believed extirpated from the Tennessee and Cumberland rivers but occurring in their tributary streams. *Strophitus undulatus* was found only in riffle and shoal areas with moderate- to fast-flowing currents and clean-swept rubble, gravel, and sand substrates. This species may be more common in the upper Clinch than records indicate since specimens were found only after considerable digging.

Actinonaias ligamentina and *A. pectorosa* were two of the most common mussels found in the Clinch. *Actinonaias ligamentina* was the more common of the two, occurring in both the upper and lower Clinch. It was reported from 103 sites between sites 65 and 202 in the upper Clinch and at three sites between sites 42 and 61 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) reported it from 13 sites throughout the river and found it extremely abundant in larger streams. It was less common in river headwaters of the Clinch where it disappears near Cedar Bluff, Virginia (site 202). While fairly common in the upper Clinch, only occasional old specimens were found in the lower Clinch.

Currently, *Actinonaias ligamentina* is a relatively common, widespread, Interior Basin species occurring in the Tennessee and Cumberland rivers and their tributaries. This mussel is becoming rare in the Tennessee and Cumberland rivers, but remains common in its tributaries. Large, old specimens occur in the pools of the upper Clinch.

Actinonaias pectorosa is an extremely common species that inhabit only the upper Clinch in Tennessee and Virginia. It was reported from 100 sites between sites 65 and 202 (Table 3; Fig. 2). Both *A. carinata* and *A. pectorosa* have similar overlapping distributions in the upper Clinch; however, *A. pectorosa* becomes the dominant species in the headwaters while *A. carinata* remains more abundant in the larger river sections. Ortmann (1918) found it to occur at eight sites throughout the river and observed that it was also more abundant than *A. carinata* north of the Virginia-Tennessee state line.

As a relatively common, Cumberlandian species, *Actinonaias pectorosa* occurs only in the tributary streams of the Tennessee and Cumberland rivers. It is now believed extirpated from the Tennessee, Cumberland, and lower Clinch rivers. Numerous, large specimens occur in the pools of the upper Clinch.

Lemiox rimosus is an extremely rare species in the upper Clinch in Tennessee and Virginia. It was reported from 12 sites between sites 97 and 169 (Table 3; Fig. 2). Ortmann (1918) found it at two sites and commented that it was widespread in distribution but found nowhere in great numbers.

In June 1976, *Lemiox rimosus* was federally listed as an endangered species. This rare Cumberlandian species is presently found only in the upper Clinch, Powell, Duck and Elk rivers (Ahlstedt 1983d). It occurs nowhere in great numbers except in the middle reaches of the Duck River below Lillard Mill Dam. *Lemiox rimosus* is generally a shallow riffle or shoal species found in moderate- to fast-flowing current in clean-swept rubble, gravel, and sand substrates. However, this species has also been observed in deeper pool areas with constant current, and hundreds of juveniles were found in the Duck River in mud, sand, and silt substrate in a slackwater area near water willow beds. This mussel spawns in October with both male and female specimens partially or totally exposed on the substrate. A previously undescribed small, black or dark grey bubble is present on the posterior margin of the females during spawning. The bubble is slit in half with equal portions on each valve of the shell. Slight movements of the bubble have been observed in flowing current which suggests it may serve as an attractor for potential fish host species. The host fish for *L. rimosus* is *Etheostoma zonale*, the greenside darter (Jenkinson 1982).

Cyprogenia stegaria is a relatively common species in the upper Clinch in Tennessee and Virginia. It was reported from 31 sites between sites 77 and 147 (Table 3; Fig. 2). Ortmann (1918) found it at only nine sites in the lower (now impounded) portion of the Clinch, where he considered it to be abundant. *Cyprogenia stegaria* extends into the headwaters of the upper Clinch in Virginia where it becomes rare.

Recent collections indicate *Cyprogenia stegaria* as a widespread, but uncommon, Ohioan species that is becoming increasingly rare in the Tennessee and Cumberland rivers. The largest known concentrations probably occur only in the upper Clinch. Only old, eroded specimens have been observed from the Tennessee and Cumberland rivers.

Dromus dromas is a rare species found only in the upper Clinch in Tennessee and Virginia. It was reported from 16 sites between sites 77 and 108 (Table 3; Fig. 2). Recently, one live specimen was found in the Virginia portion of the Clinch at Pendleton Island (site 137) by Richard Neves (Virginia Polytechnic Institute, personal communication). This represents the only known record of *D. dromas* in the Virginia portion of the river. Ortmann (1918) reported it at seven sites only in the lower (now impounded) Clinch and commented that it was abundant in the Holston River.

In June 1976, *Dromus dromas* was federally listed as an endangered species. This rare Cumberlandian species is presently found only in the upper Clinch, Powell, Tennessee, and Cumberland rivers (Ahlstedt 1983e). The largest concentrations occur in the upper Clinch and Powell rivers with occasional relict specimens reported from the upper Tennessee river below Watts Bar Dam and the middle reaches of the Cumberland River below Cordell Hull Dam. *Dromus dromas* is primarily a shallow riffle or shoal species found in moderate- to fast-flowing current in clean-swept rubble, gravel, and sand substrates. It never occurs in standing pools or slackwater. This species has also been found at depths greater than 609 cm (20 feet) in both the Tennessee and Cumberland rivers. The continued survival of *D. dromas* in the Tennessee and Cumberland rivers is tenuous.

Ortmann (1918) reported nine species of the genus *Epioblasma* from the Clinch. Of these, three *(E. triquetra, E. capsaeformis* and *E. brevidens)* were encountered during this study. Another *Epioblasma* species occurring in the Clinch *(E. torulosa gubernaculum)* was not found during this study but was collected in 1982 from the upper Clinch in Virginia by Richard Neves (Virginia Polytechnic Institute, personal communication). The remaining five species of *Epioblasma (E. lenior, E. arcaeformis, E. haysiana, E. propinqua* and *E. stewardsoni)* were considered extinct by Stansbery (1971, 1973, 1976), Bates & Dennis (1978), Jenkinson (1981), and Bogan & Parmalee (1983). Ortmann (1918) found *E. torulosa gubernaculum* in the lower Clinch, as well as in the upper river in Virginia. This species is precariously close to extinction where, prior to impoundment, it was considered by Ortmann to be locally abundant. Stansbery (1971) reported that all species of recent North American naiads believed to be extinct are members of the genus *Epioblasma*. Members of this genus, with few exceptions, are riverine species inhabiting areas with sandy gravel substrates and rapid currents. This type of habitat has nearly been eliminated by impounding rivers for flood control, power generation, and barge traffic. This is especially noticeable in the lower impounded Clinch where no *Epioblasma* species were found. The remaining *Epioblasma* species in the upper Clinch are absent in some portions of the river. While pollution problems have occurred in the upper river, their overall decline in other reaches suggests these species or their fish hosts are being killed by levels or types of impacts which do not appear detrimental to other mussel species occupying similar habitats.

Epioblasma capsaeformis is the most common of the three *Epioblasma* species in the Clinch. It was reported from 43 sites between sites 74 and 147 only in the upper river in Tennessee and Virginia (Table 3; Fig. 2). Ortmann (1918) reported it from 14 sites throughout the Clinch and found it to extend into the extreme headwaters in Virginia; it was also noted to be abundant throughout the upper Tennessee region. This species was not found above Dungannon, Virginia (site 147), but was locally common farther downstream.

Currently, *Epioblasma capsaeformis* is becoming an increasingly rare Cumberlandian species, presently found only in the tributary streams of the Tennessee and Cumberland rivers. Fresh-dead specimens have also been observed by the author from Buck Creek, a headwater tributary to the Cumberland River. *Epioblasma capsaeformis* no longer occurs in the Tennessee, Cumberland, or lower Clinch rivers. The largest concentrations are found in the upper Clinch and Powell rivers, and the Duck River.

Epioblasma capsaeformis is typically a riverine species present only in shallow riffle and shoal areas in moderate- to fast-flowing current. Specimens were found in clean-swept rubble, gravel, and sand substrates, and never occurred in standing pools. It remains buried in the substrate except during spawning. Hundreds of live male and female specimens were observed totally exposed on the substrate while spawning in early May and June. Females have an iridescent blue mantle when spawning, which is easily observed for some distance during clear water and low flows.

Epioblasma brevidens is an uncommon species in the upper Clinch in Tennessee and Virginia. It was reported from 31 sites between sites 80 and 146 (Table 3; Fig. 2). Ortmann (1918) found it at only seven sites throughout the river and commented that it was more common in medium- to larger-rivers.

As an increasingly rare Cumberlandian species, *Epioblasma brevidens* is presently found only in the Cumberland River and tributary streams of the Tennessee and Cumberland rivers. Fresh-dead specimens have also been observed by the author from Buck Creek, a headwater tributary to the Cumberland River, and relict specimens are reported from the Cumberland River by Parmalee *et al.* (1980) and Leroy Koch (Tennessee Valley Authority, personal communication). The largest concentrations occur in the upper Clinch and Powell rivers. *Epioblasma brevidens* is typically a riverine species present only in shallow riffle and shoal areas with moderate- to fast-flowing current. This mussel was found in clean-swept rubble, gravel, and sand substrates and never occurs in standing pools. It remains buried in the substrate except during spawning. Hundreds of live male and female specimens were observed totally exposed on the substrate while spawning in early May and June.

Epioblasma triquetra is a relatively common species that occurred only in the upper Clinch in Tennessee and Virginia. It was reported from 30 sites between sites 77 and 146 (Table 3; Fig. 2). Ortmann (1918) found it at nine sites throughout the river and mentioned it as frequently occurring in both large and small rivers.

Recent collections indicate *Epioblasma triquetra* as an uncommon, widespread, Ohioan species that is becoming increasingly rare throughout its range. It is present but rare in the Cumberland River, but is no longer found in the Tennessee River. The largest concentrations are found in the upper Clinch and Powell rivers. This mussel was typically found in the transition zone between pools and riffles, in moderate current, and in shallow riffle and shoal areas in moderate to fast-flowing current. *Epioblasma triquetra* remains buried in rubble, gravel, and sand substrates except during spawning. Hundreds of live male and female specimens were observed totally exposed on the substrate while spawning in early May and June.

Epioblasma torulosa gubernaculum is a federally listed, endangered, Cumberlandian species that occurs only in the upper Clinch River in Virginia (Ahlstedt 1983a). Although this species was not found during the present study, one live specimen was reported at Pendleton Island, Virginia (site 137). Based on the number of relict specimens observed from the upper Clinch between Gray's Island (site 144) and Pendleton Island, this mussel must have been locally common in this reach.

Ortmann (1918) reported three species of the genus *Lampsilis (L. fasciola, L. ovata* and *L. abrupta)* from the Clinch. All three species were found in this study.

Lampsilis fasciola is a common species in the upper Clinch in Tennessee and Virginia. It was reported from 73 sites between sites 66 and 202 (Table 3;

Fig. 2). Ortmann (1918) reported it at 15 sites throughout the river and commented that it occurs everywhere in the larger rivers and smaller streams.

Currently, *Lampsilis fasciola* is a widespread Interior Basin species believed extirpated from the Tennessee and Cumberland rivers but relatively common in their tributary streams. This mussel is extremely common in the upper Clinch and locally abundant in the lower North Fork Holston River near the Tennessee-Virginia state line.

Lampsilis ovata is a common species in the upper Clinch in Tennessee and Virginia. It was reported from 69 sites between sites 65 and 199 (Table 3; Fig. 2). Ortmann (1918) found it at 16 sites throughout the river and indicated it to be more abundant in larger rivers.

Recent surveys report *Lampsilis ovata* as a widespread Interior Basin species occurring throughout the Tennessee and Cumberland rivers and their tributary streams. It is extremely common in the upper Clinch and locally abundant in the lower North Fork Holston River near the Tennessee-Virginia state line.

Lampsilis abrupta is an extremely rare species in the Clinch River in Tennessee. It was found at only one site (site 100) in the upper Clinch, and at one site (site 27) in the lower Clinch, below Melton Hill Dam (Table 3; Figs. l and 2). Ortmann (1918) reported it from two sites in the lower (now impounded) portion of the river. The presence of this species in the upper Clinch is unusual in that it is typically a medium to large-river species.

In June 1976, *Lampsilis abrupta* was federally listed as an endangered species. This widespread Interior Basin species is present throughout the Tennessee and Cumberland rivers and 14 additional streams (Ahlstedt 1983h). *Lampsilis abrupta* is a riverine species that has been able to survive and reproduce in impoundments with river-lake conditions. This mussel was found in moderate- to fast-flowing currents in rubble, gravel, sand, and silt substrates, and rarely occurs in standing pools.

Two species of the genus *Leptodea (L. fragilis* and *L. leptodon)* have been reported from the Clinch River (Ortmann 1918), although *L. fragilis* is the only one still inhabiting the river. Ortmann considered *L. leptodon* a rare species, reporting it from only two sites in the lower Clinch. This species is now believed extirpated from the Clinch.

Leptodea fragilis is a relatively common species in the upper Clinch in Tennessee and Virginia. It was reported from 26 sites between sites 68 and 178 (Table 3; Fig. 2). Ortmann (1918) found it at three sites in the lower (now impounded) Clinch, but mentioned that it was not rare in the larger rivers. *Leptodea fragilis* occurs into the headwaters of the Clinch in Virginia where it disappears above Carbo (site 178).

A common, widespread, Ohioan species, *Leptodea fragilis* occurs in the Tennessee and Cumberland rivers and their tributary streams. It is usually found in pools and slackwater areas where it lives in mud and sand.

Ligumia recta is a relatively common species in the upper Clinch in Tennessee and Virginia, but was found at only one locality (site 42) in the lower Clinch. It was reported from 31 sites between sites 71 and 170 in the upper Clinch (Table 3; Figs. l and 2). Ortmann (1918) found it at 11 sites throughout the river and considered it abundant in larger rivers. *Ligumia recta* is more common in the Tennessee portion of the upper Clinch; however, it occurs into Virginia where it disappears near St. Paul (site 170).

Ligumia recta is a widespread Interior Basin species present in the Tennessee and Cumberland rivers and their tributary streams. It is primarily a big river species; however, it occurs with frequency in the upper Clinch and Powell rivers.

Medionidus conradicus is an extremely common species in the upper Clinch in Tennessee and Virginia. It was reported from 59 sites between sites 65 and 200 (Table 3; Fig. 2). Ortmann (1918) reported it from 12 sites throughout the river and commented that it was very abundant in the headwaters and small streams.

Recently, *Medionidus conradicus* is reported as an extremely common Cumberlandian species found only in the tributary streams of the Tennessee and Cumberland rivers. It is one of the most common and widespread of all Cumberlandian species and is typically found in slow- to fast-flowing current, along stream banks, and in shallow riffle and shoal areas.

Ortmann (1918) reported five species of *Villosa* from the Clinch River. *Three of these (V. nebulosa, V. vanuxemensis* and *V. perpurpurea)* were present in the Clinch while two *(V. fabalis* and *V. trabalis)* were not found. *Villosa fabalis* was found by Ortmann to be a relatively rare species occurring primarily in the headwaters of streams. During this study, it may have been overlooked while sampling because of its small size and/or rarity. Only relict specimens were found in the upper Clinch. The only known recent records for *V. fabalis* in the Tennessee River system are from the middle reaches of the Duck River where two live specimens were found by the author in 1982. Bogan & Parmalee (1983) consider this species endangered. *Villosa trabalis* was not found during this study; it was reported by Ortmann (1918) as extremely rare. Ortmann found only one specimen in the Clinch River where it occurred with another closely related species, *V. perpurpurea.*

Villosa nebulosa is the most common *Villosa* in the Clinch. It was found at 49 sites between sites 71 and 202 in the upper Clinch in Tennessee and Virginia (Table 3; Fig. 2). Ortmann (1918) reported *V. nebulosa* from 12 sites throughout the river and mentioned that it was widespread over all the upper Tennessee region where it favors smaller streams.

Currently, *Villosa nebulosa* is a Cumberlandian form believed extirpated from the Tennessee and Cumberland rivers but a common species in their tributary streams. *Villosa nebulosa* is typically found in gentle currents and slackwater pools along stream banks. It prefers soft mud, sand, and silt substrates.

Villosa perpurpurea is an extremely rare species present only in the Virginia portion of the upper Clinch. It was reported from four sites between sites 119 and 188 (Table 3; Fig. 2). Ortmann (1918) found it at seven sites in the upper Clinch in Virginia, where it was considered not rare.

Currently, *Villosa perpurpurea* is an extremely rare Cumberlandian species, present only in the upper Clinch, Copper Creek (a tributary to the upper Clinch), and Beech Creek (a tributary to the Holston River) (Ahlstedt 1981). This species is restricted to small head-water streams and is found in moderate- to fast-flowing water in clean-swept rubble, gravel, and sand substrates, and under large flat rocks. It rarely occurs in pools or slackwater areas and typically remains buried in the substrate; however, numerous male and female specimens were observed in Beech Creek during January, totally exposed on the substrate while spawning. *Villosa perpurpurea* is very similar to *V. trabalis*, a federally listed, endangered, Cumberlandian species reported by Ortmann (1918) from the upper Clinch. *Villosa trabalis* is now believed extirpated from the Clinch and is currently found in the tributaries of the upper Cumberland River (Ahlstedt 1983f). These two species are separated only by nacre color and there are apparently no intergrades.

Villosa vanuxemensis is a relatively uncommon species in the upper Clinch in Tennessee and Virginia. It was reported from 22 sites between sites 74 and 179 (Table 3; Fig. 2). Ortmann (1918) found it at only four sites in the Clinch, but commented that it was widespread in both the Tennessee and Cumberland rivers. Ortmann did not find *V. vanuxemi* in the Clinch above Speer's Ferry, Virginia (site 125), and indicated that it was probably overlooked while sampling. During recent studies, this species was found to extend into the headwaters of the upper Clinch in Virginia (site 199), where it becomes a rare species.

Recent collections indicate *Villosa vanuxemensis* as an uncommon Cumberlandian species believed extirpated from the Tennessee and Cumberland rivers but occurring in their tributary streams. This mussel becomes locally abundant in smaller headwater streams and is typically found in shallow riffle and shoal areas in moderate to fast-flowing current.

Potamilus alatus is a common species in the upper Clinch in Tennessee and Virginia, but rare in the lower Clinch. It was reported from 65 sites between sites 64 and 183 in the upper Clinch and at five sites between sites 11 and 24 in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) mentioned this species as common in large rivers and collected it from nine sites in the Clinch, of which eight sites were in the lower (now impounded) portion. During this study, *P. alatus* was found to extend into the headwaters of the upper Clinch in Virginia, where it disappears near Cleveland (site 183).

A common, widespread, Interior Basin species, *Potamilus alatus* is present throughout the Tennessee and Cumberland rivers and their tributary streams. *Potamilus alatus* is common in the upper Clinch and easily adapts to impoundment (Pardue 1981). It was typically found in pools and along stream banks. It has great mobility and routinely leaves a trail through soft mud and sand substrates.

Two species of the genus *Ptychobranchus* (*P. fasciolaris* and *P. subtentum*) were reported by Ortmann (1918) from the Clinch and both were encountered during this study. *Ptychobranchus fasciolaris* is a common species in the upper Clinch in Tennessee and Virginia, but rare in the lower Clinch. It was reported from 72 sites between sites 67 and 202 in the upper Clinch and at 1 site (site 42) in the lower Clinch (Table 3; Figs. 1 and 2). Ortmann (1918) found it at 13 sites throughout the river and commented that it was widely distributed over the upper Tennessee region but found nowhere in large numbers. *Ptychobranchus fasciolaris* is especially common in the upper Clinch where it extends into the headwaters near Cedar Bluff (site 202).

Ptychobranchus fasciolaris is a widespread, Interior Basin species present in the Cumberland River but apparently rare in the Tennessee River. The largest concentrations probably occur in the upper Clinch and other tributaries to the Tennessee and Cumberland rivers. In the upper Clinch it prefers the fast-moving currents near boulders and bedrock.

Ptychobranchus subtentum is a common species in the upper Clinch in Tennessee and Virginia. It was reported from 80 sites between sites 65 and 202 (Table 3; Fig. 2). *Ptychobranchus subtentum* is almost identical in distribution to *P. fasciolaris* in the upper Clinch. Both species extend into the headwaters in Virginia. Ortmann (1918) reported it at 10 sites throughout the stream and mentioned it to be rare in big rivers but locally abundant in smaller streams.

Ptychobranchus subtentum, a Cumberlandian species, is present only in tributaries of the Tennessee and Cumberland rivers. It is now believed extirpated from the Tennessee and Cumberland rivers. The largest concentrations occur in the upper Clinch and the North Fork Holston river above Saltville, Virginia. It is typically found in shallow riffle and shoal areas with moderate to swift current. This mussel prefers clean-swept rubble, gravel, and sand substrates, and is sometimes found buried along the sides of boulders. It rarely occurs in standing pools or slackwater.

Truncilla truncata is a relatively common species in the upper Clinch in Tennessee and Virginia. It was reported from 32 sites between sites 74 and 181 (Table 3; Fig. 2). Ortmann (1918) found it at six sites in the lower (now impounded) Clinch and mentioned that it was an uncommon species and absent from headwater areas. During this study, *T. truncata* was found to occur upstream to near Cleveland, Virginia (site 181).

Currently, *Truncilla truncata* is a widespread Interior Basin species rare in the Tennessee and Cumberland rivers, but more common in the tributary streams of both rivers. It was found to be locally abundant in pools near Brooks Island (site 97).

Two *Anodonta* species not recorded from the Clinch by Ortmann (1918) were found during this study. *Anodonta grandis* and *A. suborbiculata* were found only in the lower Clinch below Norris and Melton Hill dams. *Anodonta grandis* was the more abundant of the two species, occurring at 25 sites between sites 1 and 53 (Table 3; Fig. l).

Recent collections indicate *Anodonta grandis* as a common, widespread, Ohioan species found throughout the Tennessee and Cumberland rivers, and their tributary streams. It occurs only in the lower Clinch and is characteristic of impoundments where it colonizes mud and silt substrates of the overbanks (Bates 1962).

Anodonta suborbiculata is very rare in the lower Clinch; only three specimens (sites 12, 21, and 25) were found (Table 3; Fig. 1). Presently, *Anodonta suborbiculata* is reported as an uncommon, Ohioan species occurring in the Tennessee and lower Clinch rivers. It is extremely rare in the lower Clinch and is typically a big river species that colonizes the overbanks of impoundments.

Four additional mussel species previously reported from the Clinch by Ortmann (1918) were not found during this study. Three of these *(Obliquaria reflexa, Obovaria retusa* and *Ellipsaria lineolata)* are primarily big river species that were present only in the lower reaches of the Clinch prior to impoundment. The fourth species *(Toxolasma lividus)* was found by Ortmann only in the upper Clinch at one site in Virginia. The three big river species were probably eliminated from the lower Clinch when the river was impounded. No reasons can be given for the absence of *Toxolasma lividus* from the upper Clinch, since it was reported by Ortmann as widespread in the upper Tennessee drainage. It may still be present in the upper Clinch; however, intensive sampling efforts have failed to find live specimens of this species.

Mussel Community Structure

The Clinch River was divided into 32-km reaches in both the lower and upper river to simplify community structure analysis (Table 6). Mussel species reported from the river during recent surveys are listed in Table 6, and include Ortmann's (1918) mussel data. Cluster analysis was performed on these two data sets to help define the community structure (Figs. 3 and 4).

Stream reaches in the upper Clinch River above Norris Reservoir from km 241 to 434 (CRM 150 to 270) formed a cluster indicating similar species compositions (> 60% similarity) occurring in this reach (Fig. 3). An extremely tight cluster with 80% similarity formed from km 273 to 370 (CRM 170 to 230). This area contained the richest concentration of mussels found in the Clinch. Above km 466 (CRM 290), species compositions are less similar because of habitat changes and small stream size typical of most head

TABLE 6 River kilometer, elevation, gradient and number of mussel species found during recent sampling, including Ortmann's (1918) survey in each 32-km reach of the Clinch River.

Kilometer	(Mile)	Elevation m	(ft.)	Gradient m/km	(ft./mi.)	Ahlstedt no. species	Ortmann no. species
16	(10)	226	(741.0)	0.25	(1.3)	12	16
48	(30)	235	(770.0	0.26	(1.4)	3	*NS
80	(50)	241	(792.0)	0.23	(1.2)	13	42
113	(70)	257	(844.5	0.42	(2.2)	11	41
145	(90)	276	(905.5)	0..53	(2.8)	*NS	16
177	(110)	285	(935.0)	0..36	(1.9)	NS	2
209	(130)	307	(1006.0)	0.57	(3.0)	NS	42
241	(150)	339	(1111.0)	0.85	(4.5)	23	NS
273	(170)	348	(1142.5)	0.49	(2.6)	36	5
306	(190)	368	(1208.5)	0..58	(3.1)	40	14
338	(210)	381	(1250.0)	0.45	(2.4)	36	38
370	(230)	416	(1364.0)	0.87	(4.6)	38	2
402	(250)	468	(1535.5)	1.38	(7.3)	25	26
434	(270)	489	(1604.0)	0.89	(4.7)	23	24
466	(290)	594	(1950.0)	2.47	(13.1)	15	NS
499	(310)	599	(1966.0)	0.93	(4.9)	5	19
531	(330)	714	(2341.5)	2.68	(14.2)	10	17

NS = not sampled.

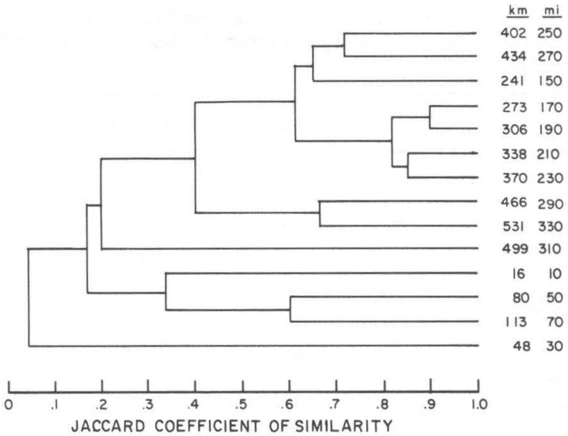

FIG. 3. Cluster analysis showing recent mussel species associations in the Clinch River (collections of Ahlstedt, 1978 to 1983).

water streams. Sampling reaches in the lower river below Norris and Melton Hill dams were less similar to each other because most mussel species reported consisted of relict specimens.

Cluster analysis of Ortmann's (1918) mussel data did not exhibit patterns similar to the recent mussel data (Fig. 3). Ortmann's data showed two groups of reaches having similarity of 50% or greater. Stream reaches below km 338 (CRM 210) formed one group, while reaches above this point formed the other. Six reaches were not grouped as would be expected, prob-

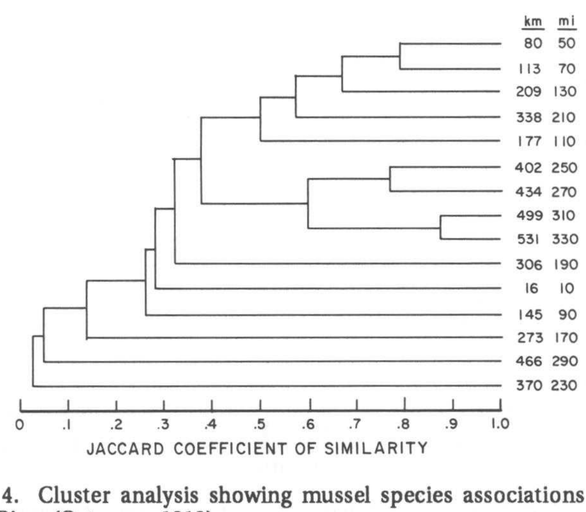

FIG. 4. Cluster analysis showing mussel species associations in the Clinch River (Ortmann, 1918).

TABLE 7. Correlation coefficients between the number of species in each 32-km (20-mi.) reach and three physical parameters for both Ahlstedt 1978-1983 and Ortmann (1918).

	Elevation	Gradient	Mile
Ahlstedt 1978-1983			
No. species	-0.833*	-0.649**	-0.756**
Elevation		0.835**	0.958*
Gradient			0.712**
Ortmann (1918)			
No. species	-0.292	-0.239	-0.429
Elevation		0.877*	0.945*
Gradient			0.749*

* = Significant at 0.01 level; ** = significant at 0.05 level.

probably because of the small amount of time and effort spent in sampling these areas.

Longitudinal Zonation

In order to further assess the effect of longitudinal zonation on the freshwater mussel community, correlations were computed between the number of species in each 32-km reach and kilometers from above the mouth of the river to include elevation and gradient (Table 7). Since the lower Clinch is affected by impoundment and channelization, these

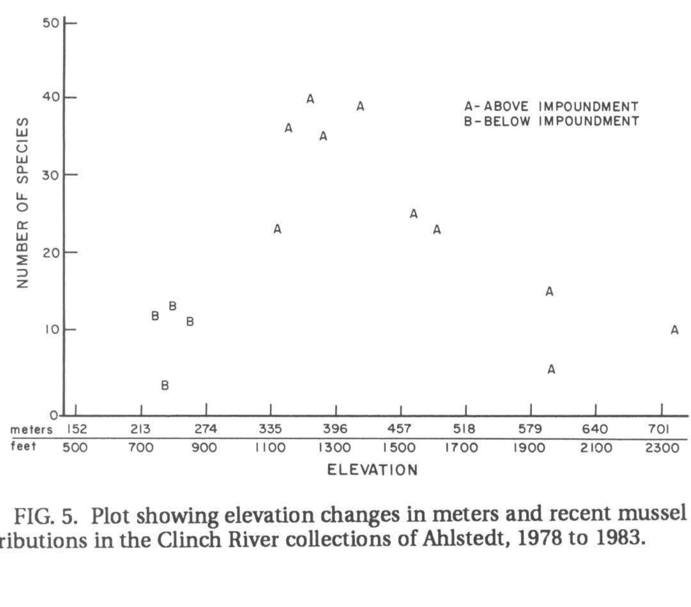

FIG. 5. Plot showing elevation changes in meters and recent mussel distributions in the Clinch River collections of Ahlstedt, 1978 to 1983.

reaches were excluded for this analysis. Correlations were computed for both recent studies and Ortmann's data. Correlations between physical parameters differ in the two matrices because some reaches were not included in each survey.

Elevation showed the highest correlation with the number of mussel species found during recent sampling (r = 0.833; V = 0.01) (Fig. 5). Stream reaches marked with a B are from the lower Clinch. These stream reaches were excluded from the correlation analysis. Stream reaches marked with an A are from the upper Clinch. Stream gradient and river kilometer were also significantly correlated with the number of mussel species found. None of these variables were significantly correlated with the number of mussel species reported by Ortmann (1918). This was probably due to the difficulty Ortmann had in sampling certain reaches of the river. Ortmann typically traveled by train and sampled at river railroad crossings. Some of the largest mussel concentrations reported from the upper Clinch were largely missed by Ortmann because of inaccessibility.

Introduced Species

The introduced Asian clam *Corbicula fluminea* has continued to spread throughout the southeastern United States since its discovery in the Tennessee River in 1959 (Sinclair & Ingram 1961). *Corbicula* was first reported from the Clinch River by Bates (1975). This species was not included in this study but was noted as widespread and extremely common throughout the Clinch. Based on the number of live specimens observed in the river and the number of fresh-dead specimens found in muskrat middens, *Corbicula* is the most abundant mussel species in the Clinch. During the course of this study, muskrats appeared to be feeding more heavily on *Corbicula* than native mussel species. This may be due in part to large densities, availability, relative small size for easy opening, and its presence in all types of habitat. At the present time, it is doubtful that *Corbicula* is outcompeting the native mussel fauna in the river for food and/or habitat, and is possible that it is relieving the pressure on the native mussel fauna.

DISCUSSION AND CONCLUSIONS

The Clinch River contains the richest assemblage of freshwater mussels (including Cumberlandian species) remaining in the upper Tennessee River. A total of 47 species of freshwater mussels were reported during recent surveys. Ortmann (1918) had previously reported 60 species of mussels prior to impoundment and major developments in the watershed (Table l, pp. 81-82).

Impoundments have had the greatest impact on the mussel fauna in the Clinch River. Stream impoundments affect species compositions by eliminating those species not capable of adapting to reduced flows, altered temperature regimes, and anoxic conditions. Both Norris and Melton Hill dams draw water from the hypolimnion of their storage reservoirs. Water drawn from the hypolimnion causes the stream below the dam (reservoir tailwater) to differ significantly from preimpoundment conditions. The effects of hypolimnial discharges include: altered temperature regimes, extreme water level fluctuations, reduced turbidity, seasonal oxygen deficits, and high concentrations of certain heavy metals (Hynes 1970; Isom 1971; Tennessee Valley Authority 1980b). Biological responses attributable to these environmental changes typically include reductions of fish and macroinvertebrate communities (Isom 1971; Fuller 1980). Hickman (1937) predicted that Norris Dam would have a deteriorating effect on the molluscan fauna in the Clinch River. Cahn (1936) reported 45 mussel species in the lower Clinch prior to closure of Norris Dam. In a return visit to the area four months later, not a single live specimen was found. During recent sampling in the lower Clinch, 20 species of freshwater mussels were found. Of these 20 species, seven species (*Amblema plicata, Anodonta grandis, A. suborbiculata, Cyclonaias tuberculata, Lasmigona complanata, Potamilus alatus* and *Quadrula pustulosa)* are surviving impoundment and reproducing in limited numbers. Three of the species (*Anodonta grandis, A. suborbiculata* and *L. complanata)* have recently colonized the lower Clinch River since being impounded. These species are typically found in the overbanks of impoundments (Bates, 1962, 1975; Parmalee *et al.*, 1982). The remaining 13 species, with the exception of *Cumberlandia monodonta,* were found in such low numbers and poor condition that their survival is tenuous. *Cumberlandia monodonta* was also found in extremely low numbers; however, evidence of reproduction (small, young specimens) was observed at one site below Norris Dam.

Freshwater mussels were relatively widespread throughout most areas of the upper Clinch. During recent studies, 43 mussel species were found. Ortmann (1918) reported 42 mussel species from the same area.

Stream reaches immediately below the Appalachian Power Company's steam-electric generating plant at Carbo, Virginia, are apparently still affected by operations at this plant (Cairns, *et al.* 1971). Freshwater mussels have failed to recolonize this reach of the river below the plant site (Bates & Dennis 1978); and more recently, experimental mussel transplants made below the plant site have failed (Richard Neves, personal communication). Tremendous amounts of fly ash are routinely deposited in holding pits along the banks of the Clinch adjacent to the plant site. The steep mountainous terrain and the close proximity of the fly ash to the river poses a serious problem in the event of a flood or the collapse of a holding pit during heavy rainfall. A large mine dump (tailings pond) is also located at Dump's Creek adjacent to the steam plant at Carbo. Freshwater mussels may be unable to recolonize this section of the river because of fly ash leaching or silt and coal fines entering the Clinch from Dump's Creek. This dump area is considered to be one of the major polluting sources impacting freshwater mussel communities in the river.

Freshwater mussels in the upper Clinch exhibited longitudinal distribution throughout the river. Masnik (1974), while studying fish distributions in the river, observed similar faunal changes with regard to increases in stream gradient. Bogan & Starnes (1983) and Starnes & Bogan (1982) made similar observations for mussel populations in the Little River and Little South Fork Cumberland River. Species diversity and abundance generally became less at collecting sites in the upper headwaters of the Clinch. The number of species varies according to the size of the drainage area, flows, stream gradient, and elevations (Hynes, 1970; Hawkes, 1975; Strayer, 1983). Abrupt changes in stream gradient are apparently a major physical barrier to mussel species distributions in the headwaters of the Clinch. Freshwater mussels were unable to colonize some of these areas because of changes in the fish fauna (lack of suitable host species), boulder and bedrock substrates, nutrient loss, or scouring action during periods of heavy rainfall. Usually near the end of a steep gradient change there was a long, deep pool not conducive for riverine mussel species.

RECOMMENDATIONS

The Clinch River contains the richest and most diverse mussel fauna remaining in the southeastern United States. In order for this fauna to survive the next century it is essential that careful management decisions are made to protect the resource at risk. An educational program must first be established to point out the basic problems, uniqueness of the river system, rarity of the resource, the river's potential value, both aesthetically and economically, and the penalties or future consequences for its abuse. A program such as this may help to eliminate some of the misconceptions about the value of preserving species and their habitats. Secondly, negative impacts occurring in the watershed (*i.e.*, fly ash, active and abandoned mines, and coal washing) must be identified and corrected before additional damage is done. Local, state and federal agencies presently have sufficient laws and regulations to protect the river system; however, the support of these agencies and greater law enforcement power are crucial for protecting the resource. Thirdly, the Clinch River should be investigated for scenic river status under the National Wild and Scenic Rivers Act program. Finally, a clearinghouse must be established to review all proposed projects or developments in the Clinch River watershed. This would help to eliminate most problems before they arise instead of after-the-fact.

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CUMBERLANDIAN MOLLUSK CONSERVATION PROGRAM: MUSSEL SURVEYS IN SIX TENNESSEE VALLEY STREAMS

Steven A. Ahlstedt[1]

ABSTRACT. – Six Tennessee River tributary streams, the Buffalo, Duck, Holston, Nolichucky, Paint Rock and Powell rivers, were surveyed as part of an intensive effort by the Tennessee Valley Authority to document the present status of endemic Cumberlandian mussel species. Results, in order of species diversity, are as follows: Powell River (37 species, 15 Cumberlandian forms, four endangered); Duck River (35 species, 11 Cumberlandian forms, two endangered); Paint Rock River (25 species, 13 Cumberlandian forms, four endangered); Nolichucky River (21 species, three Cumberlandian forms, no endangered); Holston River (13 species, no Cumberlandian forms, none endangered); and Buffalo River (seven species, three Cumberlandian forms, none endangered).

The development of the Tennessee River system and resultant changes caused by man have drastically reduced the freshwater mussel fauna in the Tennessee Valley. The mussel surveys of six Tennessee River tributary streams reported here, and of Copper Creek, and the Elk and Clinch rivers previously reported, have provided new information on range extensions, presence of endangered species, population estimates, and have documented elimination of the fauna in some portions of the streams sampled. In general, the mussel fauna today in these drainages are but a small assemblage of the fauna reported before the development of the region. The fauna appears to be on a steady decline, especially members of the Cumberlandian faunal group. Cumberlandian species are typically found in silt-free, riffle and shoal areas, which is a diminishing habitat in the Tennessee Valley.

KEY WORDS. – Freshwater mussels, Cumberlandian species, mussel sampling, endangered species, Buffalo, Duck, Holston, Nolichucky, Paint Rock and Powell rivers.

CONTENTS

INTRODUCTION

With the passage of the Endangered Species Act in 1973 by the United States Congress and the subsequent listing of federally protected endangered

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mussels, 13 of the 24 mussel species listed are endemic Cumberlandian forms. The distribution of Cumberlandian species in the Tennessee Valley is one of nine research activities developed as part of the Tennessee Valley Authority's Cumberlandian Mollusk Conservation Program (CMCP). This program was developed to answer questions about the Cumberlandian fauna including, present or potential habitats after the U.S. Fish and Wildlife Service (FWS) issued a Biological Opinion stating that completion of Columbia Reservoir on the Duck River would likely jeopardize the continued existence of two Cumberlandian mussel species: the birdwing pearly mussel, *Lemiox rimosus*, and the Cumberland monkeyface pearly mussel, *Quadrula intermedia* (Jenkinson, 1980). The name Cumberlandian refers to an endemic faunal assemblage that encompasses portions of seven states bordering the southern Appalachian Mountains and the Cumberland Plateau Region (Ortmann, 1918). This geographic region is known as one of the major centers for mussel speciation and is considered the most prolific area of the world for this particular group of organisms.

Nine Tennessee River tributary streams were selected for intensive qualitative and quantitative mussel surveys under Activity I of the CMCP. These streams are the Buffalo, Clinch, Duck, Elk, Holston, Nolichucky, Paint Rock and Powell rivers, and Copper Creek. The surveys were designed to gather information on the present distribution of Cumberlandian mollusks. The streams chosen for surveys were based on the documented presence of diverse mussel fauna, endangered mussels, and/or sufficient information (diverse fish fauna, good water quality, etc.) to suggest potential for occurrence of diverse mussel fauna or endangered species. The results of the mussel surveys for Copper Creek, and the Elk and Clinch rivers are presented in Ahlstedt (1982, 1983, 1991), and the results from the other six streams are presented below. The nomenclature used here for freshwater mussels follows Turgeon *et al.* (1988).

MATERIALS AND METHODS

The Buffalo, Duck, Holston, Nolichucky, Paint Rock and Powell rivers were surveyed for freshwater mussels by floating selected reaches of these streams. The slight modifications to mussel sampling procedures required are given separately for each study.

Prior to each survey, a detailed search for suitable access points was conducted and contacts with landowners were established to obtain water visibility and flow conditions. All potential access points were documented for emergency purposes.

Each crew consisted of a biologist competent in field identification of freshwater mussels, two certified scuba divers, and a vehicle operator. Both qualitative and, when necessary, quantitative mussel samples were collected from shoal and pool habitats.

Qualitative sampling for mussels was conducted at each site using a variety of methods. Muskrat middens were searched for fresh-dead shell. Live freshwater mussels were collected mainly by snorkel and/or scuba divers handpicking specimens from the substrate during a random search of the site. In addition, gravel and sand areas were hand-raked using a garden rake to expose mussels buried in the substrate.

Fresh–dead mussel shells collected from muskrat middens were stored in cloth collecting bags and appropriately labeled. All live freshwater mussels found were identified by the biologist, counted, recorded on data sheets, and immediately returned to the river substrate. Voucher specimens of live freshwater mussels were collected at each site. Specimens were preserved in 70 % ethanol, labeled, and taken to the laboratory for cataloging, storage, and verification. Verification of difficult specimens from the genus complex *Fusconaia/Pleurobema/Lexingtonia* was provided by Dr. David Stansbery at the Museum of Zoology, Ohio State University at Columbus, where the specimens remain.

Quantitative sampling for mussels was conducted in areas which contained endangered freshwater mussels or dense mussel concentrations. A quadrat sampler, consisting of a metal frame with a sampling area of 0.5 m^2, was randomly placed on top of the substrate and sampled to a depth of 5-10 cm. All living mussels found within the sampler were removed, identified, counted, and recorded on data sheets.

Quantitative sampling was conducted at the discretion of the biologist. The number of quadrats taken per site depended upon the size of the habitat containing mussel concentrations. The following table was developed for field use to standardize the relationship between the mussels' habitat area and the number of quantitative samples required to adequately access population densities.

Mussels Habitat Area (m^2)	Number of Quadrat Samples (0.5 m^2)
100–300	12
400	16
500	20
600	24
700	28
800	32
900	36
1,000	40
1,000 or larger	40

Data analysis consisted of estimating the total number of mussels found per square meter at each site where quantitative samples were taken. Estimates were determined on a species by species basis.

POWELL RIVER

During June 1979, the Powell River was float surveyed from Olinger, Virginia, (Powell River Mile, PRM, 167.4) downstream to State Highway 25E bridge (PRM 65.1) (Fig. 1). Five field crews were each assigned 22-mile reaches of river to survey. Riffle and shoal areas encountered were sampled for freshwater mussels as were the pool areas at the head of each shoal (Table 1). Each crew consisted of three scuba-equipped divers and/or snorkelers. Sampling time averaged between 45 and 90 minutes per shoal. Quantitative mussel samples using a 0.25m^2 quadrat sampler were taken in areas which contained dense mussel concentrations. All mussels were identified in the field, and representative voucher specimens, including fresh-dead specimens, were taken to the laboratory for positive identification.

Results

Thirty-seven species of freshwater mussels including 15 Cumberlandian forms were found alive during this survey (Table 2). Five of the sixteen Cumberlandian species *(Lemiox rimosus, Fusconaia cor, Dromus dromas, Quadrula intermedia* and *Quadrula sparsa)* are federally listed endangered species.

Distribution, abundance, and diversity of the mussel fauna in the Powell River are apparently significantly impacted by various forms of pollution. Collecting sites in the upper reaches of the Powell above site 57 (PRM 138.3) were heavily affected by silt and coal fines derived from land disturbances and coal mining activities in the watershed and pollution from the North Fork Powell River and Callahan Creek. Seventeen mussel species were found in this reach of the Powell (above site 57) but only in extremely low numbers. This portion of the river is also situated in steep mountainous terrain with a high stream gradient. During periods of heavy rainfall, high

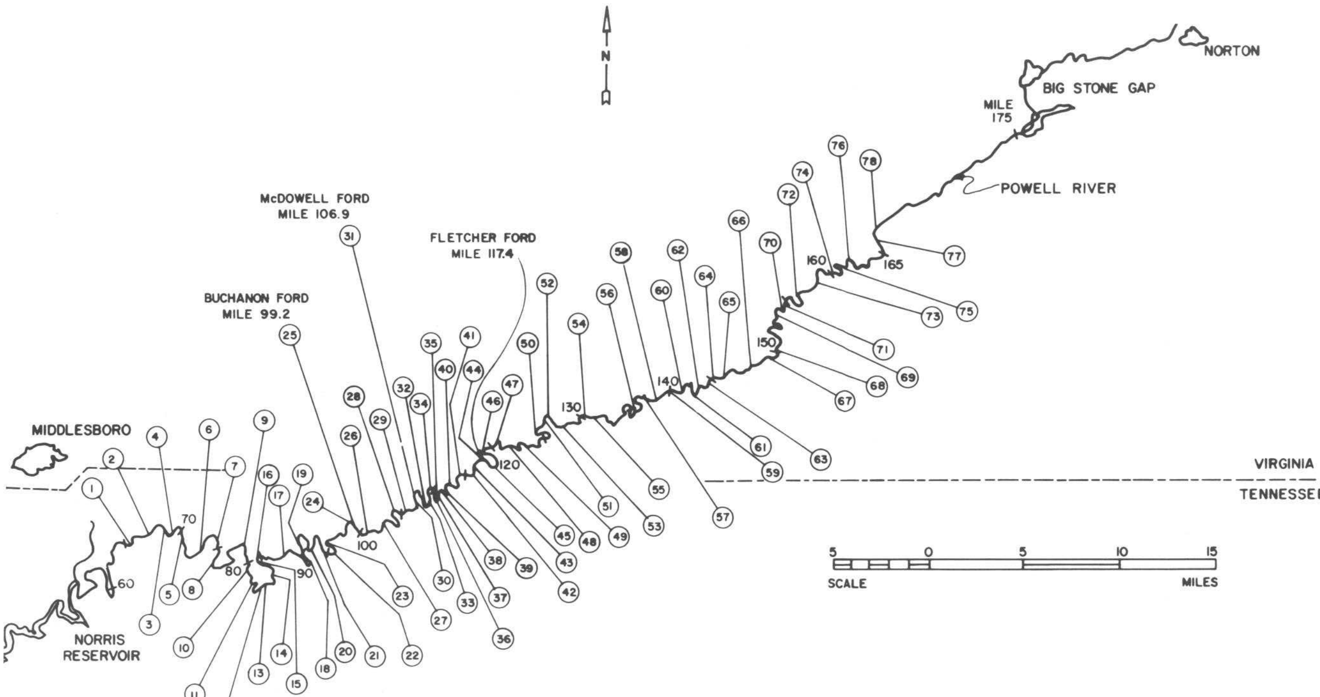

FIG. 1. Powell River mussel sampling sites.

TABLE 1. Location of all Powell River collecting sites in river miles (PRM), June 1979.

Site	PRM	Location
1	65.1	Highway 25E Bridge, Claiborne County, Tennessee
2	67.0	Half mile below Indian Creek, Claiborne County, Tennessee
3	68.5	Below Sugar Hollow, Claiborne County, Tennessee
4	69.1	Sugar Hollow, Claiborne County, Tennessee
5	70.4	Bussell Ford, Claiborne County, Tennessee
6	72.8	Above Ellison Bend, Claiborne County, Tennessee
7	74.8	Claiborne County, Tennessee
8	75.9	Massengille Bend, Claiborne County, Tennessee
9	78.7	Cosby Bridge, Claiborne County, Tennessee
10	80.4	Double S Bend, Claiborne County, Tennessee
11	81.4	Campbell Cemetery, Claiborne County, Tennessee
12	82.6	At Russell Creek, Claiborne County, Tennessee
13	82.8	Above Russell Creek, Claiborne County, Tennessee
14	83.5	Claiborne County, Tennessee
15	84.6	Yellow Shoals Ford, Claiborne County, Tennessee
16	84.8	Yellow Shoals Ford, Claiborne County, Tennessee
17	86.8	Below Cox Shoals, Claiborne County, Tennessee
18	89.2	Below the Narrows, Claiborne County, Tennessee
19	90.5	Below Eastridge Bend, Claiborne County, Tennessee
20	92.4	Elk Bend, Claiborne County, Tennessee
21	94.8	Below Brooks Bridge, Claiborne County, Tennessee
22	95.6	Below Hoop Creek, Claiborne County, Tennessee
23	96.5	Claiborne County, Tennessee
24	99.0	Below Buchanan Ford, Claiborne County, Tennessee
25	99.2	Buchanan Ford, Claiborne County, Tennessee
26	100.3	Fugate Ford, Claiborne County, Tennessee
27	102.0	Hancock County, Tennessee
28	104.4	Above town of Alanthus Hill, Hancock County, Tennessee
29	105.2	Hancock County, Tennessee
30	106.5	Below McDowell Shoal, Hancock County, Tennessee
31	106.9	McDowell Shoal, Hancock County, Tennessee
32	108.3	At unnamed island, Hancock County, Tennessee
33	109.1	Below unnamed island, Hancock County, Tennessee
34	109.7	Unnamed island, Hancock County, Tennessee
35	110.2	Above Wolfenbarger Church, Hancock County, Tennessee
36	110.7	Wallen Ridge, Hancock County, Tennessee
37	110.9	Wallen Ridge, Hancock County, Tennessee
38	111.8	Unnamed island below Bales Ford, Hancock County, Tennessee
39	112.3	Bales Ford, Hancock County, Tennessee
40	112.8	Above Martin Creek, Hancock County, Tennessee
41	114.3	Above creek at Blue Hollow, Hancock County, Tennessee
42	115.4	Baldwin Ford, Hancock County, Tennessee
43	115.8	Above Baldwin Ford, Lee County, Virginia
44	117.3	Fletcher Ford, Lee County, Virginia
45	117.9	Island at Fletcher Cliff, Lee County, Virginia
46	119.3	At Yellow Creek, Lee County, Virginia
47	120.7	Ford, Lee County, Virginia
48	121.6	Unnamed island, Lee County, Virginia
49	123.4	Below Snodgrass Ford, Lee County, Virginia
52	127.6	At Hardy Creek, Lee County, Virginia
53	128.5	Hall Ford, Lee County, Virginia
54	130.6	Flanary Bridge, Lee County, Virginia
55	131.2	Unnamed island above Flanary Bridge, Lee County, Virginia
56	136.1	Lee County, Virginia
50	126.4	Above Tyler Bend, Lee County, Virginia

TABLE 1 (cont.)

Site	PRM	Location
51	127.2	White Shoals, Lee County, Virginia
57	138.3	Below Hurricane Bridge, Lee County, Virginia
58	138.9	Above Hurricane Bridge, Lee County, Virginia
59	140.0	Above McConnell Chapel, Lee County, Virginia
60	140.8	Lee County, Virginia
61	142.4	Oxford Ford, Lee County, Virginia
62	143.5	Sewell Bridge, Lee County, Virginia
63	144.6	Poteet Ford, Lee County, Virginia
64	145.1	Tanbark Ridge, Lee County, Virginia
65	145.6	Below Cheek Spring, Lee County, Virginia
66	147.9	At Graham Cemetery, Lee County, Virginia
67	149.9	Above unnamed ford to Pond View Church, Lee County, Virginia
68	149.9	Half mile below Poteet Ferry Bridge, Lee County, Virginia
69	153.4	Unnamed island near Highway 640, Lee County, Virginia
70	154.3	Near Wampler Cemetery, Lee County, Virginia
71	154.7	Unnamed island near Highway 642, Lee County, Virginia
72	156.8	Above North Fork Powell River, Lee County, Virginia
73	158.3	Unnamed ford, Lee County, Virginia
74	160.5	Unnamed ford to Highway 642, Lee County, Virginia
75	161.7	Lee County, Virginia
76	163.4	Below swinging bridge, Lee County, Virginia
77	166.3	Unnamed island below Highway 58A, Lee County, Virginia
78	167.4	Below Olinger, Lee County, Virginia

stream flows have eliminated mussel habitat by scouring away suitable substrate exposing bedrock and boulders. When pools and island bypass channels were present, the river habitat was full of silt and coal fines so that a long handled boat paddle was easily sunk into the river substrate. Mussels that were observed were found to occur in small isolated pockets in low numbers.

Collecting sites in the lower 70 miles of the Powell below site 57 (PRM 138.3) contained the greatest concentrations of freshwater mussels. Thirteen sites were found to support 18 or more mussel species. Site 21 (PRM 94.8) had the highest species diversity with 28 mussel species and sites 43 and 45 (PRM 115.8 and PRM 117.9) each had 27 species. Habitat in this reach of the river is generally more stable than that in the upper Powell because of lower stream gradient and greater stream width, thus lower current velocities. Silt and coal fines are present in large concentrations but long, deep pools have helped to trap much of this material.

Mussel population densities were quantified at 15 collecting sites on the Powell (Table 3). A total of 441 quadrat samples were taken. Eleven of the fifteen sites averaged five or more mussels per square meter. Three sites with the lowest densities occurred above site 51 (PRM 127.2). Four sites between sites 25 (PRM 99.2) and 50 (PRM 126.4) had densities averaging 10 or more mussels per square meter with the highest number reported at site 46 (PRM 119.3) with 21 specimens. *Actinonaias ligamentina* and *Actinonaias pectorosa* were the most abundant species found during quantitative sampling.

TABLE 2. Powell River qualitative mussel survey data.

Species	Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	River mile	65.1	67.0	68.5	69.2	70.4	72.8	74.8	75.9	78.7	80.4	81.5	82.6	82.8	83.5	84.6	84.8	86.8	89.2	90.5	92.4	94.8	95.6	96.5	99.0	99.2	100.3
Actinonaias ligamentina		22	138	1	–	12	125	11	14	25	232	21	8	–	26	225	35	–	11	2	2	10	1	15	10	55	5
*Actinonaias pectorosa**		3	73	–	1	7	24	–	4	20	69	4	–	–	6	145	4	–	1	–	–	10	–	5	–	16	–
Alasmidonta marginata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
Amblema plicata		–	33	1	–	2	74	1	33	–	6	–	3	1	10	6	2	–	9	–	2	6	1	–	–	2	–
Cyclonaias tuberculata		–	4	–	–	1	10	–	3	–	8	–	–	–	3	6	3	–	1	–	–	–	–	1	–	1	–
*Dromus dromas**†		–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	10	–	–	–	–	–
Elliptio crassidens		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	1	–	–	–	–	–	–	2	–
Elliptio dilatata		–	–	–	–	–	–	–	–	–	6	–	–	–	4	3	2	–	2	–	–	1	–	–	–	–	–
*Epioblasma brevidens**		–	–	–	–	2	3	–	–	–	1	–	–	–	–	1	–	–	1	–	–	10	–	–	–	–	–
*Epioblasma capsaeformis**		–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	3	–
Epioblasma triquetra		–	3	–	–	–	1	–	–	–	2	1	1	–	–	–	–	–	–	–	–	1	–	1	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia cor**†		–	2	–	–	–	2	–	–	–	1	–	–	–	–	3	–	–	–	–	–	10	–	–	–	–	–
Fusconaia subrotunda		–	14	–	–	3	13	–	–	–	7	–	–	–	2	5	1	–	9	–	–	1	–	3	4	10	–
Hemistena lata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lemiox rimosus**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Lampsilis fasciola		–	2	–	–	1	1	–	1	–	6	–	–	–	4	3	1	1	1	–	–	1	–	–	–	–	–
Lampsilis ovata		–	5	–	1	1	8	1	2	–	2	1	2	–	1	1	1	–	–	–	–	–	–	3	2	2	1
Lasmigona costata		–	9	–	–	2	2	–	4	1	10	–	1	–	5	8	4	–	1	–	4	–	–	1	–	2	–
Leptodea fragilis		–	2	–	–	–	2	–	–	1	1	–	–	–	1	–	–	–	2	–	–	–	–	2	–	–	–
*Lexingtonia dolabelloides**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta		–	1	–	–	–	2	–	–	–	1	1	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–
*Medionidus conradicus**		–	7	–	–	–	1	–	1	–	20	–	–	–	4	3	2	–	–	–	–	1	–	–	1	10	1
Plethobasus cyphyus		–	4	–	–	–	3	–	–	–	2	–	–	–	1	5	–	–	1	–	–	1	–	1	–	1	–
*Pleurobema oviforme**		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		–	20	2	–	3	16	2	4	–	3	–	3	–	–	2	–	–	2	–	1	–	–	3	–	4	–
Ptychobranchus fasciolaris		1	5	–	–	1	2	1	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	1	–
*Ptychobranchus subtentum**		–	5	–	–	1	1	–	–	–	10	–	–	–	4	3	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica		–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
*Quadrula intermedia**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	–	–	–	–
Quadrula pustulosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula sparsa**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–
Strophitus undulatus		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Total		27	327	4	2	36	290	17	66	46	389	30	18	1	71	420	61	1	46	2	9	78	2	35	17	110	7

*Cumberlandian species; †endangered species.

TABLE 2 (cont.)

Species / Site	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
River mile	102.0	104.4	105.2	106.5	106.9	108.3	109.1	109.7	110.2	110.7	110.9	111.8	112.2	112.8	114.3	115.4	115.8	117.3	117.9	119.3	120.7	121.6	123.4	126.4	127.2	127.6
Actinonaias ligamentina	8	14	15	19	19	5	6	1	68	1	1	1	–	1	1	2	19	10	10	10	27	1	10	6	16	4
*Actinonaias pectorosa**	–	–	11	1	2	3	3	–	24	–	–	1	–	1	10	5	12	10	9	10	4	1	10	3	–	–
Alasmidonta marginata	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata	5	–	2	1	2	1	–	–	2	–	–	–	–	1	1	–	6	–	6	1	8	–	–	1	–	–
Cyclonaias tuberculata	–	–	3	1	1	–	–	–	1	–	–	–	–	1	1	–	1	–	1	–	1	–	3	1	–	1
*Dromus dromas**†	–	–	1	1	1	–	–	1	6	–	–	–	–	1	1	6	1	1	2	2	–	–	1	1	–	–
Elliptio crassidens	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio dilatata	–	–	2	1	3	1	–	1	8	1	–	–	–	1	1	3	7	1	7	1	19	1	3	4	–	1
*Epioblasma brevidens**	1	–	–	1	–	2	–	–	1	–	–	–	–	–	1	8	42	1	28	1	6	–	–	1	–	–
*Epioblasma capsaeformis**	–	–	–	1	–	–	–	–	4	–	–	–	–	2	1	4	–	1	1	–	–	–	–	–	–	–
Epioblasma triquetra	–	–	–	1	2	1	–	–	4	–	–	1	–	–	–	3	10	–	17	–	–	–	–	–	–	–
*Fusconaia barnesiana**	–	–	–	1	–	1	4	–	3	–	–	–	–	–	–	2	1	1	1	1	1	1	10	4	–	–
*Fusconaia cor**†	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	3	–	2	–	2	–	–	–	–	–
Fusconaia subrotunda	2	5	7	7	1	1	1	–	–	–	–	–	–	–	1	–	1	1	1	1	1	–	10	–	–	1
Hemistena lata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–
Lampsilis fasciola	–	–	–	–	–	1	1	1	3	–	–	–	–	1	–	–	4	1	4	1	3	1	–	–	–	–
Lampsilis ovata	1	1	–	–	1	–	1	–	2	1	–	1	–	–	–	–	9	–	3	1	1	–	2	1	–	2
Lasmigona costata	–	–	1	–	–	2	–	–	4	–	–	–	–	1	1	–	1	–	1	1	3	1	1	1	–	5
*Lemiox rimosus**†	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	1	2	–	–	–	1	–	–	–	–	–
Leptodea fragilis	–	–	–	1	–	1	–	–	1	–	–	1	–	–	–	–	5	–	2	–	9	1	–	–	–	1
*Lexingtonia dolabelloides**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Ligumia recta	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	1
*Medionidus conradicus**	–	–	–	3	3	–	–	–	16	–	–	–	–	1	1	11	1	1	1	10	1	1	4	6	2	–
Plethobasus cyphyus	–	–	1	1	–	2	2	–	3	–	–	–	–	1	–	–	13	–	3	–	–	–	–	–	–	–
*Pleurobema oviforme**	–	–	–	–	–	–	–	–	2	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–
Potamilus alatus	1	–	1	–	1	1	2	–	–	–	–	–	–	1	1	–	2	–	6	1	5	1	1	2	–	4
Ptychobranchus fasciolaris	–	–	–	1	–	–	–	–	1	–	–	–	–	1	–	1	2	1	5	1	1	1	1	–	–	–
*Ptychobranchus subtentum**	–	–	1	–	–	–	–	1	2	–	–	–	1	–	–	–	1	–	1	–	–	–	1	–	–	–
Quadrula cylindrica	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–
*Quadrula intermedia**†	–	–	1	1	1	–	–	–	1	–	–	–	–	–	–	–	2	1	6	1	–	–	1	1	–	–
Quadrula pustulosa	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula sparsa**†	–	–	–	1	–	1	–	–	1	–	–	–	1	–	–	–	3	–	–	–	–	–	–	–	–	–
Strophitus undulatus	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–	2	–	5	–	–	1	–	–
*Villosa vanuxemensis**	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	18	20	46	51	38	24	20	5	159	3	2	5	2	14	23	47	153	31	122	43	98	10	59	33	18	20

*Cumberlandian species; †endangered species.

TABLE 2 (cont.)

Species	Site	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
	River mile	128.5	130.6	131.2	136.1	138.3	138.9	140.0	140.8	142.4	143.5	144.6	145.1	145.6	147.9	149.2	149.9	153.4	154.3	154.7	156.8	158.3	160.5	161.7	163.4	166.3	167.4
Actinonaias ligamentina		20		2	5	5	–	–	3	1	–	9	1	4	12	3	1	–	–	–	–	–	–	–	–	–	1
*Actinonaias pectorosa**		12		2	2	12	–	–	–	–	–	1	–	–	1	–	–	–	1	–	13	–	–	–	–	–	–
Alasmidonta marginata		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata		–		–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Dromus dromas**†		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio crassidens		–		–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio dilatatus		–		2	2	1	–	–	–	–	–	–	–	–	–	7	–	–	–	–	–	–	–	–	–	–	–
*Epioblasma brevidens**		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Epioblasma capsaeformis**		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia cor**†		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia subrotunda		–		3	2	4	–	–	1	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Hemistena lata		–		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola		–		–	1	–	–	–	–	–	–	–	1	–	–	–	1	–	–	1	–	–	5	–	–	2	3
Lampsilis ovata		4		2	2	–	–	–	–	–	1	1	–	1	–	–	–	–	–	–	1	–	–	–	–	1	1
Lasmigona costata		1		1	4	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1	–
*Lemiox rimosus**†		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis		–		–	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
*Lexingtonia dolabelloides**		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ligumia recta		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Medionidus conradicus**		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Plethobasus cyphyus		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Pleurobema oviforme**		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		1		1	5	–	–	–	2	–	2	–	1	–	–	–	–	–	–	–	–	–	–	–	–	5	1
Ptychobranchus fasciolaris		–		–	1	–	–	–	1	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
*Ptychobranchus subtentum**		–		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica		–		–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula intermedia**†		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa		–		–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula sparsa**†		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Strophitus undulatus		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**		–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–
*Villosa vanuxemensis**		–		1	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	2	–	2	4	–
Total		38		15	36	27	0	1	8	2	3	14	3	6	14	11	2	2	2	1	15	0	7	0	2	16	6

*Cumberlandian species; †endangered species.

TABLE 3. Number of mussels per square meter in Powell River quantitative samples.

Species / Site / River mile	6 72.8	11 81.5	15 84.6	16 84.8	21 94.8	25 99.2	31 106.9	39 112.2	44 117.3	46 119.3	50 126.4	51 127.2	54 130.6	56 136.1	77 166.3
Actinonaias ligamentina	1.90	1.00	2.20	3.69	3.20	5.50	2.46	1.80	1.90	4.33	3.38	2.00	1.78	0.82	–
*Actinonaias pectorosa**	0.70	0.80	1.80	0.46	0.10	1.60	1.03	1.60	4.86	10.00	4.75	–	2.22	–	–
Alasmidonta marginata	–	–	–	–	–	0.10	–	–	–	–	–	–	–	–	–
Amblema plicata	2.10	0.20	0.20	0.15	1.40	0.20	0.31	–	0.10	–	–	–	–	–	–
Cyclonaias tuberculata	0.20	–	0.60	–	0.10	0.10	–	0.20	0.10	–	–	–	–	0.12	–
*Dromus dromas**†	–	–	–	–	–	–	0.10	0.20	–	–	–	–	–	–	–
Elliptio crassidens	–	–	–	0.15	0.10	0.20	0.21	–	–	–	–	–	–	–	–
Elliptio dilatata	–	–	0.40	–	–	–	0.10	0.20	0.48	2.67	0.63	–	0.11	0.12	–
*Epioblasma brevidens**	0.40	–	0.20	–	–	–	0.10	–	0.38	–	–	–	–	–	–
*Epioblasma capsaeformis**	–	–	–	–	–	0.30	–	0.40	0.29	–	–	–	–	–	–
Epioblasma triquetra	0.10	–	–	–	–	–	–	–	0.10	–	–	–	–	–	–
*Fusconaia barnesiana**	–	–	–	–	0.10	–	–	0.80	0.19	–	0.75	–	–	–	–
*Fusconaia cor**†	–	–	–	0.31	0.10	–	0.10	0.20	–	–	–	–	–	–	–
Fusconaia subrotunda	0.60	–	0.20	0.15	1.10	1.00	0.10	–	0.38	–	–	–	0.33	0.82	–
Lampsilis fasciola	0.10	0.20	0.40	–	–	–	0.21	–	0.38	–	0.25	0.20	–	–	0.20
Lampsilis ovata	0.10	0.20	–	–	0.30	0.20	0.21	0.20	–	1.00	0.13	–	0.11	–	–
Lasmigona costata	0.40	–	0.40	0.92	0.10	0.20	–	–	–	0.67	–	–	0.22	0.12	–
Leptodea fragilis	–	–	–	0.15	0.10	–	–	–	0.19	–	–	–	–	–	0.20
Ligumia recta	–	–	–	–	–	–	–	–	–	0.33	–	–	–	–	–
*Medionidus conradicus**	–	0.40	0.60	–	0.10	1.00	0.21	0.80	1.43	1.00	0.88	–	0.22	–	–
Plethobasus cyphyus	0.10	0.20	0.20	–	0.40	0.10	0.10	–	–	–	–	–	–	–	–
*Pleurobema oviforme**	–	–	–	–	0.10	–	–	–	0.19	–	–	–	–	–	–
Potamilus alatus	0.20	–	–	0.15	0.10	0.30	–	–	–	0.33	–	–	–	0.12	0.40
Ptychobranchus fasciolaris	0.10	–	–	0.31	0.20	0.10	0.10	0.20	0.10	–	–	–	0.11	–	–
*Ptychobranchus subtentum**	0.10	–	0.80	–	0.10	–	–	0.60	–	0.67	–	–	–	–	–
Quadrula cylindrica	–	–	–	–	–	–	0.10	–	–	–	–	–	–	–	–
*Quadrula intermedia**†	–	–	–	–	–	–	0.21	–	0.10	–	–	–	–	–	–
*Quadrula sparsa**†	–	–	–	–	–	–	–	–	–	–	–	–	0.11	–	–
*Villosa iris**	–	–	–	–	–	–	–	–	–	–	0.13	–	–	–	–
*Villosa vanuxemensis**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.40
Total	7.10	3.00	8.00	6.46	7.70	10.90	5.64	7.20	11.14	21.00	10.88	2.20	5.22	2.12	2.20
Total Number Quadrats	40	20	20	26	40	40	39	20	42	12	32	20	36	34	20
Total Number Mussels	71	15	40	42	77	109	55	36	117	63	87	11	47	18	11

*Cumberlandian species; †endangered species.

The middle to lower reaches of the Powell provide habitat for a number of endangered Cumberlandian species. *Lemiox rimosus*, was found fresh-dead in muskrat middens at five sites between sites 56 (PRM 136.1) and 21 (PRM 94.8). One live specimen was found at site 30 (PRM 106.5). This species was not found in any of the quantitative samples.

Dromus dromas was found alive and fresh-dead in muskrat middens at 17 locations between sites 50 (PRM126.4) and 10 (PRM 80.4). Quantitative sampling produced average densities of 0.20 and 0.10 specimens per square meter at sites 39 (PRM 112.2) and 31 (PRM 106.9) (Table 3). This species is the most common and widespread of the five endangered mussels occurring in the Powell.

Specimens of *Fusconaia cor* were found alive and fresh-dead in muskrat middens at 14 sites between sites 56 (PRM 136.1) and 2 (PRM 67.0). This species occurs with frequency throughout the middle to lower reaches of the river. Quantitative sampling produced density estimates ranging from 0.10 to 0.31 specimens per square meter at four sites (sites 39, 31, 21, and 16).

Quadrula intermedia and *Quadrula sparsa* were also found alive and fresh-dead. *Quadrula intermedia* was reported from 11 sites between sites 50 (PRM 126.4) and 21 (PRM 94.8). Quantitative sampling produced density estimates of 0.21 individuals per square meter at site 31 (PRM 106.9) and 0.10 per square meter at site 44 (PRM 117.3). *Quadrula sparsa* was reported from eight sites between sites 54 (PRM 130.6) and 18 (PRM 89.2). Quantitative sampling produced one live specimen at site 54 (PRM 130.6) with density estimates of 0.11 per square meter. Both species of *Quadrula* are extremely rare in the Powell and appear to be limited to the middle reaches of the river. This section contains the greatest mussel concentrations found in the river and has several excellent gravel and sand shoals areas.

The Asian clam, *Corbicula fluminea*, although not part of this study, was recently found in the Powell River. *Corbicula*, at the time of this survey (1979), was considered rare. This species has since increased in abundance and now occurs throughout the river.

NOLICHUCKY RIVER

During June 1980, the Nolichucky River was float-surveyed from Nolichucky Dam (Nolichucky River Mile, NRM 46.0) downstream to its confluence with the French Broad River in Douglas Reservoir (Fig. 2). Riffle or shoal areas encountered were sampled for freshwater mussels as were the pool areas at the head of each shoal (Table 4).

Mussels were collected using wading, snorkeling, and scuba diving sampling techniques to randomly search for live mussels throughout each sample area. Stream banks were also searched for fresh-dead shells (evidence of meat inside shell) in muskrat middens. Four to five divers worked each shoal area for approximately 45 to 90 minutes. All mussels found were identified in the field, and representative voucher specimens, including fresh-dead specimens were taken to the laboratory for positive identification. Voucher specimens are currently deposited with the Academy of Natural Sciences, Philadelphia, Pennsylvania.

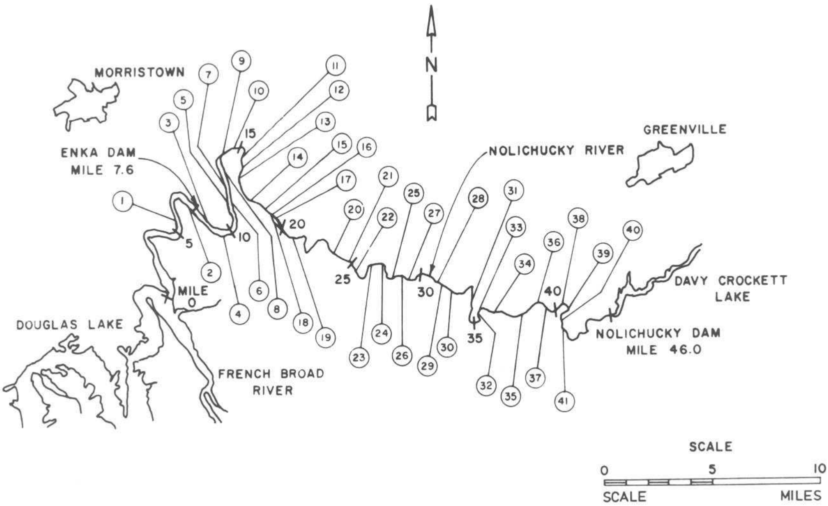

FIG. 2. Nolichucky River mussel sampling sites.

TABLE 4. Location of all Nolichucky River collecting sites in river miles (NRM), June 1980.

Site	NRM	Location
1	6.1	Above Hale Bridge, Cocke/Hamblen County, Tennessee
2	7.4	Below Enka Dam, Cocke/Hamblen County, Tennessee
3	8.5	Thomas Island, Cocke/Hamblen County, Tennessee
4	9.5	Above Thomas Island, Cocke/Hamblen County, Tennessee
5	11.4	Island at Beech Bottoms, Cocke/Hamblen County, Tennessee
6	11.8	Beech Bottoms, Cocke/Hamblen County, Tennessee
7	12.4	Below Johnson Island, Cocke/Hamblen County, Tennessee
8	13.0	Johnson Island, Cocke/Hamblen County, Tennessee
9	13.5	Below Susong Bridge, Cocke/Hamblen County, Tennessee
10	14.8	Below Bent Creek, Cocke/Hamblen County, Tennessee
11	15.2	Below Cooper Branch, Cocke/Greene County, Tennessee
12	16.0	Island at Lick Creek, Cocke/Greene County, Tennessee
13	16.6	Above Lick Creek, Cocke/Greene County, Tennessee
14	17.7	Soloman Island, Cocke/Greene County, Tennessee
15	18.5	Above Soloman Island, Cocke/Greene County, Tennessee
16	19.2	Below Steele Island, Cocke/Greene County, Tennessee
17	19.3	Below Steele Island, Cocke/Greene County, Tennessee
18	19.6	Steele Island, Cocke/Greene County, Tennessee
19	21.0	Above Steele Island, Cocke/Greene County, Tennessee
20	24.0	Above Little Chuckey Creek, Cocke/Greene, County, Tennessee
21	25.0	Above Stillhouse Branch, Cocke/Greene County, Tennessee
22	25.5	Island above Needmore Branch, Cocke/Greene County, Tennessee
23	27.0	Below Bewley Island, Greene County, Tennessee
24	27.9	Bewley Island, Greene County, Tennessee
25	28.5	Island below Pate Hill, Greene County, Tennessee
26	29.1	Island above Pate Hill, Greene County, Tennessee
27	29.4	Island above Pate Hill, Greene County, Tennessee
28	31.0	Evans Island near Arch Cave, Greene County, Tennessee

TABLE 4. (cont.)

Site	NRM	Location
29	31.3	Island above Evans Island, Greene County, Tennessee
30	31.9	Below Easterly Bridge, Greene County, Tennessee
31	33.8	Evans Island above Cochran Bend, Greene County, Tennessee
32	35.4	Island in Linebaugh Bend, Greene County, Tennessee
33	35.7	Island in Linebaugh Bend, Greene County, Tennessee
34	36.8	Island above Love Bridge, Greene County, Tennessee
35	38.0	Island above Gregg Creek, Greene County, Tennessee
36	39.0	Jones Island, Greene County, Tennessee
37	39.5	Island above Jones Island, Greene County, Tennessee
38	40.3	Grays Island, Greene County, Tennessee
39	40.8	Russell Island, Greene County, Tennessee
40	41.7	Below Johnson Island, Greene County, Tennessee
41	42.0	Johnson Island, Greene County, Tennessee

Results

Twenty-one species of freshwater mussels including three Cumberlandian species were found at 41 collecting sites below Nolichucky Dam (Table 5). Mussels were found to be relatively rare throughout the survey area. Most species, except for *Cyclonaias tuberculata, Lampsilis ovata* and *Amblema plicata,* were represented by only occasional specimens. Small concentrations of *Elliptio dilatata* and *Quadrula pustulosa* were also noted. Cumberlandian species were rare in the Nolichucky with only three species *(Epioblasma capsaeformis, Fusconaia barnesiana* and *Villosa vanuxemensis)* found.

Stream reaches immediately below Nolichucky Dam (above site 41) were not sampled due to dangerous flows and large boulders. Substrate compositions between sites 35 and 41, an area largely devoid of mussels, consisted of bedrock, large boulders, and cobble substrate generally not suitable for mussel colonization. The river reach below site 35 becomes much wider with large riffle and shoal areas consisting mainly of gravel and sand substrates, and long deep pools. Large dense mats of aquatic vegetation (*Fontinalis* sp.) virtually covered the river substrate between sites 18 and 23. Mussels were present in this reach but were extremely difficult to find. The largest mussel concentrations were reported from sites 4 and 12 where 11 and 13 species were found. Only one mussel species *(Elliptio dilatata)* was found at sites 1 and 2 in the lower Nolichucky below Enka Dam (NRM 7.6). This area is apparently affected by pollution from a rayon manufacturing plant at Enka, Tennessee, in addition to being influenced by the impounded backwaters of Douglas Reservoir.

In general, freshwater mussels found were old eroded specimens that were in such poor condition that aging was not possible. Apparently the only species continuing to reproduce in the Nolichucky are *Lampsilis fasciola* and *Elliptio dilatata.* The extreme low numbers of mussels present in the river suggests habitat is only marginally suitable for mussels and/or most mussel species have failed to reproduce over the past several years. It is unknown whether this is due to poor health, stress related to turbid water

TABLE 5. Nolichucky River qualitative mussel survey data.

Species	Site / River mile	1 6.1	2 7.4	3 8.5	4 9.5	5 11.4	6 11.8	7 12.4	8 13.0	9 13.5	10 14.8	11 15.2	12 16.0	13 16.6	14 17.7	15 18.5	16 19.2	17 19.3	18 19.6	19 21.0	20 24.0	21 25.0
Actinonaias ligamentina		–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	–
Alasmidonta marginata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata		–	–	1	1	1	–	–	–	–	–	–	9	–	2	1	–	–	4	–	1	8
Cumberlandia monodonta		–	–	–	–	1	–	–	1	1	–	–	2	1	–	–	–	–	–	–	–	–
Cyclonaias tuberculata		–	–	35	65	16	13	13	–	–	–	–	42	2	16	2	2	–	27	–	2	18
Elliptio crassidens		–	–	–	1	–	–	–	–	–	–	–	1	–	–	–	–	–	4	–	–	–
Elliptio dilatata		–	1	12	4	4	3	–	–	1	–	–	19	1	–	1	–	–	2	–	–	–
*Epioblasma capsaeformis**		–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Fusconaia subrotunda		–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Lampsilis fasciola		–	–	1	1	2	1	–	–	–	6	–	4	1	1	–	1	–	1	–	–	–
Lampsilis ovata		–	–	5	4	7	12	2	1	1	19	–	12	8	9	2	1	–	9	1	6	21
Lasmigona costata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hemistena lata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum		–	–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		–	–	–	1	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris		–	–	6	2	1	1	–	–	–	–	–	2	1	–	2	–	–	–	–	1	1
Quadrula pustulosa		–	–	11	2	2	5	1	1	1	–	–	7	–	2	1	–	1	1	–	–	–
Truncilla truncata		–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total		0	1	74	83	35	36	16	3	4	25	0	102	14	30	9	4	1	50	1	10	48

*Cumberlandian species.

TABLE 5 (cont.)

Species	Site / River mile	22 / 25.5	23 / 27.0	24 / 27.9	25 / 28.5	26 / 29.1	27 / 29.4	28 / 31.0	29 / 31.3	30 / 31.9	31 / 33.8	32 / 35.4	33 / 35.7	34 / 36.8	35 / 38.0	36 / 39.0	37 / 39.5	38 / 40.3	39 / 40.8	40 / 41.7	41 / 42.0
Actinonaias ligamentina		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alasmidonta marginata		1	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Amblema plicata		19	1	–	–	1	2	19	5	1	1	9	–	25	–	2	1	1	1	–	–
Cumberlandia monodonta		–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata		22	2	1	1	3	1	46	8	5	–	3	1	7	–	–	–	–	–	–	–
Elliptio crassidens		–	–	–	–	–	–	2	1	–	–	–	–	1	–	–	–	–	–	–	–
Elliptio dilatata		3	–	–	–	–	2	10	6	–	–	–	–	–	–	1	–	–	–	–	–
*Epioblasma capsaeformis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra		–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
*Fusconaia barnesiana**		–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–
Fusconaia subrotunda		–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–
Lampsilis fasciola		3	–	2	1	–	2	8	4	1	–	5	1	1	–	–	–	–	–	1	1
Lampsilis ovata		18	2	1	1	–	3	6	3	1	–	15	–	3	–	1	1	–	–	–	1
Lasmigona costata		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hemistena lata		–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–
Pleurobema cordatum		–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–
Potamilus alatus		–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	1	1	1	1	–
Ptychobranchus fasciolaris		–	1	–	–	–	2	–	–	2	–	3	1	–	–	–	–	–	–	–	–
Quadrula pustulosa		3	–	–	–	–	–	–	1	–	–	2	–	3	–	–	–	–	–	–	–
Truncilla truncata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa vanuxemensis**		1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Total		71	6	4	3	5	13	94	28	11	1	42	3	42	2	5	3	2	2	2	3

*Cumberlandian species.

conditions, or failure of juvenile mussels to survive in silted habitats after dropping from appropriate host species. The entire reach of the river has tremendous concentrations of silt, originating from abandoned mica and feldspar mines located in the headwater tributaries of the upper Nolichucky and from heavy agricultural runoff.

The Asian clam, *Corbicula fluminea*, although not counted during this study, was present in large numbers in sand and gravel habitat throughout the survey area. Also, hundreds of fresh-dead specimens of *Corbicula* were found along the river banks in muskrat middens.

HOLSTON RIVER

During April 1981, a survey of freshwater mussels was initiated in the lower Holston River below Cherokee Dam (Holston River Mile, HRM 52.3) (Fig. 3). Initially, this survey was to sample mussels from Cherokee Dam downstream to the stream's confluence with the Tennessee River; however, because of drought conditions, stream flows in the Holston below the dam had been shut-off for a long period of time so boat travel was impossible. In addition, large concentrations of aquatic macrophytes obscured the substrate to such a degree that sampling was virtually impossible. Consequently, only the upper five miles below the dam (sites 5-7) were surveyed by boat, while sites 1 through 4 were sampled at road access (Table 6). At each site, four scuba equipped divers spent an average of one to two hours searching the substrate for mussels. All mussels found were identified in the field, and representative voucher specimens, including fresh-dead shells, were taken to the laboratory for positive identification. Voucher specimens are currently deposited with the Museum of Zoology, Ohio State University at Columbus.

Results

Thirteen species of freshwater mussels were found at seven sampling sites on the Holston below Cherokee Dam (Table 7). The upper sites below the dam (sites 5-7) were devoid of any living mussels except the Asian clam, *Corbicula fluminea*, Although the river substrate in this reach of the river was obscured by dense growths of aquatic vegetation, much of the substrate consisted of alternating ledges of bedrock scoured-free of aquatic macrophytes by hydroelectric peaking flows. Mussels were found at collecting sites l through 4 (HRM 14.6 - HRM 26.1) in the lower reach of the river but were considered scarce and extremely scattered. Most specimens were observed to be old individuals. Three mussel species *(Actinonaias ligamentina, Lampsilis ovata* and *Plethobasus cyphyus)* were the most abundant found. *Elliptio crassidens* and *Lampsilis fasciola* were the rarest of the 13 species with one specimen each. No Cumberlandian species were found during this study.

The middle and lower reaches of the Holston River consisted of excellent mussel habitat with large expanses of gravel and sand shoals and numerous by-pass channels. However, the river has a history of pollution problems which have decimated the mussel fauna to the point that recovery may not

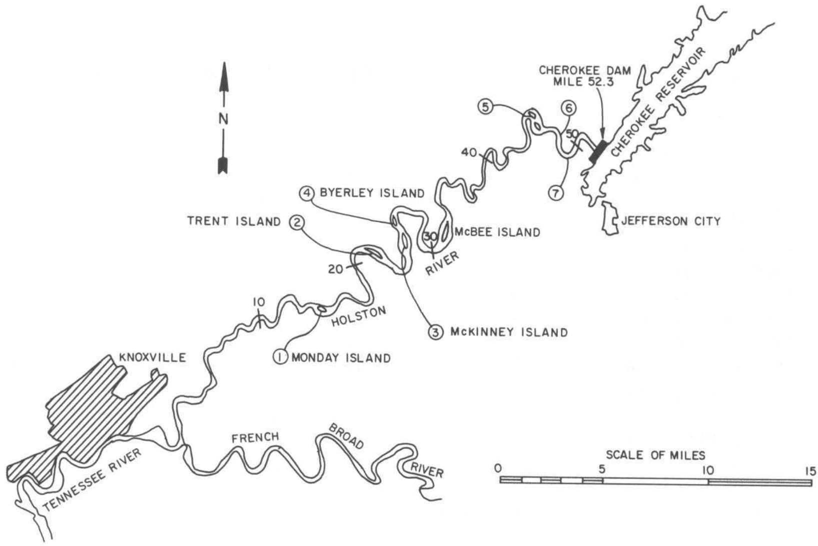

FIG. 3. Holston River mussel sampling sites.

TABLE 6. Location of all Holston River collecting sites in river miles, (HRM), April 1981.

Site	HRM	Location
1	14.6	Monday Island, Knox Co., Tennessee
2	21.5	Trent Island, Knox/Jefferson Co., Tennessee
3	25.0	McKinney Island, Grainger/Jefferson Co., Tennessee
4	26.1	Byerly Island, Grainger/Jefferson Co., Tennessee
5	46.8	Gilmore Island, Grainger/Jefferson Co., Tennessee
6	48.3	Below West Branch, Grainger/Jefferson Co., Tennessee
7	49.6	Below Mill Spring Creek, Grainger/Jefferson Co., Tennessee

be possible due to low population densities of recolonizers and/or the removal of fish host species. During the survey, extreme low-flows drastically reduced mussel habitat and may have had a significant impact on the mussel fauna since the substrate in the middle reaches of the river were essentially dry and exposed half the distance across the normal width of the river channel. Freshwater mussels previously observed living in the Holston River at site 1 (HRM 14.6) while sampling for snail darters in 1978 were found dead in the dried-up portions of the stream bed. Mussel sampling was discontinued at this point due to the small number of mussels found, the absence of Cumberlandian species, and the dense growth of aquatic macrophytes.

TABLE 7. Holston River qualitative mussel survey data.

Species	Site / River mile	1 / 14.6	2 / 21.5	3 / 25.0	4 / 26.1	5 / 46.8	6 / 48.3	7 / 49.6
Actinonaias ligamentina		18	21	32	52	–	–	–
Amblema plicata		1	2	3	3	–	–	–
Cyclonaias tuberculata		4	3	3	10	–	–	–
Elliptio crassidens		–	–	–	1	–	–	–
Eliptio dilatatus		1	2	1	2	–	–	–
Lampsilis fasciola		–	1	–	–	–	–	–
Lampsilis ovata		8	27	4	13	–	–	–
Leptodea fragilis		–	–	3	1	–	–	–
Ligumia recta		2	3	1	1	–	–	–
Plethobasus cyphyus		8	21	11	3	–	–	–
Pleurobema cordatum		2	4	–	8	–	–	–
Potamilus alatus		–	3	1	2	–	–	–
Quadrula pustulosa		3	3	4	10	–	–	–
Total		47	90	63	106	0	0	0

DUCK RIVER

From May through June 1979, the Duck River was float-surveyed from Normandy Dam (Duck River Mile, DRM 248.2) downstream to the old Columbia Dam (DRM 132). In May 1980, the upper reaches of the Duck above Normandy Reservoir (DRM 280.1 to DRM 263.8) were sampled for mussels at road access points (Fig. 4). Five field crews were assigned 22-mile reaches of the river to survey during the May-June sampling period. Generally each crew consisted of two to three scuba equipped divers and/or snorkelers. Sampling in May 1980 was accomplished by one four man crew. The substrate in each shoal and adjacent pool area was searched for approximately 1 to 2 hours for mussels (Table 8). Quantitative mussel samples using a $0.25m^2$ quadrat sampler were taken in areas which contained dense mussel concentrations. All mussels were identified in the field and representative voucher specimens, including fresh-dead specimens, were taken to the laboratory for positive identification. Voucher specimens are currently deposited with the Museum of Zoology, Ohio State University at Columbus.

Results

Thirty-five species of freshwater mussels, including 11 Cumberlandian forms, were collected from 99 sites on the Duck (Table 9). Two of the 12 Cumberlandian species *(Lemiox rimosus* and *Quadrula intermedia)* are federally listed endangered species.

The upper Duck River above Normandy Reservoir, between sites 99 and 93 (DRM 280 and DRM 263.8), were practically devoid of living mussels. *Vil-*

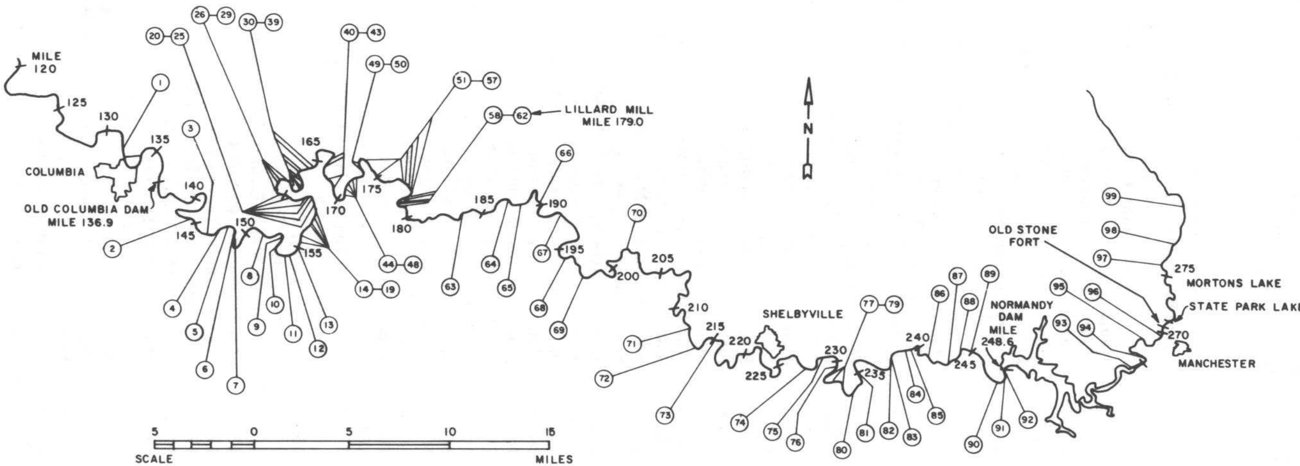

FIG. 4. Duck River mussel sampling sites.

TABLE 8. Location of all Duck River collecting sites in river miles (DRM), May-June 1979, and May 1980.

Site	DRM	Location
1	132.0	Columbia Mill Dam, Maury County, Tennessee
2	144.8	Vaughan Bend, Maury County, Tennessee
3	146.0	Rieves Bend, Maury County, Tennessee
4	147.0	Maury County, Tennessee
5	147.5	Maury County, Tennessee
6	147.9	Maury County, Tennessee
7	148.4	Maury County, Tennessee
8	151.6	I-65 Bridge, Maury County, Tennessee
9	152.5	Maury County, Tennessee
10	153.0	Maury County, Tennessee
11	153.5	Cheek Bend, Maury County, Tennessee
12	154.2	Maury County, Tennessee
13	155.0	Maury County, Tennessee
14	155.3	Below Cedar Creek, Maury County, Tennessee
15	155.9	Maury County, Tennessee
16	156.4	Maury County, Tennessee
17	156.5	Leftwich, Maury County, Tennessee
18	157.0	Jolly's Ford Island, Maury County, Tennessee
19	157.4	Maury County, Tennessee
20	157.7	Maury County, Tennessee
21	158.3	Bull Bluff, Maury County, Tennessee
22	158.5	Maury County, Tennessee
23	158.7	Maury County, Tennessee
24	159.5	Sowell Ford, Maury County, Tennessee
25	160.1	Sowell Bend, Maury County, Tennessee
26	160.5	Butter Flat Island, Maury County, Tennessee
27	161.0	Maury County, Tennessee
28	161.3	Above Derryberry Branch, Maury County, Tennessee
29	161.8	Maury County, Tennessee
30	162.3	Rattle Flat Island, Maury County, Tennessee
31	162.5	Maury County, Tennessee
32	162.7	Maury County, Tennessee
33	162.8	Maury County, Tennessee
34	163.0	Hooper Island, Maury County, Tennessee
35	163.2	Maury County, Tennessee
36	163.4	Maury County, Tennessee
37	163.8	Maury County, Tennessee
38	164.0	Maury County, Tennessee
39	164.5	Island below Carpenters Bridge, Maury County, Tennessee
40	167.4	Cundy Ford Island, Maury County, Tennessee
41	168.0	Tugas Bend, Maury County, Tennessee
42	168.8	Maury County, Tennessee
43	169.2	Maury County, Tennessee
44	170.6	Cole Bend, Maury County, Tennessee
45	171.0	Maury County, Tennessee
46	171.2	Maury County, Tennessee
47	171.6	Below Hardison Mill, Maury County, Tennessee
48	172.0	Hardison Mill, Maury County, Tennessee
49	173.1	Maury County, Tennessee
50	173.2	Island, Maury County, Tennessee
51	173.9	Steen Bend, Marshall County, Tennessee
52	174.9	Cundiff Island, Marshall County, Tennessee
53	176.8	Marshall County, Tennessee
54	176.9	Marshall County, Tennessee
55	177.3	Below Venable Spring, Marshall County, Tennessee

TABLE 8. (cont.)

Site	DRM	Location
56	177.4	McLean Bend, Marshall County, Tennessee
57	177.5	Above Venable Spring, Marshall County, Tennessee
58	178.0	Marshall County, Tennessee
59	178.4	Marshall County, Tennessee
60	178.6	Island at Lillard Mill, Marshall County, Tennessee
61	178.7	Island at Lillard Mill, Marshall County, Tennessee
62	179.0	Lillard Mill, Marshall County, Tennessee
63	183.9	Marshall County, Tennessee
64	186.9	Wilhoite Mill, Marshall County, Tennessee
65	188.0	Island, Marshall County, Tennessee
66	190.0	Below Dry Branch, Marshall County, Tennessee
67	192.0	Hopkins Bridge, Marshall/Bedford County, Tennessee
68	195.9	White Ford, Bedford County, Tennessee
69	197.5	Bedford County, Tennessee
70	202.2	Halls Mill, Bedford County, Tennessee
71	212.9	Above Temple Ford, Bedford County, Tennessee
72	213.8	Below Sugar Creek, Bedford County, Tennessee
73	215.0	Above Rabbit Branch, Bedford County, Tennessee
74	227.0	Above Morgan Branch, Bedford County, Tennessee
75	228.7	Bedford County, Tennessee
76	230.3	Bedford County, Tennessee
77	231.1	Bedford County, Tennessee
78	231.8	Bedford County, Tennessee
79	232.4	Below Woods Bluff, Bedford County, Tennessee
80	233.5	Above Little Flat Creek, Bedford County, Tennessee
81	235.0	Bedford County, Tennessee
82	237.9	Bedford County, Tennessee
83	238.4	Bedford County, Tennessee
84	239.4	Bedford County, Tennessee
85	239.7	Three-Forks Bridge, Bedford County, Tennessee
86	241.3	Bedford County, Tennessee
87	243.1	Dement Bridge, Bedford County, Tennessee
88	244.3	Bedford County, Tennessee
89	244.9	Cortner's Mill, Bedford County, Tennessee
90	247.3	Bedford County, Tennessee
91	248.0	Below Normandy Dam, Bedford County, Tennessee
92	248.2	Below Normandy Dam, Bedford County, Tennessee
93	268.8	Below Cat Creek, Coffee County, Tennessee
94	265.4	Powers Bridge, Coffee County, Tennessee
95	267.7	Above Bone Cave, Coffee County, Tennessee
96	269.4	Below Old Stone Fort, Coffee County, Tennessee
97	276.0	Bridge at Fredonia, Coffee County, Tennessee
98	277.7	Bridge above Parks, Coffee County, Tennessee
99	280.1	Bridge near Goose Pond School, Coffee County, Tennessee

losa iris was the only mussel species found in this section of the river at site 94 (DRM 265.4). The upper river is heavily impacted by gravel removal from the stream bed and silt runoff from agricultural land along the river.

Below Normandy Dam, between sites 92 and 86 (DRM 248.2 and DRM 241.3), no live mussels were found for almost seven miles. This reach of the Duck is affected by regulated water releases from Normandy Dam which results in extreme water level fluctuations, cold temperatures, and seasonal oxygen deficits. Typically, these conditions cause reduction in fish com

TABLE 9. Duck River qualitative mussel survey data.

Species	Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	River mile	132.0	144.8	146.0	147.0	147.5	147.9	148.4	151.6	152.5	153.0	153.5	154.2	155.0	155.3	155.9	156.4	156.5	157.0	157.4	157.7	158.3	158.5	158.7	159.5	160.1
Actinonaias ligamentina		–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
*Actinonaias pectorosa**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata		1	6	1	–	1	3	–	1	1	1	–	1	1	–	–	–	–	1	1	–	–	–	–	–	3
Cyclonaias tuberculata		–	48	1	1	1	21	1	1	6	5	1	4	1	2	1	–	–	3	3	–	–	4	3	–	3
Elliptio dilatata		–	–	1	–	1	3	–	1	1	1	–	1	–	–	3	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	1	–	1	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–
Lampsilis fasciola		–	–	–	–	–	2	–	1	–	1	–	1	1	–	–	–	1	–	–	–	–	–	–	–	1
Lampsilis ovata		1	–	–	1	–	–	–	1	–	1	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata		–	–	–	–	–	3	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lemiox rimosus**†		1	–	–	–	–	3	–	1	–	1	–	–	–	1	–	1	1	–	–	–	–	1	–	–	–
Leptodea fragilis		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lexingtonia dolabelloides**		–	2	1	1	1	4	–	1	1	1	–	1	–	3	–	1	1	–	–	1	–	–	–	–	–
*Medionidus conradicus**		–	–	–	1	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	1	–	–	1	–	–
Megalonaias nervosa		1	22	1	1	1	5	–	1	5	1	–	–	1	–	15	–	–	–	8	–	–	1	–	1	8
Obliquaria reflexa		1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Obovaria subrotunda		–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–
*Pleurobema oviforme**		–	1	–	–	1	1	–	–	–	–	–	–	1	1	–	–	1	–	–	–	–	–	–	–	–
Pleurobema rubrum		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		1	–	–	–	–	1	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris		1	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica		–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
*Quadrula intermedia**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa		1	5	1	1	1	6	–	1	1	1	1	2	1	1	–	–	1	1	–	–	1	1	–	–	–
Quadrula quadrula		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa		1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata		1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total		13	86	6	7	8	52	2	11	15	18	3	13	6	9	22	2	6	5	12	3	2	7	5	1	15

*Cumberlandian species; †endangered species.

TABLE 9 (cont.)

Species / Site	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
River mile	160.5	161.0	161.3	161.8	162.3	162.5	162.7	162.8	163.0	163.2	163.4	163.8	164.0	164.5	167.4	168.0	168.8	169.2	170.6	171.0	171.2	171.6	172.0	173.1	173.2
Actinonaias ligamentina	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Actinonaias pectorosa**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Amblema plicata	–	1	5	–	1	–	–	1	12	–	–	3	–	4	–	–	–	1	2	–	–	1	–	–	2
Cyclonaias tuberculata	2	1	46	–	6	4	–	21	34	1	7	45	54	22	2	5	1	5	–	13	29	36	10	2	11
Elliptio dilatata	–	–	4	–	–	–	1	3	2	–	3	2	4	1	–	2	–	1	–	–	1	–	–	–	2
Epioblasma triquetra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
*Fusconaia barnesiana**	–	–	–	–	–	–	–	–	–	–	1	2	3	–	–	–	–	–	–	1	–	1	1	–	2
Lampsilis fasciola	–	–	3	–	2	–	–	–	–	–	2	–	1	–	–	1	–	1	–	–	–	–	–	–	1
Lampsilis ovata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	1	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	3
*Lemiox rimosus**†	–	–	3	1	1	1	2	4	2	1	4	8	3	–	–	2	–	–	–	2	2	3	–	–	–
Leptodea fragilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lexingtonia dolabelloides**	–	–	12	2	3	–	8	8	1	–	1	5	5	1	1	9	1	4	1	8	7	4	1	1	11
*Medionidus conradicus**	–	–	3	–	–	–	–	2	5	–	1	2	2	–	–	–	–	–	–	–	–	–	–	–	–
Megalonaias nervosa	12	5	39	1	–	4	21	20	29	–	9	9	5	39	2	4	5	10	4	–	30	20	2	–	20
Obliquaria reflexa	–	–	–	–	–	–	–	–	3	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–	–
Obovaria subrotunda	–	–	1	–	2	–	2	1	4	–	1	–	–	3	–	1	–	1	1	1	–	1	–	–	–
Pleurobema cordatum	–	–	–	–	1	–	1	–	1	–	–	1	4	1	1	2	2	–	–	1	1	–	–	–	–
*Pleurobema oviforme**	–	–	1	–	–	–	1	–	–	–	–	–	–	–	1	1	–	1	–	3	4	2	–	–	–
Pleurobema rubrum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Quadrula cylindrica	1	–	3	–	–	–	1	–	1	–	–	–	3	–	–	–	–	–	–	–	2	–	–	1	8
*Quadrula intermedia**†	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	3
Quadrula pustulosa	–	–	–	–	1	2	10	8	6	1	2	3	3	1	1	4	1	2	1	6	6	12	6	–	3
Quadrula quadrula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa	–	–	2	–	–	–	–	–	2	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa vanuxemensis**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	16	7	123	4	17	11	47	72	103	3	32	80	88	73	8	31	11	26	9	36	84	82	20	4	68

*Cumberlandian species; †endangered species.

TABLE 9 (cont.)

Species	Site / River mile	51 / 173.9	52 / 174.9	53 / 176.8	54 / 176.9	55 / 177.2	56 / 177.4	57 / 177.5	58 / 178.0	59 / 178.4	60 / 178.6	61 / 178.7	62 / 179.0	63 / 183.9	64 / 186.9	65 / 188.0	66 / 190.0	67 / 192.0	68 / 195.9	69 / 197.5	70 / 202.2	71 / 212.9	72 / 213.8	73 / 215.0	74 / 227.0	75 / 228.7
Actinonaias ligamentina		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Actinonaias pectorosa**		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	–	5	–	–	–	1	–	–
Amblema plicata		–	1	1	1	–	–	2	–	–	8	–	23	–	–	2	1	5	–	–	–	2	1	5	–	–
Cyclonaias tuberculata		1	1	6	–	–	3	14	–	2	10	–	54	9	–	1	–	4	9	3	2	1	–	4	1	–
Elliptio dilatata		–	1	–	–	–	–	–	–	–	–	–	3	1	–	–	–	–	1	–	–	–	–	–	–	–
Epioblasma triquetra		–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	–	–	–	–	4	–	1	2	–	–	–	–	–	2	–	–	–	–
Lampsilis fasciola		1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis ovata		–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata		–	–	–	1	–	–	–	–	–	5	–	5	–	–	–	–	1	–	–	–	–	–	1	–	–
*Lemiox rimosus**†		–	–	1	–	–	4	5	1	2	7	2	25	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis		–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lexingtonia dolabelloides**		1	–	–	–	1	–	–	–	–	–	–	11	–	1	–	–	–	–	–	1	–	–	–	–	–
*Medionidus conradicus**		–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Megalonaias nervosa		4	–	2	1	–	3	5	–	–	9	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Obliquaria reflexa		–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Obovaria subrotunda		1	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	1	–	–	–	–
Pleurobema cordatum		–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
*Pleurobema oviforme**		1	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum		–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica		–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula intermedia**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa		1	–	1	2	–	1	1	–	–	5	–	28	1	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula quadrula		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa		–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata		–	–	–	–	–	–	–	–	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	4	–	1	–	1	1	4	1	–	–
*Villosa vanuxemensis**		–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total		10	4	11	5	2	11	27	1	5	45	2	175	12	5	7	5	11	11	8	4	7	5	12	1	0

*Cumberlandian species; †endangered species.

TABLE 9 (cont.)

	Site	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
Species	River mile	230.3	231.1	231.8	232.4	233.4	235.0	237.9	238.4	239.4	239.7	241.3	243.1	244.3	244.9	247.3	248.0	248.2	263.8	265.4	267.7	269.4	276.0	277.7	280.1
Actinonaias ligamentina		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Actinonaias pectorosa**		–	–	1	–	–	–	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclonaias tuberculata		–	2	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elliptio dilatata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epioblasma triquetra		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis ovata		–	–	–	–	–	–	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata		–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lemiox rimosus**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leptodea fragilis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Lexingtonia dolabelloides**		–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Medionidus conradicus**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Megalonaias nervosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Obliquaria reflexa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Obovaria subrotunda		–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema cordatum		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Pleurobema oviforme**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurobema rubrum		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potamilus alatus		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptychobranchus fasciolaris		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula cylindrica		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Quadrula intermedia**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula quadrula		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Truncilla truncata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12	–	–	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total		0	5	5	0	0	0	1	3	1	4	0	0	0	0	0	0	0	0	12	0	0	0	0	0

*Cumberlandian species; †endangered species.

munities, thus indirectly affecting the reproductive life cycle of freshwater mussels by eliminating potential host fish species.

Mussels were only occasionally found between sites 86 and 63 (DRM 241.2 to DRM 183.9). Mussels occurred in small, isolated pockets in this section of the river. Numerous relict shells were observed indicating substantial mussel populations had previously inhabited this section of the river. Past chronic pollution from the city of Shelbyville near site 71 (DRM 212.9) has undoubtedly had a significant affect on mussel populations.

The largest mussel concentrations were observed downstream from Lillard Mill Dam at site 62 (DRM 179) with 19 mussel species and at site 34 (DRM 163) with 18 species. Mussels were consistently found at every site below site 62 with 14 species reported from sites 33, 28, and 10 This reach of the Duck consists of numerous gravel and sand shoals interspersed with alternating bedrock ledges, boulders, and long deep pools. The pool areas of the lower river consisted primarily of small populations of *Megalonaias nervosa, Potamilus alatus* and *Cyclonaias tuberculata.*

Mussel population densities were quantified at 22 sites on the Duck River (Table 10). A total of 509 quadrat samples were taken. Seven of the 22 sites averaged three or more mussels per square meter. Sites 62 (DRM 179) and 34 (DRM 163) had the highest density estimates with 17.9 specimens and 10 specimens per square meter, respectively. *Cyclonaias tuberculata* and *Quadrula pustulosa* were the most abundant species found during quantitative sampling.

The two endangered freshwater mussels *(Lemiox rimosus* and *Quadrula intermedia)* found during this study occur only in the lower reaches of the Duck downstream from Lillard Mill Dam (DRM 179). *Lemiox rimosus* was found both alive and fresh-dead at 31 sites between sites 62 (DRM 179) and 1 (DRM 132). Quantitative sampling produced density estimates ranging from 0.11-2.52 specimens per square meter at ten sites with the largest densities (2.52 specimens) reported at Lillard Mill Dam (site 62).

Quadrula intermedia was found alive at three sites in the lower Duck. Three specimens were found at site 50 (DRM 173.2), two at site 33 (DRM 162.8), and one at site 46 (DRM 171.2). This species was not found in any of the quantitative samples and is considered extremely rare in the river. Since the conclusion of this survey of the Duck, three additional live specimens were reported at Lillard Mill Dam, site 62, during *Lemiox rimosus* transplant activities.

The mussel fauna in the Duck is limited to a small portion of the river between Lillard Mill Dam and Columbia Dam (approximately 50 miles). The river has suffered from chronic municipal pollution problems in the past, impoundment, and phosphate mining throughout its watershed. If the Columbia Dam project is completed, it will impound the richest mussel habitat remaining in the Duck including the largest population of *Lemiox rimosus* known to exist.

The Asian clam, *Corbicula fluminea,* although not part of this study, is widespread and common throughout the river and was always present in large numbers in gravel and sand substrates. In some areas, both dead and live specimens appeared to be the dominant substrate. The Asian clam has a history of colonizing streams that have pollution problems or are in the

TABLE 10. Number of mussels per square meter in Duck River quantitative samples..

Species	Site River mile	6 147.9	11 153.5	12 154.2	14 155.3	15 155.9	16 156.4	28 161.3	31 162.5	32 162.7	33 162.8	34 163.0	36 163.4	37 163.8	41 168.0	46 171.2	47 171.6	49 173.1	52 174.9	54 176.9	58 178.0	61 178.7	62 179.0
Actinonaias ligamentina		–	–	–	–	–	–	–	–	–	–	0.30	–	–	–	–	–	–	–	–	–	–	–
*Actinonaias pectorosa**		–	–	–	–	–	–	–	–	–	–	0.10	–	–	–	–	–	–	–	–	–	–	–
Amblema plicata		–	–	0.15	–	–	–	–	–	–	–	0.40	0.32	–	–	–	0.22	–	0.33	0.33	–	–	2.30
Cyclonaias tuberculata		–	0.77	0.62	0.27	–	–	1.00	2.33	–	0.80	4.00	0.80	1.70	0.27	0.67	0.65	–	0.33	–	–	0.50	5.40
Elliptio dilatatus		–	–	0.15	–	–	–	0.60	–	0.20	0.30	0.50	0.16	0.10	–	–	0.11	–	0.33	–	0.92	0.50	0.30
*Epioblasma capsaeformis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.40
*Fusconaia barnesiana**		–	–	0.15	–	–	–	–	–	–	–	0.10	–	–	–	–	0.11	–	–	–	–	–	0.40
Lampsilis fasciola		–	–	0.15	–	–	–	–	–	–	0.10	0.20	–	–	–	–	–	–	–	–	–	–	0.10
Lampsilis ovata		–	–	0.15	0.13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.20
Lasmigona costata		–	0.15	–	–	–	–	–	–	–	–	0.20	–	–	–	–	–	–	–	0.33	–	–	0.50
*Lemiox rimosus**†		–	–	–	0.13	–	0.15	0.20	–	–	0.20	–	0.48	0.60	–	0.33	0.11	–	–	–	0.31	–	2.50
Leptodea fragilis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.10
*Lexingtonia dolabelloides**		0.33	–	0.15	0.40	–	0.15	0.20	0.67	0.40	–	1.00	0.32	0.30	0.13	1.00	0.65	–	–	–	–	–	1.00
*Medionidus conradicus**		–	–	0.31	–	–	–	0.20	–	–	0.10	0.80	0.16	–	–	–	–	–	–	–	–	–	0.10
Megalonaias nervosa		–	–	–	–	–	–	0.40	–	0.60	0.20	1.20	0.64	0.90	–	0.67	0.11	0.20	–	0.33	–	–	0.10
Obliquaria reflexa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.20
Obovaria subrotunda		–	0.15	–	–	–	–	–	–	–	0.10	0.20	0.16	0.10	–	–	–	–	–	–	–	–	–
Pleurobema cordatum		0.33	–	–	–	–	–	–	–	–	0.10	–	0.16	0.10	0.13	0.67	–	–	–	–	–	–	0.10
*Pleurobema oviforme**		–	–	–	0.13	–	–	–	–	–	–	0.20	–	–	0.13	0.33	–	–	–	–	–	–	–
Potamilus alatus		–	–	–	–	–	–	–	–	–	0.10	–	–	–	–	–	–	–	–	–	–	–	0.20
Quadrula cylindrica		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.33	–	–	–	–
Quadrula pustulosa		–	0.46	0.31	0.13	–	–	0.60	0.33	0.40	0.40	0.80	0.32	0.10	0.40	0.67	0.43	–	–	0.67	–	–	2.80
Strophitus undulatus		–	–	–	0.13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**		–	–	–	–	–	–	0.20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tritogonia verrucosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.20
Truncilla truncata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.90
Total		0.67	1.54	2.15	1.33	0.00	0.31	3.40	3.33	1.60	2.40	10.00	3.52	3.90	1.07	4.33	2.38	0.20	1.33	1.67	1.23	1.00	17.80
Total Number Quadrats		12	26	26	30	8	26	20	12	20	40	40	25	40	30	12	37	20	12	12	13	8	40
Total Number Mussels		2	10	14	10	0	2	17	10	8	24	100	22	39	8	13	22	1	4	5	4	2	178

*Cumberlandian species; †endangered species.

BUFFALO RIVER

From June through September 1980, the Buffalo River was float-surveyed from Natches Trace Bridge (Buffalo River Mile, BRM 102.8) downstream to Route 13 bridge (BRM 59.1) (Fig. 5; Table 11). Because of the scarcity of live mussels in the river below site 6 (BRM 59.1), only access points were surveyed in the lower portion of the stream. Two to three scuba equipped divers sampled each shoal for approximately one hour. The survey was discontinued at site 1 (BRM 25.9) when sampling efforts consistently failed to find any live mussels.

Results

A total of 21 live mussels representing seven species were found, including three Cumberlandian species (*Villosa iris, Villosa taeniata* and *Villosa vanuxemensis*) (Table 12). Collecting sites in the Buffalo were practically devoid of living mussels. Fourteen of the 24 sites sampled contained no mussels, while seven sites had one specimen each. Relict mussels were observed at numerous sites.

Habitat throughout the Buffalo consisted of sand and silt runoff from agricultural land along the river and tremendous quantities of loose transient gravel. During periods of heavy rainfall, large amounts of gravel and sand were washed into windrows along the stream banks and farm fields. The upper reaches of the river consisted of bedrock and boulder habitat mixed with small pools and gravel shoals.

The middle to lower reaches of the river have numerous transient cobble, gravel, and sand shoals separated by long pools and occasional bedrock. Normally, this type of stable habitat should support excellent mussel populations; however, the transient nature of the substrate and unknown polluting sources have decimated the mussel fauna. The few mussels remaining in the Buffalo are so widely scattered and rare that reproduction is at an extremely low level or has ceased.

The Asian clam, *Corbicula fluminea*, was found throughout the study area. Large concentrations were found buried in the substrate and numerous fresh-dead specimens were observed in muskrat middens.

PAINT ROCK RIVER

From May through November 1980, the Paint Rock River was float-surveyed for freshwater mussels from its headwaters (Paint Rock River Mile, PRRM 60) downstream to Hellum Ford (PRRM 24.5) (Table 13; Fig. 6). Two field crews consisting of two to three scuba equipped divers and/or snorkelers sampled each shoal and adjacent pool for approximately one hour. Collections were also made at road access points on two tributary streams of the upper Paint Rock River at Estill Fork and Hurricane Creek. Only the lowermost portions of these streams were sampled. All mussels were identified in the field and representative voucher specimens, including fresh-dead specimens, were taken to the laboratory for positive identification.

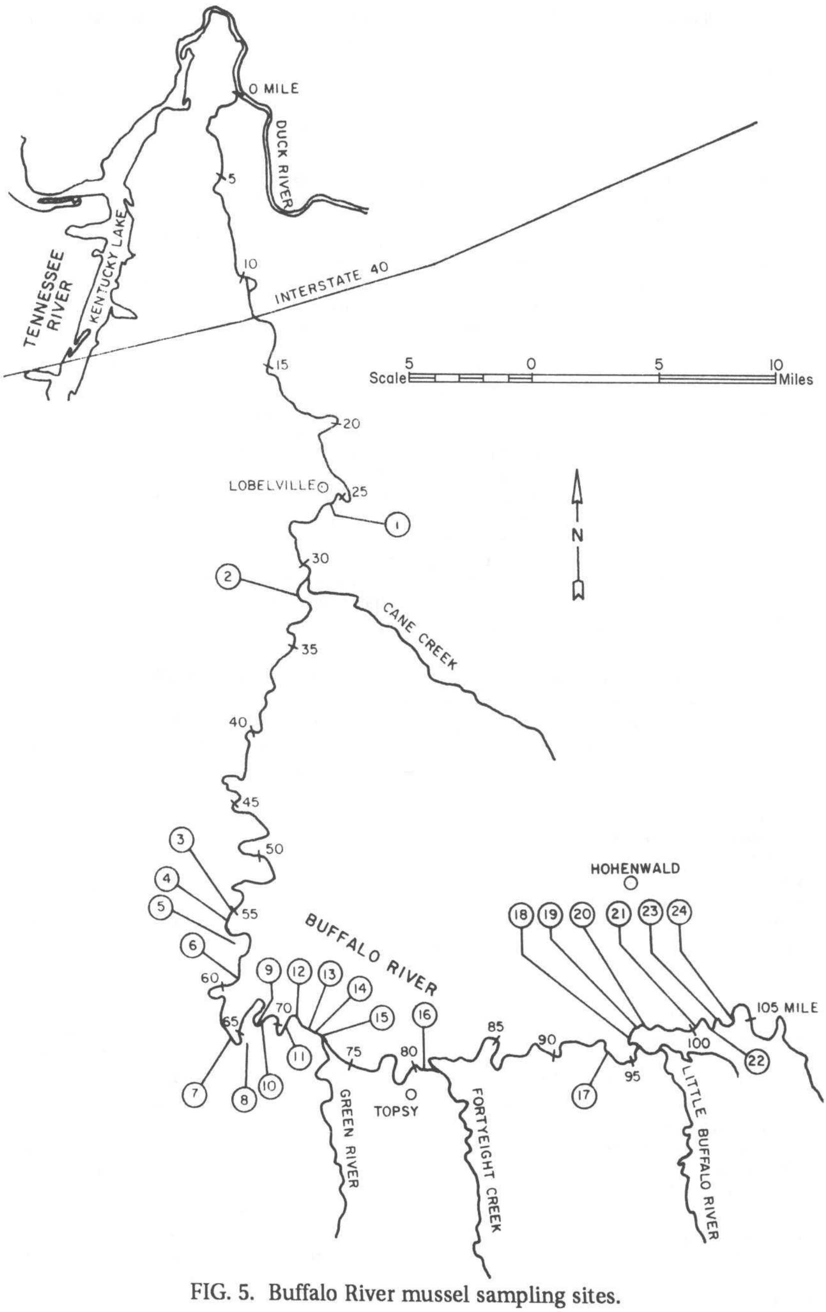

FIG. 5. Buffalo River mussel sampling sites.

TABLE 11. Location of all Buffalo River sites in river miles (BRM), June-Sept. 1980.

Site	BRM	Location
1	25.9	Mill Bridge, Perry County, Tennessee
2	31.7	Island below King Branch, Perry County, Tennessee
3	55.1	Camp Linden, Perry County, Tennessee
4	55.6	Island, Perry County, Tennessee
5	58.1	Mt. Olive Bridge, Perry County, Tennessee
6	59.1	Route 13 Bridge, Perry County, Tennessee
7	63.7	Island at Horseshoe Bend, Wayne County, Tennessee
8	64.7	Wayne County, Tennessee
9	68.6	Island at Bastin Bend, Wayne County, Tennessee
10	69.0	Wayne County, Tennessee
11	71.2	Choate Bend, Wayne County, Tennessee
12	72.0	Island, Wayne County, Tennessee
13	72.7	Island below Bell Bridge, Wayne County, Tennessee
14	73.0	Wayne County, Tennessee
15	73.2	Bell Bridge, Wayne County, Tennessee
16	80.5	Topsy Bridge, Wayne County, Tennessee
17	93.5	Voorhies Bridge, Lewis County, Tennessee
18	96.5	Davis Bend, Lewis County, Tennessee
19	97.3	Davis Ford, Lewis County, Tennessee
20	97.7	Lewis County, Tennessee
21	100.1	Lewis County, Tennessee
22	202.0	Lewis County, Tennessee
23	101.8	Below Steel Branch, Lewis County, Tennessee
24	102.8	Natchez Trace Bridge, Lewis County, Tennessee

TABLE 12. Buffalo River qualitative mussel survey data.

Species	Site / River mi.	1 / 25.9	2 / 31.7	3 / 55.1	4 / 55.6	5 / 58.1	6 / 59.1	7 / 63.7	8 / 64.7
Actinonaias ligamentina		–	–	–	–	–	–	–	–
Cyclonaias tuberculata		–	–	–	–	–	–	1	1
*Fusconaia barnesiuana**		–	–	–	–	–	–	–	–
Leptodea fragilis		–	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–
Total		0	0	0	0	0	0	1	1

*Cumberlandian species.

TABLE 12 (cont.)

Species	Site / River mi.	9 / 68.6	10 / 69.0	11 / 71.2	12 / 72.0	13 / 72.7	14 / 73.0	15 / 73.2	16 / 80.5
Actinonaias ligamentina		–	–	–	–	–	–	–	–
Cyclonaias tuberculata		–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	–
Leptodea fragilis		1	–	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	1	–	–	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–
Total		1	0	0	0	1	0	0	0

*Cumberlandian species.

TABLE 12 (cont.)

Species	Site / River mi.	17 / 93.5	18 / 96.5	19 / 97.3	20 / 97.7	21 / 100.1	22 / 101.0	23 / 101.8	24 / 102.8
Actinonaias ligamentina		–	7	–	1	–	–	–	–
Cyclonaias tuberculata		–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	1	–
Leptodea fragilis		–	–	–	–	–	–	–	–
*Villosa iris**		–	1	1	1	1	1	–	–
*Villosa vanuxemensis**		–	–	–	2	1	–	–	–
Total		0	8	1	4	2	1	1	0

*Cumberlandian species.

TABLE 13. Location of all Paint Rock River, Estill Fork and Hurricane Creek collecting sites in river miles (PRRM, EFRM, and HCM), May-Nov., 1980.

Site	PRRM	Location
1	24.5	Hellum Ford, Madison County, Alabama
2	26.0	Below Highway 72 Bridge, Jackson County, Alabama
3	32.2	Jackson County, Alabama
4	32.5	Jackson County, Alabama
5	34.2	Hales Cove, Jackson County, Alabama
6	34.5	Island at Hales Cove, Jackson County, Alabama
7	38.7	Walker Mill Ford, Jackson County, Alabama
8	41.6	Above Flippo Ford, Jackson County, Alabama
9	44.8	Above bridge at Little Nashville, Jackson County, Alabama
10	45.0	Jackson County, Alabama
11	45.1	Jackson County, Alabama
12	45.5	Below Robertson Spring, Jackson County, Alabama
13	46.5	Jackson County, Alabama
14	47.8	Jackson County, Alabama
15	48.2	Jackson County, Alabama
16	48.3	Jackson County, Alabama
17	50.2	Below Graham Cove, Jackson County, Alabama
18	50.4	Jackson County, Alabama
19	50.5	Jackson County, Alabama
20	51.9	Below Lick Fork, Jackson County, Alabama
21	52.5	Above Cowan Hollow, Jackson County, Alabama
22	53.5	Jackson County, Alabama
23	58.5	Jackson County, Alabama
24	59.9	Jackson County, Alabama
25	60.0	Jackson County, Alabama
EFRM		
1	0.1	Jackson County, Alabama
2	1.0	Freedom Bridge, Jackson County, Alabama
HCM		
1	2.9	Bishop Cove, Jackson County, Alabama

Results

Twenty-five species of freshwater mussels including 13 Cumberlandian species were found during this survey (Table 14). Four of the thirteen Cum-

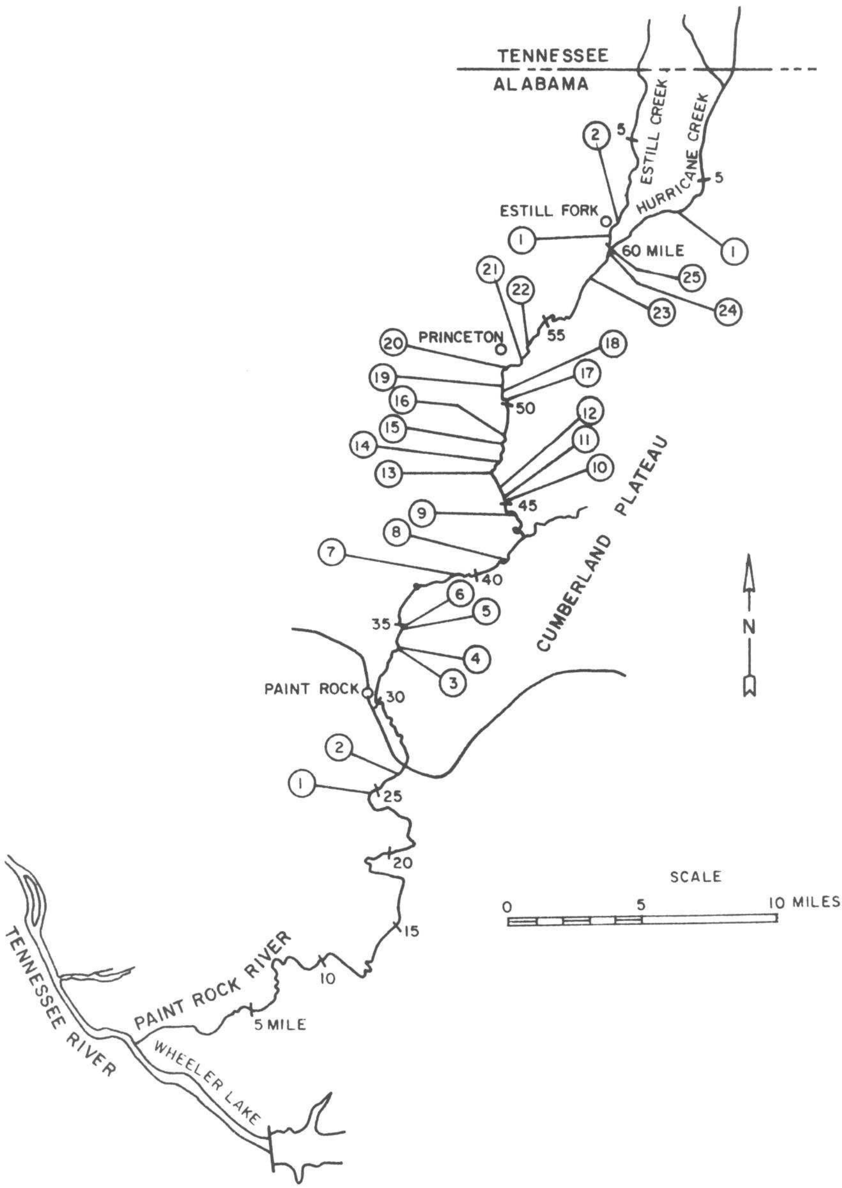

FIG. 6. Paint Rock River, Estill Fork and Hurricane Creek mussel sampling sites.

TABLE 14. Paint Rock River, Estill Fork and Hurricane Creek qualitative mussel survey data.

Species	Site / River mile	1 24.5	2 26.0	3 32.2	4 32.5	5 34.2	6 34.5	7 38.7	8 41.6	9 44.8	10 45.0	11 45.1	12 45.4	13 46.5	14 47.8	15 48.2
Amblema plicata		–	–	–	–	–	–	–	1	6	–	3	–	2	1	–
*Epioblasma capsaeformis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Fusconaia barnesiana**		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
*Fusconaia cor**†		–	–	–	–	–	–	–	–	1	2	1	–	–	6	–
*Fusconaia cuneolus**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola		–	–	–	–	–	–	–	1	–	–	1	–	–	–	–
Lampsilis ovata		–	–	–	–	–	–	–	1	1	–	7	1	2	–	–
*Lampsilis virescens**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata		–	–	–	–	–	–	–	–	–	–	1	–	–	4	–
*Lexingtonia dolabelloides**		–	–	–	–	–	–	–	3	1	–	–	1	2	2	1
*Medionidus conradicus**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Megalonaias nervosa		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Obliquaria reflexa		–	–	–	–	–	–	–	1	–	1	–	–	–	–	–
Obovaria subrotunda		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
*Pleurobema oviforme**		–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Potamilus alatus		–	–	–	–	–	–	–	–	7	–	9	–	1	–	–
Ptychobranchus fasciolaris		–	–	–	–	–	–	–	–	1	–	2	–	–	2	–
Quadrula cylindrica		–	–	–	–	–	–	1	–	1	–	–	–	–	–	–
Quadrula pustulosa		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
*Toxolasma cylindrellus**†		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma lividus**		–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Tritogonia verrucosa		–	–	–	–	–	–	–	–	–	–	–	–	–	5	–
*Villosa iris**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Villosa taeniata**		–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
*Villosa vanuxemensis**		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total		0	0	0	0	0	0	1	7	22	3	24	2	8	21	1

*Cumberlandian species; †endangered species.

TABLE 14 (cont.)

Species	Site / River mile	16 / 48.3	17 / 50.2	18 / 50.4	19 / 50.5	20 / 51.9	21 / 52.5	22 / 53.5	23 / 58.5	24 / 59.9	25 / 60.0	Estill Fork 0.1	Estill Fork 1.0	Hurricane Creek 2.9
Amblema plicata		–	–	–	–	4	–	–	–	–	–	–	–	10
*Epioblasma capsaeformis**		–	–	–	–	–	–	–	–	–	1	–	–	1
*Fusconaia barnesiana**		–	–	–	–	–	–	–	1	1	5	–	–	–
*Fusconaia cor**†		3	–	2	–	–	–	–	1	–	–	–	–	–
*Fusconaia cuneolus**†		1	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis fasciola		–	–	1	–	–	–	1	–	1	2	–	–	1
Lampsilis ovata		1	–	1	1	1	2	2	3	–	1	–	–	–
*Lampsilis virescens**†		–	–	–	–	–	–	–	–	7	1	–	–	1
Lasmigona costata		1	–	–	–	3	–	1	–	–	–	–	–	2
*Lexingtonia dolabelloides**		1	–	–	–	–	–	1	1	–	–	–	–	1
*Medionidus conradicus**		–	–	–	–	–	–	–	–	4	–	1	–	1
Megalonaias nervosa		–	–	–	–	–	–	1	–	–	–	–	–	–
Obliquaria reflexa		–	–	–	–	–	–	–	–	–	–	–	–	–
Obovaria subrotunda		–	–	–	–	1	1	2	1	–	–	–	–	1
*Pleurobema oviforme**		–	–	–	–	–	–	–	1	–	–	–	–	–
Potamilus alatus		–	–	–	–	–	3	–	–	–	–	–	–	–
Ptychobranchus fasciolaris		1	–	1	–	–	–	1	2	1	–	–	–	1
Quadrula cylindrica		–	–	–	–	–	–	–	–	–	–	–	–	–
Quadrula pustulosa		–	–	–	–	–	–	–	–	–	–	–	–	–
*Toxolasma cylindrellus**†		–	–	–	–	–	–	–	–	2	–	–	–	1
*Toxolasma lividus**		–	–	–	–	–	–	–	–	–	–	–	1	1
Tritogonia verrucosa		1	–	–	–	1	–	1	–	–	–	–	–	–
*Villosa iris**		–	–	–	–	–	–	–	–	12	–	1	–	1
*Villosa taeniata**		–	–	–	–	–	–	–	1	20	–	–	–	2
*Villosa vanuxemensis**		–	–	1	–	–	1	–	–	1	–	–	–	1
Total		9	0	6	1	10	7	10	11	49	10	2	1	25

*Cumberlandian species; †endangered species.

berlandian species *(Toxolasma cylindrellus, Fusconaia cuneolus, Fusconaia cor* and *Lampsilis virescens)* are federally listed endangered species.

The largest concentration of freshwater mussels was found in Hurricane Creek, where 15 species of mussels were reported and in the Paint Rock River at site 9 (PRRM 44.8), where 11 species were found (Table 14). At least 12 collecting sites in the upper 19 miles of the river above site 8 (PRRM 41.6) averaged five or more mussel species per site. Collecting sites below site 7 (PRRM 38.7) produced only one live species *(Quadrula cylindrica)*. This reach of the Paint Rock appears heavily affected by silt from agricultural runoff and streambank erosion. Estill Fork was practically devoid of any living mussels with only three species *(Toxolasma lividus, Medionidus conradicus* and *Villosa iris)* found.

Endangered freshwater mussels were present only in the upper 19 miles of the Paint Rock River above site 8 (PRRM 41.6) and Hurricane Creek. *Toxolasma cylindrellus* was found alive in the Paint Rock at site 24 (PRRM 59.9) and fresh-dead in muskrat middens in Hurricane Creek (Table 14). This species is considered extremely rare in the Paint Rock drainage.

Fusconaia cor was the most numerous of the endangered species found. This species was found in the Paint Rock at seven sites between sites 9 and 23 (PRRM 44.8 and 58.5) (Table 14). Another closely related species, *F. cuneolus*, was also found live in the river at site 16 (PRRM 48.3).

Lampsilis virescens was reported live in the Paint Rock at sites 24 and 25 (PRRM 59.9 and 60.0) and one fresh-dead specimen was found in Hurricane Creek. This species is considered extremely rare in the Paint Rock drainage.

DISCUSSION AND SUMMARY

The development of the Tennessee River system and resultant changes caused by man have drastically reduced the freshwater mussel fauna in the Tennessee Valley. The mussel surveys of six Tennessee River tributary streams reported here, and of Copper Creek, and Elk and Clinch rivers (Ahlstedt, 1982, 1983, 1991), have provided new information on the current status of the fauna in those streams. Additional information from these surveys includes range extensions, presence of endangered species, population estimates, and in some instances documented elimination of the fauna in portions of the streams sampled. In general, the mussel fauna today in these drainages are but a small assemblage of the fauna reported before the development of the region. The fauna appears to be on a steady decline, especially members of the Cumberlandian faunal group. Cumberlandian species are typically found in silt-free, riffle and shoal areas; a diminishing habitat in the Tennessee Valley.

Of the nine streams surveyed (this report and Ahlstedt, 1982, 1983, 1991), the Clinch River contains the richest assemblage of freshwater mussels remaining in the Tennessee River system. Forty-three species were reported including 16 Cumberlandian forms and seven Federally listed endangered species. Following in order of species diversity: Elk (38 species, 11 Cumberlandian forms, four endangered); Powell (37 species, 15 Cumberlandian forms, four endangered); Duck (35 species, 11 Cumberlandian forms, two endangered); Paint Rock River (25 species, 13 Cumberlandian forms, four endangered); Nolichucky (21 species, three Cumberlandian forms, no endangered); Copper Creek (19 species, 11 Cumberlandian forms, two endangered); Holston (13 species, no Cumberlandian forms, no endangered); and Buffalo (seven species, three Cumberlandian forms, no endangered).

The large number of mussel species found in the Clinch, including Cumberlandian forms, probably results from the inaccessibility and geographic isolation of the river. There are some pollution problems in the extreme headwaters of the river, and the operation of the Clinch River Steam Plant at Carbo, Virginia, has some adverse impacts. The mussel fauna in the middle reaches appear relatively healthy. Approximately 80 miles of the Clinch were identified as prime mussel habitat with almost 60 miles occurring in the Virginia portion bordering Tennessee. The appearance of *Lampsilis abrupta, Pleurobema cordatum, Pleurobema plenum* and *Pleurobema rubrum* is unusual for the upper Clinch since these species are commonly associated with larger rivers such as the Tennessee and Cumberland. Sixteen Cumberlandian forms were also reported from the Clinch. Of the seven endangered species found, five were Cumberlandian. The Clinch is one of few river systems remaining that support such a large endemic group (Ahlstedt, 1991).

Thirty-eight species of mussels were reported from the Elk River. Abundance and diversity were highest in the lower reaches of the river with few live mussels observed in the 10-mile reach below Tim's Ford Dam (ERM 130). The Elk is affected by operations of the dam with continuous flow manipulations and cold water releases. Mussel abundance in the river was low with specimens present only in scattered, isolated pockets. Many mussels were observed dead in the substrate, probably a result of pollution from the city of Fayetteville. Eleven Cumberlandian forms including four endangered species were rare in the Elk. In many instances, specimens were reported as single individuals. The Cumberlandian fauna has been reduced to such a low number of individuals that reproduction is extremely limited or has ceased. The river has excellent mussel habitat in the form of gravel and sand shoals; however, many of these shoals are affected by gravel dredging. Faunal recovery is unlikely to occur because of cold water releases from Tim's Ford Dam and pollution and gravel dredging in the lower Elk (Ahlstedt, 1983).

Large numbers of mussels were found in the Powell River, a major tributary stream to the Clinch. Thirty-seven species of mussels including 15 Cumberlandian forms were reported in the mid-to-lower reaches of the river bordering Tennessee and Virginia. The large number of Cumberlandian forms, five of which are Federally listed endangered species, is an indication of the valuable resource of the Powell. Unfortunately, the Powell River flows through one of the major coal fields of the southern Appalachian mountains. The river is largely affected by silt and coal fines from strip-mining and coal washing facilities located in the headwaters (Virginia portion) of the river. Large silt deposits occur throughout the upper channel of the river and have gradually washed downstream into the more productive reaches bordering Tennessee. Upon occasion, the full length of the river has been observed running black with coal fines. The

(Ahlstedt, 1982).

The mussel faunas in the Nolichucky (21 species), Holston (13 species) and Buffalo Rivers (seven species) should all be considered relict based on the small number of specimens found. Mussels observed in each river, including Cumberlandian forms, were old, eroded individuals. No Cumberlandian forms were found in the Holston River, while three species were found in both the Nolichucky and Buffalo rivers. If reproduction is occurring in these streams, it is probably limited due to the rarity of mussels found and/or the non-availability of colonizers from tributary streams. Excellent mussel habitat exists in all three rivers; however, the Nolichucky is heavily affected by silt from mica and feldspar mining in the headwaters, the Holston has suffered from chronic water quality problems, and an unknown polluting source has decimated the Buffalo River fauna. If silt and pollution problems were corrected, all three streams could be recovered via transplants, artificial culture, or infecting host fish species.

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upper 35 miles of the Powell are largely devoid of mussels, except for a few scattered individuals in isolated pockets. Fifteen Cumberlandian species occur in the river, five are Federally listed endangered species. The Powell is one of few river systems remaining that support such a large endemic group. Excellent mussel habitat exists in the river, but is largely restricted to a 50-mile reach bordering Virginia and Tennessee. Unless reclamation efforts are established in the watershed to control silt and coal fines, the mussel fauna is in jeopardy of being lost due to unstable habitat and the smothering action of these materials.

The mussel fauna in the Duck is largely limited to a 30-mile reach below Lillard Mill Dam (DRM 179). A total of 35 species of mussels were reported from the river, including the largest known population of *Lemiox rimosus*, an endangered Cumberlandian form. Mussels were found in the upper portion of the river above Lillard Mill Dam but exist only as scattered, old individuals. Reproduction in this portion of the river is extremely limited and may have ceased due to the non-availability of colonizers or continuing water quality problems. The Duck has a history of chronic water quality problems originating from the city of Shelbyville. The river has also been affected by the construction and operation of Normandy Dam, which also affects the fauna in this portion of the river. Eleven Cumberlandian forms reported from the river were extremely rare above Lillard Mill Dam. Excellent mussel habitat exists throughout the river; however, the largest mussel concentrations occur only in a 30-mile reach below Lillard Mill Dam. The mussel fauna in the upper Duck may be affected by on-going water quality problems and/or the non-availability of colonizers to support a reproducing population.

Twenty-five species of mussels were found in the Paint Rock River, including the lower portions of Estill Fork, and Hurricane Creek. Thirteen were Cumberlandian forms, including four Federally listed endangered species. The mussel fauna in the Paint Rock is largely limited to the upper 20 miles (headwaters) of the river, including the two tributary streams sampled. Mussel surveys were discontinued in the lower reaches of the river below PRRM 24.5 due to the absence of live specimens. The Paint Rock has been channelized for flood control and is heavily affected by silt runoff from agricultural lands. Mussels are further affected by herbicides and pesticides used to spray cotton and bean fields throughout the Paint Rock River system. Based on the low number of mussels found, the mussel fauna is in jeopardy unless corrective measures are taken. This river system supports the only known populations of two Federally listed endangered species *(Toxolasma cylindrellus* and *Lampsilis virescens).*

Copper Creek, a small tributary of the upper Clinch River is situated in mountainous terrain away from urban development. Nineteen species of mussels including 11 Cumberlandian forms and two Federally listed endangered species were reported from this stream. The relative stability of the watershed and geographic isolation have kept the mussel fauna relatively healthy. The presence of two endangered Cumberlandian forms *(Fusconaia cuneolus* and *Fusconaia cor)* are unusual for such a small stream; however, specimens were found only in the lower reaches of the creek which are affected by migratory host fish species from the Clinch

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