Recent Changes in the Freshwater Molluscan Fauna of the Greenfield Lake Basin, North Carolina

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ABSTRACT.— The molluscan fauna of the Greenfield Lake basin has undergone significant changes in recent years. In surveys conducted from January 1984 through October 1987, 16 species of mollusks were found in the basin. Twelve of those species were recorded from the basin for the first time; 15 species previously recorded in the basin were not found. The most noticeable change was the almost total elimination of the Unionidae. Changes in the molluscan fauna of the Greenfield Lake basin have probably been caused by a combination of factors and events. Those agents of change are still at work today and undoubtedly keep the molluscan population of the lake from ever establishing any type of equilibrium. Partial winter drawdowns are believed to be the most damaging aspect of the water management presently undertaken in the watershed. Pollution from non-point sources has probably also played a role in changing the fauna.

Mollusks in Greenfield Lake, in Wilmington, New Hanover Co., N.C., were frequently sampled by malacologists during the early part of the twentieth century. Records of those collections are scattered in the literature, but a comprehensive survey of the fauna has never been undertaken.

Because of its prominence in the literature of freshwater malacology on the south Atlantic slope, any changes in the molluscan fauna of Greenfield Lake are of general interest. Because of the available data on prior species occurrence, a comprehensive survey was undertaken to assess what changes have taken place in the composition of the lake's molluscan fauna.

Many of the taxa cited in this paper are in need of systematic revision. Resolving taxonomic problems was not a purpose of this study, but the subject has to be addressed because of the abundance of synonyms for some species and the revisions that have taken place since the time of the first Greenfield Lake records. A synonymy section has therefore been included to deal with this problem to the level necessary for identification of species. Gender problems in the species names used by previous authors have not been rectified.

HISTORY OF GREENFIELD LAKE

Greenfield Lake was created prior to 1750 by the impoundment of a small low-lying stream located south of Wilmington to provide a source of fresh water for a nearby rice plantation and for the operation of grist and saw mills. The rice plantation, lake, and surrounding lands were known collectively as "Greenfields" (Moore 1968). The surface elevation is 1.85 m above mean sea level, the surface area is 75 ha, and the drainage basin is approximately 1,100 ha. Maximum depth is approximately 2.5 m.

The City of Wilmington purchased the lake in 1925 for use as a public park, and a circumferential road approximately 8 km long was constructed as a public works project during the Great Depression (Moore 1968). In 1935, fallen trees were removed from the lake and the surrounding area was landscaped (Moore 1975). Removal of marsh grasses and additional snags took place in 1945 for mosquito control (Appleberry 1945).

Today, Greenfield Lake is well within Wilmington, and its watershed is almost completely developed. Land use consists primarily of residential and commercial areas with open space in the form of a golf course and small, isolated tracts of woodlands. Lands immediately adjacent to the lake are still used as a public park, which is a major recreation center for Wilmington.

Urbanization of the watershed has resulted in a decreased detention time for storm waters and, consequently, an increased introduction of nutrients, pesticides, and metals into Greefield Lake. Breaks in sewer lines on the bottom of the lake and sewage overflow from nearby manholes during storms have also added large pulses of nutrients. The latter are now a major problem and in recent years have contributed to severe algal blooms (*Lyngbya*). Control has been attempted through algacides (chelated copper and dichlobenil); introductions of the exotic fishes tilapia, *Tilapia aurea* (Steindachner), and grass carp, *Ctenopharyngodon idella* Valenciennes; and partial drawdowns during the winter months to desiccate and freeze the algae. Central portions of the lake have been dredged in attempts to remove nutrient-laden sediments and deepen the lake beyond the photic zone.

All of the tributaries leading into Greenfield Lake have been channelized to improve drainage in the basin. Maintenance of the channels is periodic and is confined to portions upstream of Lakeshore Drive, the perimeter road. The outlet creek below the dam has been channelized to its confluence with the Cape Fear River and has changed from a freshwater system to an intermittently brackish one.

HISTORICAL COLLECTIONS

Documentation of the historical occurrence of species in the lake was taken from published literature. Records from unpublished collections in museums and universities were not sought. In summarizing her private collection of North Carolina freshwater mollusks plus those in the Academy of Natural Sciences, Philadelphia, and in the Museum of Zoology of the University of Michigan, Dawley (1965) provided several Greenfield Lake citations of both bivalves and gastropods. However, this work was not exhaustive, as major mollusk collections, such as those at Harvard University and the National Museum of Natural History, were not searched. Early in this century, Bartsch searched for *Planorbis magnificus* (Pilsbry, 1903), which had been first described from "the lower Cape Fear River." He found that snail to be fairly abundant in the lake; discovered and described another new planorbid, *Planorbis eucosmius* (Bartsch, 1908); and noted but did not describe two other apparently new mollusks. Bartsch's (1908) discussion of the habitat of *P. magnificus* provides the only available description of the aquatic macrophyte community in Greenfield Lake early in this century. Rehder (1949) reported *Campeloma rufum* (Haldeman, 1841) from the lake in his discussion of land and freshwater snails collected during his travels through the region. Walter (1954) reported *Pseudosuccinea columella* (Say, 1817) from the lake in his discussion of the range of the species but did not disclose the source of the record. Porter (1985) reported forms of *Campeloma* believed to be *C. geniculum* (Conrad, 1834) from Greenfield Lake and mentioned other species of gastropods reported by Dawley (1965).

Records of Bivalvia from Greenfield Lake deal principally with the Unionidae and were summarized by Johnson (1970), who recorded eight species from the lake or the creek below the spillway: *Lampsilis radiata* (Gmelin, 1791), *Villosa delumbis* (Conrad, 1834), *Villosa vibex* (Conrad, 1834), *Anodonta couperiana* (Lea, 1842), *Anodonta imbecillis* (Say, 1829), *Uniomerus tetralasmus* (Say, 1831), *Elliptio complanata* (Lightfoot, 1786), and *Elliptio lanceolata* (Lea, 1828). *Elliptio fisherianus* (Lea, 1838) was recorded from the lake by Bailey (1940), and Morrison (1972) mentioned that *Anodonta imbecillis, A. couperiana,* and *A. teres* (Conrad, 1834) occur there. Porter (1985) reported *Anodonta cataracta* (Say, 1817) and, in citing correspondence with J. P. E. Morrison, also reported *E. fisherianus, A. teres, Villosa vaughaniana* (Lea, 1838), and *Lampsilis ochracea* (Say, 1817) from the lake. Heard (1963, 1965) reported Greenfield Lake specimens of *Musculium transversum* (Say, 1829) and *Eupera cubensis* (Prime, 1865). Walter (1954) also reported *E. cubensis* from the lake in his discussion of the range of the species but did not disclose the source of the record.

All published records from the Greenfield Lake system are summarized in Table 1. Names are presented as published without regard to subsequent taxonomic revisions or the possibilities of misidentifications, which are discussed later.

SYNONYMY

Most of the collections cited in Table 1 are old, and the names have undergone substantial taxonomic revision. The following brief discussion of synonymy brings these historical records into a modern taxonomic framework. Species names are still considered valid if they appear in Table 1 and are not discussed below.

Gastropoda

Clench (1962) synonomized the three forms of *Campeloma rufum* (Haldeman, 1841) with three separate species. *Campeloma rufum* was synonymized with *C. crassulum* Rafinesque, 1819, a species of the Great Lakes-St. Lawrence and the Mississippi drainages. *Campeloma r. meridionale* (Pilsbry, 1916) was synonomized with *C. limum* (Anthony, 1860), and *Campeloma r. geniculiforme* (Pilsbry, 1916) was synonymized with *C. geniculum*. Which form Rehder (1949) collected in Greenfield Lake is unknown, and the ranges of *C. geniculum* and *C. limum* reported by Burch (1982) make either species a possibility.

The genus *Gillia* Stimpson, 1865, has not been revised. *Gillia crenata* (Haldeman, 1840) has not been synonymized with any other forms; however, modern taxonomic keys make no reference to this species. Specimens of *G. crenata* in the National Museum of Natural History are being treated as *G. altilus* (Lea, 1841) (A. G. Gerberich, personal communication).

Although its taxonomic status is still in doubt, *Planorbis eucosmius* (Bartsch, 1908) has been transferred to the genus *Helisoma* Swainson, 1840 (Burch 1982). Burch (1982) speculated that *P. eucosmius* may simply be a juvenile form of *H. anceps anceps* (Menke, 1830), whereas Fuller (1977) assigned *P. eucosmius* to the South American genus *Taphius* H. & A. Adams, 1855. Proper taxonomic placement will not be possible until additional specimens are acquired for soft-tissue analysis.

Planorbis magnificus (Pilsbry, 1903) was transferred to *Planorbella* Haldeman, 1842, by Baker (1945) and the species epithet emended to the feminine *magnifica*. *Planorbis* Muller, 1774, refers to Palearctic and Ethiopian forms (Burch 1982).

Table 1. Published records of freshwater mollusks from the Greenfield Lake drainage basin.

Species	Authority[a]										
	1	2	3	4	5	6	7	8	9	10	11
GASTROPODA											
Viviparidae											
Campeloma geniculum	x		x								x
Campeloma rufum				x							
Lymnaeidae											
Pseudosuccinea columella										x	
Planorbidae											
Planorbis eucosmius						x					
Planorbis magnificus					x	x					x
Hydrobiidae											
Gillia altilis	x										x
Gillia crenata	x										x
Liogyrus sp.						x					
Ancylidae											
Laevapex diaphanus	x										
BIVALVIA											
Unionidae											
Elliptio complanata							x				
Elliptio fisherianus	x		x				x				x
Uniomerus tetralasmus							x				
Anodonta imbecillis	x	x					x				
Anodonta couperiana		x					x				
Anodonta teres		x									x
Anodonta cataracta											x
Villosa delumbis							x				
Villosa vaughaniana											x
Villosa vibex							x				
Lampsilis radiata							x				
Lampsilis ochracea											x
Sphaeriidae											
Limosina sp.						x					
Eupera cubensis								x		x	
Musculium transversum									x		

[a](1) Dawley 1965, (2) Morrison 1972, (3) Bailey 1940, (4) Rehder 1949, (5) Pilsbry 1903, (6) Bartsch 1908, (7) Johnson 1970, (8) Heard 1965, (9) Heard 1963, (10) Walter 1954, (11) Porter 1985.

The genus *Liogyrus* Gill, 1863, is now considered a subgenus of *Amnicola* Gould, 1841 (Burch 1982).

Bivalvia

Johnson (1970) synonymized *Elliptio fisheriana* (Lea, 1838) with *E. lanceolata* (Lea, 1828). Davis (1984) determined that *E. fisheriana* was distinct from *E. lanceolata* and that *E. folliculata* (Lea, 1838) and *E. producta* (Conrad, 1836), which had also been synonymized with *E. lanceolata* by Johnson (1970), were also distinct from it and from each other. Johnson (1984) synonymized *E. producta* with *E. angustata* (Lea, 1831). The ranges of these species are uncertain, and which species occurred historically in Greenfield Lake is unknown.

Uniomerus tetralasmus (Say, 1831) is still a valid species, but south Atlantic drainage *Uniomerus* are now considered to be *U. obesus* (Lea, 1831) (Johnson 1984).

Johnson (1970) synonymized *Anodonta teres* with *A. cataracta* and *Villosa vaughaniana* with *V. delumbus*. However, *Anodonta teres* and *Villosa vaughaniana* are still regarded as distinct by some researchers (e.g. Porter 1985, Turgeon et al. 1988).

The genus *Limosina* Clession, 1872, is synonymous with *Eupera* Bourguignat, 1877 (Heard 1965). *Eupera cubensis* (Prime, 1865) and *Musculium transversum* (Say, 1829) are still considered to be valid names.

METHODS

All of the major tributaries, the nearshore lake bottom out to a distance of about 10 m, and the creek downstream of the dam were sampled between January 1984 and October 1987. Eighteen stations were investigated and are shown in Fig. 1. During January 1984 and again in January 1986, the lake was drained for several weeks, and the substrate for 6-30 m from the bank was exposed. This permitted thorough searches, although some mollusks may have retreated with the receding water. Because movements of unionids during such events have been shown to be random (Samad and Stanley 1986), the species obtained are considered to be representative. The central portions of the lake could not be sampled, as soft sediments and deep water made collecting by the methods used impossible. Summer collections of gastropods were made by sweeping a fine-mesh net through floating aquatic macrophytes, by raking mats of submerged aquatic macrophytes, and by hand. The creek below the dam was sampled by hand and by raking during low tides in summer 1985 and during the winter drawdown. Approximately 40 man-hours were spent in collecting.

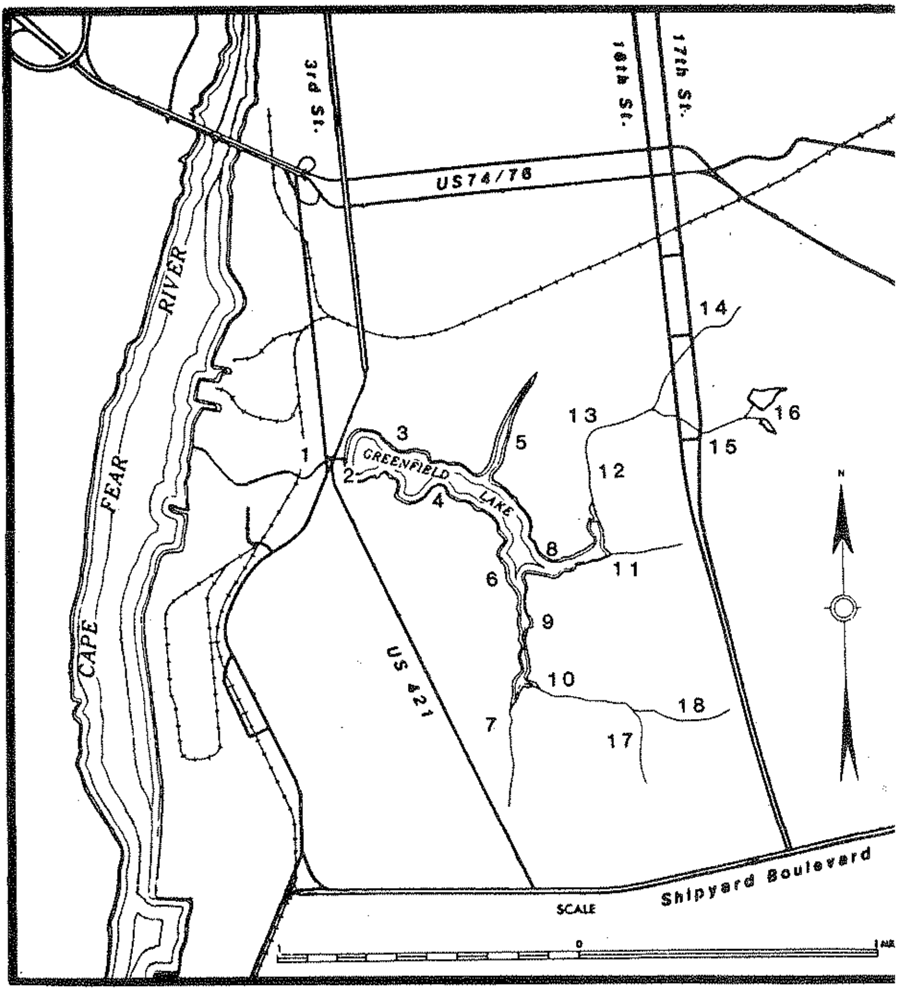

Fig. 1. Location of collection stations in the Greenfield Lake drainage basin.

Salinity measurements in the creek below the dam were taken during and after the 1986 drawdown. All measurements were taken from surface waters and determined by using a refractometer.

Identifications of Unionidae were made using Johnson (1970). Sphaeriidae were determined from Herrington (1962) and Burch (1975), and the nomenclature follows Burch (1975). Gastropods, excepting the Ancylidae, were identified using Burch (1982), and his nomenclature is used. Identification and nomenclature of the Ancylidae follow Basch (1963).

RESULTS

Sixteen species of mollusks, 10 gastropods and 6 bivalves, were collected from Greenfield Lake, its tributaries, and the creek below the spillway (Table 2). Twelve species were recorded from the lake or the drainage basin for the first time, and 15 species previously reported were not relocated.

Campeloma decisum occurred in only one tributary. *Planorbella trivolvis* and *Helisoma anceps* were relatively common throughout the lake in the nearshore area. *Pseudosuccinea columella* was found in quiet waters of the finger portions of the lake but was absent from the main body of the lake. Because of the fragility of the shell of *P. columella*, occasional waves may render the main body of the lake unsuitable habitat for that species. *Menetus dilatatus* and *Gyraulus deflectus* were common in the upper end of the lake. *Gyraulus parvus* was found only in the golf course ponds of Station 16. *Ferrissia fragilis* was common on leaf litter and trash throughout the lake.

Anodonta is the only unionid genus now occurring in the basin. *Anodonta* species are normally associated with lentic habitats, and all live specimens were obtained from the upper portions of the lake. *Anodonta cataracta* may be common in the central portions of the lake; numerous valves of this species were found at the interior base of the dam during the drawdown period. Three forms of *A. cataracta* occur in the lake: a form with dorsal and ventral margins roughly parallel, a form with a broadly rounded ventral margin, and a form with a concave ventral margin.

Only one valve of *Andonta imbecillus* was found during the present study, in the fall of 1987 on a spoil pile resulting from rechannelization of the tributary at Station 13. Despite extensive searches of other spoil piles, no additional specimens could be located, and none were found during drawdowns. Because this tributary was at least temporarily disrupted, the status of *A. imbecillus* cannot be determined. It is at best extremely rare, and perhaps it is extirpated from the Greenfield Lake basin.

Table 2. Species of freshwater mollusks collected from Greenfield Lake with collection stations.

Species	Collection stations
GASTROPODA	
Viviparidae	
Campeloma decisum (Say, 1817)	12, 13, 15
Lymnaeidae	
Pseudosuccinea columella (Say, 1817)	9, 11, 16, 17, 18
Physidae	
Physella hendersoni (Clench, 1925)	3, 4, 6, 8, 11, 18
Physella heterostropha (Conrad, 1834)	4, 7, 8, 10, 11, 16, 18
Planorbidae	
Gyraulus deflectus (Say, 1824)	6, 8, 10
Gyraulus parvus (Say, 1817)	16
Menetus dilitatus (Gould, 1841)	7, 10
Planorbella trivolvis (Say, 1817)	4, 5, 12
Helisoma anceps (Menke, 1830)	6, 8, 17
Ancylidae	
Ferrissia fragilis (Tryon, 1863)	3, 7, 8, 10, 11, 14
BIVALVIA	
Mactridae	
Rangia cuneata (Gray, in Sowerby 1831)	1
Cyrenidae	
Polymesoda caroliniana (Bosc, 1802)	1
Unionidae	
Anodonta cataracta (Say, 1817)	2, 7, 10, 12, 13
Anodonta imbecillus (Say, 1829)	13
Sphaeriidae	
Musculium transversum (Say, 1829)	5, 15
Sphaerium occidentale (Prime, 1853)	4

Sphaeriid clams were numerically the most abundant bivalve mollusks in the lake system. High densities of *Sphaerium occidentale* and *Musculium transversum* were discovered under algal mats in nearshore areas during the January 1984 drawdown, but numbers were much reduced in the summer of 1987.

Only *Rangia cuneata* (Gray, in Sowerby 1831) and *Polymesoda caroliniana* (Bosc, 1802), both brackish-water species, occur in the creek below the spillway. Salinity appears to be the limiting factor for freshwater species in this area as tides bring brackish water from the Cape Fear River into the creek. Surface salinity measurements taken during February 1986 indicate a range of 0 parts per thousand (ppt) to 5 ppt when the lake was being reimpounded after a drawdown and there was no water being released from the lake. Concentrations up to 3 ppt were observed during normal summer releases from the lake. Hopkins et al. (1973) note that *R. cuneata* is restricted to areas where salinity is below 15 ppt most of the time and may occupy portions of creeks and tidal rivers where salinities are continuously below 1 ppt for extended periods.

DISCUSSION

Distributions of many species in the lake appear to be spotty based on the collection station records (Table 2). Differences between stations may be caused by microhabitat conditions, by disturbance histories, or by differing efficiency of collecting at each station. Species of mollusks not recorded in this survey may yet be found to exist in the lake.

Misidentifications in Historical Records

The record of *Laevapex diaphanus* by Dawley (1965) may be based on a misidentification of *L. fuscus*; she did not mention the source of the specimen or the determination. *Laevapex diaphanus* typically inhabits rock bottoms in slowly flowing waters, and I have collected it on debris in swamp streams near Wilmington. However, *L. fuscus* is fairly common in southeastern North Carolina, and it would be more likely than *L. diaphanus* to have occurred in the lacustrine habitats provided by the lake.

Campeloma geniculum may also have been misidentified, because it is difficult to separate from *C. decisum*. In discussing current taxonomy of the genus *Campeloma*, Clench (1962) correctly remarked that "few genera among our North American freshwater mollusks are in a more confused state." Bailey (1940) states that Pilsbry examined specimens of *C. geniculum* from the lake and referred to them as "a rather unusually rounded form of the species." That would imply that the specimens may have been *C. decisum*, which is separated from *C. geniculum* by its more rounded shoulders (Burch 1982). Rehder (1949) collected *C. rufum* (which would now be synonymized with either *C. geniculum* or *C. limum*, see Synonymy above) from Lake Waccamaw, approximately 50 km W of the study area, as well as from Greenfield Lake. *Campeloma* that had characteristics of both *C. geniculum* and *C. decisum* were noted by Porter (1985) in his collections from Lake Waccamaw, and one specimen that had characteristics of *C. geniculum* was found during the present survey. *Campeloma geniculum* is generally expected to have a more southern range, but a population is certainly possible in southeastern North Carolina.

CHANGES IN THE MOLLUSCAN FAUNA

All of the species recorded during this survey are common natives and were probably present in the lake in prior years but were simply not mentioned in previously published accounts.

Neither *Planorbella magnifica* nor *Helisoma eucosmius* has survived in Greenfield Lake, as Fuller (1977) conjectured. Until recently both of these species were considered extinct by some authors (Opler 1976, Imlay 1977, Palmer 1985), but *P. magnifica* has recently been found in Orton Pond, approximately 40 km S of Greenfield Lake (Adams and Gerberich 1988). *Helisoma eucosmius* has not been located at Orton Pond, but the habitat appears to be suitable for it.

Campeloma geniculum was not positively identified from the lake. One specimen of what appeared to be this species was collected at Station 15, but owing to the difficulties associated with separating it from *C. decisum* and the fact that only one was encountered, the specimen was counted as *C. decisum*.

Gillia altilus and members of the genera *Amnicola* and *Laevapex* were not found in this study. Suitable habitat for these species has probably been eliminated by changes in the lake.

By comparing Tables 1 and 2, it can be seen that virtually all of the gastropods collected during this study represent new species records for the lake. Of the species represented in Table 2, only the identifications of the Physidae are uncertain. The species *Physella hendersoni* and *P. heterostropha* could be expected to occur in Greenfield Lake. These species are difficult to separate based on shell characters, and Burch (1982) provides only illustrations. *Physella heterostropha* tends to be more robust than *P. hendersoni*, and it was on this character that the species were separated. "Robustness," however, is a very weak taxonomic character.

Changes in the molluscan fauna of the lake are most dramatically shown in the virtual elimination of the Unionidae. Only two species, *Anodonta cataracta* (= *A. teres*) and *A. imbecillus*, are found in the Greenfield Lake system today compared with 10 that were recorded historically. The loss of *Anodonta couperiana* from the lake, previously suspected by Shelley (1987), has been confirmed. *Eupera cubensis*, a sphaeriid also previously reported from the lake, could not be relocated. When the decline of the Unionidae began is impossible to place. However, since Bailey collected *Elliptio fisheriana* in 1940 and Morrison mentioned three species of *Anodonta* in the lake in 1972, it would appear that this is a recent and rapid phenomenon.

The two brackish-water species, *Rangia cuneata* and *Polymesoda caroliniana*, and the freshwater sphaeriid, *Sphaerium occidentale*, are the only new records of bivalves from the Greenfield Lake basin.

Possible Causes of Change

Degraded water quality has been a persistent problem in Greenfield Lake in recent years, and its decline has been brought about primarily by the urbanization of the watershed. Elevated levels of nutrients, pesticides, and metals and the occurrences of algal blooms have been documented or suspected to have adverse effects on mollusks (Havlik 1987, Havlik and Marking 1987) and have probably done so in the lake. Several fish kills that occurred in the lake during the study period were attributed by local authorities to low levels of dissolved oxygen resulting from excess nutrients. The copper-based algacides used to control *Lyngbia* may be adversely affecting the entire benthic macroinvertebrate community. Havlik and Marking (1987) report that copper sulfate is toxic to freshwater bivalves at concentrations of 2 to 18.7 mg/liter in acute exposures and as low as 25 parts per billion in long-term exposures. Hanson and Stefan (1984) studied the effects of long-term copper sulfate application on lakes in Minnesota and found that the normal functioning of the ecosystems were severely disrupted. Long-term effects that were discovered included copper accumulation in lake sediments, changes in species composition from game fishes to rough fishes, disappearance of macrophytes, and severe reductions in benthic macroinvertebrates.

The water quality of tributaries of Greenfield Lake may have changed over time, because of improved drainage in the upper portions of its basin and the removal of groundwater from the underlying aquifer by residential wells. Bartsch (1908) states that Greenfield Lake was spring fed at the time of his collection, but much of the present freshwater input comes from runoff. In addition, groundwater in the vicinity of the lake may be polluted. If so, it may take many years for pollutants entering the lake to be purged, even if similar pollutants from overland runoff are curbed.

I suspect that the factor most damaging to the unionid populations has been winter-season partial drawdowns. They have a twofold purpose: to permit removal of nearshore trash and debris and to kill the exposed algae mats through cold temperatures and desiccation. These drawdowns have had, and continue to have, a profound effect on the mollusks of the lake ecosystem, because all mollusks occurring in this exposed area are subjected to desiccation and to nighttime temperatures that are frequently well below freezing. *Anodonta cataracta* killed by exposure were observed in several locations. Long (1983) noted significant mortality of *A. cataracta, A. imbecillis,* and *Lampsilis radiata* in a Maryland reservoir when summer water levels were drawn down rapidly. Samad and Stanley (1986) found that *Elliptio complanata* and *L. radiata* were almost totally eliminated by drawdowns of a lake in Maine. Libois and Hallet-Libois (1987) found that thin-shelled unionids such as *Anodonta* suffered high mortality during a 3-week drawdown of the River Meuse in Belgium. From those studies, and the observations gathered here, it appears clear that as long as drawdowns are used as a management measure in Greefield Lake, the unionid population cannot recover.

Not all of the effects of drawdowns are obvious and direct. Lake drawdowns drastically reduce the amount of nearshore habitat available for the fish community and were observed to result in substantial mortality of fish through strandings, increased predation by wading birds and gulls, and cold shock. This loss to the fishery is directly related to the health of the unionid population, because the Unionidae rely on a fish host for the glochidial stage of their life cycle. A reduction in the species diversity or abundance of fishes will, therefore, reduce the number of glochidial hosts available.

Drawdowns also reduce the cross-sectional area of the impounded portions of tributaries. This reduction in cross-section, with tributary inflow remaining the same, causes an increase in water velocities in normally lacustrine areas, and that results in a massive shifting and redistribution of the bottom sediments. Several *Anodonta cataracta* were observed with trails in the sand behind them, apparently attempting to reestablish themselves. While shifting substrates can be a normal occurrence in lotic environments, the lacustrine organisms of the lake probably have difficulty coping with such changes.

During reimpoundment, which takes from 2 to 3 weeks, virtually no fresh water is released from the dam. Therefore, undiluted waters from the Cape Fear River reach the base of the dam with each high tide, and all fish and benthic organisms in the outlet stream are exposed to abnormally high salinities. *Uniomerus tetralasmus* and *Villosa vibex* were recorded below the spillway by Johnson (1970), and Dawley (1965) reported *Gillia altilis* from that area. Habitat for those species has been altered by increased salinity levels.

As discussed previously, all of the tributaries of Greenfiled Lake have been channelized to enhance drainage. These creek channels are periodically maintained by dragline, which results in almost total removal of all benthic organisms and aquatic vegetation. The consequences of such actions for molluscan populations are undoubtedly profound; Greenfield Lake and its tributaries will be repopulated only from undisturbed waters upstream or downstream of the maintenance area or from outside sources. Because channels run from the lake all the way to the headwaters, recolonization is presumed to be very slow.

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