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The Naiades (Bivalvia: Unionoidea) of the Delmarva Peninsula

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Abstract. A survey comprising 307 stations of the freshwaters of the Delmarva Peninsula of Delaware, Maryland, and Virginia was conducted to determine the species diversity and zoogeographic distribution of unionid bivalves. The unionid fauna included *Elliptio fisheriana* (Lea, 1838), *E. complanata* (Lightfoot, 1786), *Lampsilis radiata* (Gmelin, 1791), *Leptodea ochracea* (Say, 1817), *Anodonta cataracta* Say, 1817, *A. implicata* Say, 1829, *Ligumia nasuta* (Say, 1817), *Strophitus undulatus* (Say, 1817), *Alasmidonta undulata* (Say, 1817), and the rare and endangered *A. heterodon* (Lea, 1830). Although a review of the literature and a survey of museum collections revealed records for *E. dilatata* (Rafinesque, 1820), *L. cariosa* (Say, 1817) and *A. varicosa* (Lamarck, 1819), these species were not found during the field survey. No populations of freshwater unionids were found south of the Maryland/Virginia state line. Comparisons of collections in this study with those reported in the literature and in museums indicate a general decline in diversity. The federally listed rare and endangered *A. heterodon* is reported from the Choptank drainage in Maryland. No populations of the zebra mussel, *Dreissena polymorpha* (Pallas, 1771) were found.

Rhoads (1904), in a brief examination of the molluscan fauna of Delaware, remarked that the literature on the molluscan fauna of Delaware was practically nonexistent. This was true in 1904 and is still true nearly 80 years later, not only for Delaware but for the entire Delmarva Peninsula. Rhoads (1904), after collecting at three localities, reported the presence of ten unionid species: *Lampilis nasutus* (Say, 1817) [= *Ligumia nasuta* (Say, 1817)], *L. radiatus* (Gmelin, 1791) [= *L. radiata* (Gmelin, 1791)], *L. cariosus* (Say, 1817) [= *L. cariosa* (Say, 1817)], *L. ochraceus* (Say, 1817) [= *L. ochracea* (Say, 1817)], *Unio complanatus* ('Solander' Dillwyn, 1817) [= *Elliptio complanata* (Lightfoot, 1786)], *U. fisherianus* Lea, 1838 [= *E. fisheriana* (Lea, 1838)], *Anodonta cataracta* Say, 1817, *Strophitus edentulus* (Say, 1829) [= *S. undulata* (Say, 1817)], *S. undulatus*, and *Alasmidonta marginata varicosa* (Lamarck, 1819) [= *A. varicosa* (Lamarck, 1819)]. This list remains the most complete faunal record for the naiades of the entire Delmarva peninsula.

Since the report of Rhoads, several other works have mentioned the unionid fauna of the peninsula only in passing (Ortmann, 1919; Johnson, 1970; Davis and Fuller, 1981; Davis *et al.*, 1981; Clarke, 1981; Davis, 1984). Ortmann (1919) mentioned *Elliptio fisheriana* from the Chester River system of Maryland. Johnson (1970), in his treatment of the freshwater bivalves of the Atlantic Slope, documented only the unionid species inhabiting the waters draining the western shore of Chesapeake Bay. He (Johnson, 1970) made reference to only *E. fisheriana* (Lea, 1838), which he considered a junior synonym of *E. lanceolata,* as having its type locality at the head of the Chester River in Kent Co., Maryland. Davis and Fuller (1981) reported *Lampilis radiata* (Gmelin, 1791) from Sussex Co., Delaware, without more precise locality data. Davis (1984) reported *E. fisheriana* and *E. dilatata* (Rafinesque, 1819) from Concord Pond, Sussex Co., Delaware, *E. complanata* from Deep Creek, Sussex Co., Delaware, and the Sassafras River, Kent Co., and Chester River, Queen Anne's Co., Maryland. Clarke (1981) noted the presence of *Alasmidonta undulata* at "Choptank Mills," Kent Co., and *A. varicosa* at the head of Red Clay Creek, New Castle Co., Delaware.

These few reports constitute the published information available on the freshwater naiades of the Delmarva Peninsula. Given this paucity of information, the potential threat of exotic species introductions, e.g. *Dreissena polymorpha* (Pallas, 1771) (Counts *et al.*, 1991; Handwerker and Counts, 1991), and the geographic features unique to the peninsula, the present study was undertaken to provide a recent baseline study of species diversity and zoogeographic distribution of the freshwater unionids indigenous to the Delmarva Peninsula. The distribution of the Asian clam, *Corbicula fluminea* (Müller, 1774) on the Delmarva Peninsula is discussed in Handwerker *et al.* (1991).

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DESCRIPTION OF THE STUDY AREA

The Delmarva Peninsula, as defined here, extends from Cecil Co., Maryland, east of the Susquehanna River, and New Castle Co., Delaware, and includes all that land lying between the Susquehanna River and Chesapeake Bay on the west and the Delaware River and Bay and Atlantic Ocean on the east, south to Cape Charles, Virginia. The peninsula is bisected on an east-west axis by the brackish waters of the Chesapeake-Delaware Canal. Hence, the lower portion of the peninsula is an island. The study area included the entire state of Delaware, the nine Eastern Shore counties of Maryland (from Cecil Co. in the north to Somerset - Worcester counties in the south) and Virginia (Accomack and Northampton counties). Geologically, the Delmarva Peninsula is composed of deposits ranging from the Late Cretaceous Potomac Group in the north to the Pleistocene sands of the southern half of the peninsula (Stephenson *et al.*, 1933).

The freshwaters of the Delmarva Peninsula drain into the Chesapeake Bay on the west or into the Delaware Bay or Atlantic Ocean on the east. River systems draining into Chesapeake Bay are generally longer and wide than those of the eastern portions of the peninsula that drain into the Atlantic Ocean, either directly or via the Delaware River and Bay. Regardless of the drainage, the streams of the peninsula are tidal and saline for major portions of their length. The transition from brackish to freshwater is usually abrupt and occurs at mill dams. In some cases (e.g. the Sassafras River) the tidal, brackish portion of the stream is substantially longer than the freshwater. The freshwater drainages of the Maryland portion of the peninsula have been described by Carpenter (1983). Generally, streams flow at a slow rate (0.25 - 3.74 m^3/sec) and have a maximum discharge rate ranging between 30.0 - 212.25 m^3/sec and minimum discharge rates ranging between 0 - 0.37 m^3/sec (Carpenter, 1983).

All ponds of the Delmarva Peninsula were originally impounded to store water for livestock and to power grain mills or, in the case of those on the upper peninsula, manufacturing facilities. While none of the mills are now operational, the ponds have been preserved and many are maintained as recreational areas.

The Delmarva Peninsula is also the northern-most point at which cypress swamps occur on the Atlantic coast. Many of the streams of southern Delaware and Somerset, Wicomico, and Worcester counties, Maryland (e.g. Nanticoke River, Pocomoke River, Dividing Creek), drain these swamps and these streams are typical "blackwater" systems.

Many of the freshwater streams of the peninsula are channelized and characterized by steep banks that lack vegetation other than grasses. These streams, and their headwaters, serve to drain cultivated fields. Because of the intense agricultural development of the peninsula, freshwaters show a high degree of eutrophication south of the Chesapeake-Delaware Canal. Most of the stream systems in this agricultural region are little more than drainage ditches between cultivated fields, particularly those of the Virginia counties.

METHODS

A review of the literature (Rhoads, 1904; Ortmann, 1919; Clarke, 1981; Davis and Fuller, 1981; Davis, 1984) was conducted in conjunction with a survey of the unionid collections of the Academy of Natural Sciences of Philadelphia (ANSP) and Delaware Museum of Natural History (DMNH) for collections made on the Delmarva Peninsula. This museum survey was conducted to verify published records and to record and consolidate any unpublished records reflected by these collections. These records were collated and localities listed were then surveyed for the presence of species historically reported or collected.

A survey of major drainage systems of the Delmarva Peninsula (Appendix, Fig. 1) was conducted from August 1989 through August 1990. The survey included 307 stations. A description of all stations surveyed is on file at the Academy of Natural Sciences of Philadelphia. Stations were defined as the section of the stream 100 m above and below the point

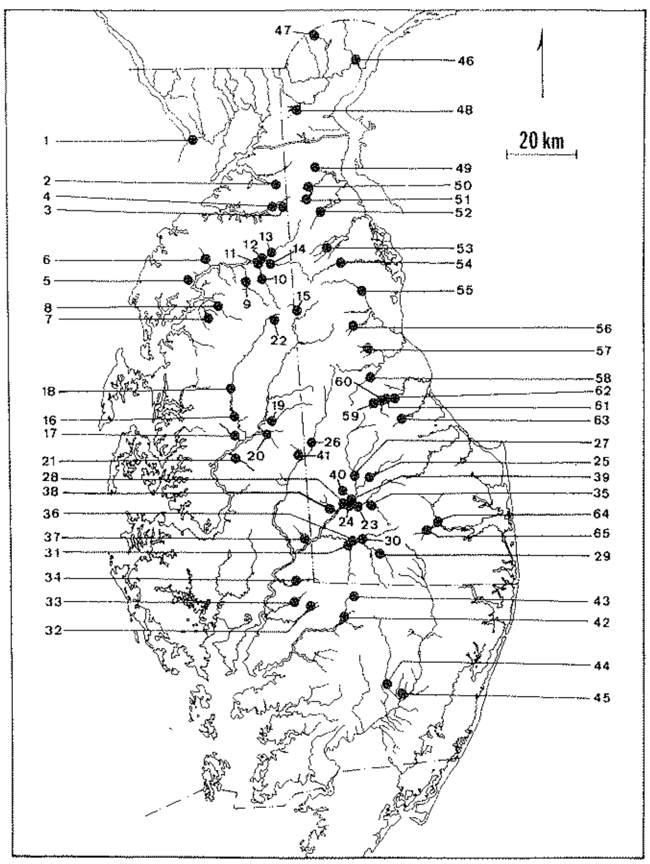

Fig. 1. Station locations at which naiades were collected in the northern half of the Delmarva Peninsula (Delaware and Maryland).

at which the stream was entered. Stream surveys included tidal and brackish water portions of streams where these conditions occurred, along the Chesapeake Bay and the Delaware River estuary. Bivalves were collected by hand and small dredge and by screening substrata. Representative specimens were placed in the collections held at the Coastal Ecology Research Laboratory at the University of Maryland Eastern Shore (UMES).

Collections made at sites reported in the literature or which were represented in the ANSP and DMNH were compared to determine changes in species diversity. All localities reported from those sources were surveyed when locality data were sufficient to relocate the original site.

RESULTS

Ten species of unionids were found in the waters of the Delmarva Peninsula. Historic records were found for three additional species. Station numbers from the present study are given in parentheses for surveys conducted at localities listed in published works and the museum records. Station localities are provided in the appendix.

Elliptio fisheriana (Lea, 1838)

Published Records. Chester River System: Head of the Chester River (Kent Co.) MD [Type Locality (Lea, 1838)]; Stations 5 (Ortmann, 1919), 8 (Ortmann, 1919), 15 (Rhoads, 1904), 23 (Davis, 1984), 28 (Rhoads, 1904).

Museum Materials Examined. Stations 5, 13, 17, 18, 23, 24, 28. Also examined were specimens from an unnamed body of water, Chestertown, Kent Co., MD (DMNH 174253) and from Sussex Co., DE (ANSP 345052).

Records from Present Study. Stations 11, 17, 29, 30, 31, 34, 35 - 39.

There has been confusion as to the systematic position of *Elliptio fisheriana*. Ortmann (1919) noted that a close morphological similarity exists between *E. fisheriana* and *E. cupreus* and believed that *E. fisheriana* could be a lowland race of *E. cupreus*. However, he also noted that he could not detect intergrades between the two species. He further noted that specimens collected in White Clay Creek, Chester Co., Pennsylvania (Hartman and Michener, 1874), could in fact have been collected in Delaware. Johnson (1970) reported *E. fisheriana* to be a synonym of *E. lanceolata* (Lea, 1828) which he considered to be a highly variable species (25 synonyms listed for *E. lanceolata*); however, Davis (1984) found *E. fisheriana* to be genetically distinct from *E. lanceolata*. No published reports exist regarding the glochidia, soft tissue anatomy, or breeding season of *E. fisheriana*.

Elliptio complanata (Lightfoot, 1786)

Published Records. Stations 4 (Davis, 1984), 24 (Davis, 1984). An additional record was published for the Chester River, Queen Annes Co., MD (Davis, 1984).

Museum Materials Examined. Stations 3, 4, 12 - 14, 17, 18, 21, 22 - 24, 28, 43, 46. Additional specimens: Elk River, Sandy Cove, Cecil Co., MD (DMNH 75226); an unnamed ditch, Petersburg, Kent Co., DE, No Date, (DMNH 131124); Christmas Creek, Newark, New Castle Co., DE (ANSP 366090); Small Creek, Kent Co., DE (ANSP 358279).

Records from Present Study. Stations 1, 6, 9, 10, 12, 13, 17 - 19, 21, 22, 25 - 27, 30 - 32, 34, 37, 48, 49, 53, 54, 59, 61, 63.

Elliptio complanata can demonstrate local morphological variability in both shell shape and coloration. Further, the species has the widest zoogeographic distribution of those unionid bivalves indigenous to the Atlantic Slope, ranging from the Apalachicola River drainage of Florida to the St. Lawrence drainage and Interior Basin of Canada (Burch, 1973; Clarke, 1973). Perhaps it is because of this wide variability and zoogeographic distribution that numerous synoyms exist for the species [124 in Johnson (1970)]. Soft tissue anatomy has been described by Ortmann (1911) and Reardon (1929).

Elliptio complanata is reported to breed from April through July or August. The host species is the anadromous yellow perch, *Perca flavescens* (Mitchill) (Lefevre and Curtis, 1912; Matteson, 1948). *E. complanata* is the most common species of freshwater bivalve encountered in the Atlantic drainage (Clarke and Berg, 1959) and is typically found in lakes, ponds, rivers, and small streams on all types of substrata except very soft mud. Clarke and Berg (1959) reported that often this is the only species found in a particular locality and, if other species of unionids are present, it is the most abundant. Our survey confirms this finding.

Elliptio dilatata (Rafinesque, 1820)

Published Records. Chesapeake Bay drainage. Nanticoke River System: Concord Pond, Sussex Co., DE (Davis, 1984) Station 23).

Elliptio dilatata is an Interior Basin species that closely resembles *E. complanata* and is common throughout its range (Clarke and Berg, 1959) in large and small rivers in either rapid or slow-flowing reaches, as well as in lakes on rocky, gravel, sand, or mud substrata (Clarke and Berg, 1959). Soft tissue anatomy was described by Ortmann (1911). Reproduction occurs in the spring although Ortmann (1919) reported gravid females were found in Pennsylvania from May through August. Glochidia are retained in the marsupium until August (Ortmann, 1919; Clarke and Berg, 1959). The host fish in unknown.

No specimens of *Elliptio dilatata* were found during the present study but a single published record is reported. Since the voucher specimen for this record was not found in the collections of the Academy of Natural Sciences of Philadelphia, it is believed that the specimens were late identified as *E. complanata*. An examination of the collection locality failed to reveal the presence of this species. Therefore, no verified specimen of *E. dilatata* has been taken from the Delmarva Peninsula.

Alasmidonta undulata (Say, 1817)

Published Record. Chesapeake Bay Drainage. (Station 15) (Clarke, 1981).
Museum Materials Examined. Stations 15 and 17.
Record from Present Study: Station 17.

Clarke (1981) published a single locality for *Alasmidonta undulata* on the Delmarva Peninsula, and two lots from the Choptank River system are at ANSP. We located a single specimen during our survey.

Ortmann (1919) noted that *Alasmidonta undulata* is gravid from July to the following June and Clarke (1981) reported collecting gravid females between August and October. The host fish is unknown. *A. undulata* is reported to occur in moderately flowing streams, from rivers to creeks, and is most abundant on gravel and sand substrata, being absent from mud (Ortmann, 1919; Clarke and Berg, 1959; Clarke, 1981). The species is also found in lakes on sand and gravel substrata (but growth can be stunted in these habitats) and reaches its maximum size in stream outlets located downstream of lakes (Clarke and Berg, 1959). The species is reported to be commonly associated with *Elliptio complanata* and secondarily with *Strophitus undulatus* (Clarke and Berg, 1959; Clarke, 1981). Ortmann (1911) described the soft tissue anatomy.

Alasmidonta varicosa (Lamarck, 1819)

Published Record. Station 47 (Clarke, 1981).
Museum Materials Examined. Station 47.

Clarke (1981) published a single locality for *Alasmidonta varicosa* on the Delmarva Peninsula. However, we were unable to locate the species and a survey of the Clarke's locality failed to reveal the presence of the species.

Alasmidonta heterodon (Lea, 1830)

Museum Materials Examined. Station 17. One lot (ANSP 174899) collected by G. A. Coventry, August 1939, "Delaware."

Although *Alasmidonta heterodon* has been reported from streams to areas adjacent to the Delmarva Peninsula (Clarke and Berg, 1959; Johnson, 1970; Clarke, 1981), it has never been described from the waters of the peninsula-proper. The species was first collected on the peninsula in August 1939 by G. A. Coventry without specific collection data other than "Delaware." One population was found during this study in (Station 17) Norwich Creek, a tributary of Tuckahoe Creek, Choptank River system, near Hillsboro, Maryland. The population is located just within the Talbot Co. line and appears to be locally abundant. A second population, which we were unable to locate, was reported from Long Marsh Ditch (pers. comm., Maryland Nature Conservancy, 1991). Because of its rare and endangered status, no collections were made.

Alasmidonta heterodon has been described as inconspicuous with a disjunctive distribution along the Atlantic coast (Clarke and Berg, 1959; Clarke, 1981). The species is bradytictic and Clarke and Berg (1959) noted that its breeding season is not well known with gravid females being reported in February and April. Clarke (1981) noted gravid females have been found in June and, in the Tar River, North Carolina, in late August. The fish host species is not known. Details of soft tissue anatomy are presented in Clarke (1981). The reported habitats include medium-sized rivers or rather slow-moving rivers of varying size on substrata of gravel, sand, or muddy sand, and sometimes among submerged aquatic vegetation (Clarke and Berg, 1959; Johnson, 1970; Clarke, 1981). The population at Norwich Creek (Station 17) is living in slow-moving water over a sandy substratum. Clarke and Berg (1959) also noted that *A. heterodon* was associated commonly with *Elliptio complanata* and *Strophitus undulatus* in central New York. Although we found neither of these species in direct association with *A. heterodon* at Norwich Creek, contemporaneous historical collections from this locality indicated the presence of *E. complanata, S. undulatus*, as well as *Anodonta cataracta, E. fisheriana*, and *A. undulata*.

Anodonta cataracta Say, 1817

Published Record. Seaford, Sussex Co., DE (Rhoads, 1904).
Museum Materials Examined. Stations 8, 11, 15, 17, 24, 55, 61. Other materials examined: Leonards Brick Pond, Choptank River System, Cambridge, Dorchester Co., MD. (collections made before 1930, a note with the lot states that the locality now has dwellings) (DMNH 87400): Tributary of Brandywine Creek, Christina River System, Greenville, New Castle Co., DE (ANSP 182963).

One lot from Cambridge, Dorchester Co., MD. (ANSP 132477) is from a fish pond, with no outlets to streams. Another lot (ANSP 355544) gives a locality of "Wye Mills, Norwich Creek, Talbot Co., MD." Wye Mills is located in Queen Anne's Co. and Norwich Creek is in Talbot Co. approximately 8 km east of Wye Mills.
Records from Present Study. Stations 1 - 3, 6, 11, 20, 24, 29, 30, 32, 34, 35, 38, 40 - 42, 51, 52, 55 - 63, 65.

This was the second most commonly found freshwater bivalve on the Delmarva Peninsula. Clarke and Berg (1959) report the species to be common in lakes and ponds and streams varying in size from large rivers to small creeks, it is most abundant on substrata of sand or mud. They further noted that it was the only species found in soft and substrata of ponds and backwater areas. On Delmarva, the species has been collected historically from small streams but our collections were entirely from the small mill ponds, usually from sand-silt substrata.

Anodonta cataracta is reported to breed from the middle of July to the following April or May (Clarke and Berg, 1959). The host fish species is unknown. Details of soft tissue anatomy are presented in Reardon (1929).

Anodonta implicata Say, 1829

Museum Materials Examined. Stations 4, 5, 11, 13.

One lot (ANSP 355543) gives a locality of "Wye Mills, Norwich Creek, Talbot Co., MD." Wye Mills is located in Queen Anne's Co. and Norwich Creek is in Talbot Co. approximately 8 km east of Wye Mills.

Records from Present Study. Stations 12, 13, 16, 31, 49, 50, 60.

Anodonta implicata is found most commonly in sand or gravel substrata and, very rarely, in mud (Clarke and Berg, 1959; Johnson, 1970). Johnson (1970) notes that the species seems to prefer stream habitat although it can be found in coastal ponds with an unobstructed outlet to the ocean. *A. implicata* was found during our study in ponds without such direct access to the ocean in the Delaware River and Bay drainage (Stations 49, 50, 60).

Ortmann (1919) reported *Anodonta implicata* to be bradytictic (winter breeders) with larvae present in the marsupium between July and September. Johnson (1970) reported gravid females in Massachusetts in early May and June. Larvae are released the followiong spring and the host species is the anadromous alewife, *Alosa pseudoharengus* (Wilson, 1811) (Clarke and Berg, 1959). No report of soft tissue anatomy is known. The glochidia were described by Johnson (1946). Unionids most commonly associated with *A. implicata* are *A. cataracta, Lampsilis radiata radiata, L. ochracea,* and *Elliptio complanata* (Clarke and Berg, 1959). There are no published records for *A. implicata* on the Delmarva Peninsula.

Lampsilis radiata radiata (Gmelin, 1791)

Published Record. Sussex Co., DE (Davis and Fuller, 1981).

Museum Materials Examined. Stations 3, 5, 11 - 13, 24. Additional materials were examined from Grays Branch, Choptank River System, near Denton, Caroline Co., MD (ANSP 106007).

Collections from Present Study. Stations 1, 2, 12, 13, 33, 44.

Lampsilis r. radiata is distributed widely over the Atlantic Slope (Johnson, 1970). Clarke and Berg (1959) noted that the breeding season appears to begin in August and end the following August. It is not known if this implies continuous breeding or if a hiatus occurs between breeding years. The host fish is unknown but these authors suggested that many of the species serving as hosts for *L. siliquoidea* (Barnes, 1823) also serve as hosts for glochidia of *L. r. radiata* [bluegill, *Pomoxis annularis* Rafinesque; black crappie, *P. nigromaculatus* (LeSueur); largemouth bass, *Micropterus salmoides* (Lacepede); smallmouth bass, *M. dolomieui dolomieui* Lacepede); white bass, *Roccus chrysops* (Rafinesque); yellow perch, *Perca flavescens* (Mitchill); eastern sauger, *Stizostedion canadense* (Smith); and yellow pikeperch, *S. vitreum* (Mitchill)].

Lampsilis r. radiata is found typically on gravel or sand substrata and occasionally on mud. It occurs in lakes and rivers of all sizes but can be absent from smaller ponds and creeks (Clarke and Berg, 1959).

Lampsilis cariosa (Say, 1817)

Published Record. Seaford, Sussex Co., DE (Rhoades, 1904).

Museum Materials Examined. Stations 24, 28.

The anatomy of *Lampsilis cariosa* was described by Lea (1838). Ortmann (1911) found it to be similar to that of *L. ventricosa* (Barnes, 1823). The length of the breeding season is unknown but Clarke and Berg (1959) believed the species to be bradytictic. The host species is unknown. *L. cariosa* is found in riffles and shoals of large to medium-sized streams in fine to coarse gravel, usually in sand bars (Clarke and Berg, 1959; Johnson, 1970).

There are only three records for *Lampsilis cariosa* from the Delmarva Peninsula, all from the Nanticoke River system. The species was not encountered during our study even though collections were made at the same stations as the historic records. This absence of *L. cariosa* could not be explained on the basis of misidentification.

Leptodea ochracea (Say, 1817)

Published Record. Seaford, Sussex Co., DE (Rhoads, 1904).

Museum Materials Examined. Stations 5, 24, 28, 55.

Collections from Present Study. Stations 1, 2, 60, 61.

Ortmann (1919) reported *Leptodea ochracea* to be restricted to the tidal portions of the Delaware River. Clarke and Berg (1959) noted the species occurs in ponds, canals, and slow-flowing portions of rivers. The soft tissue anatomy was described by Reardon (1929). Very little is known concerning the glochidia, breeding season, or host species (Ortmann, 1919; Johnson, 1947; Clarke and Berg, 1959) although Johnson (1970) reported finding gravid females in early May at Plymouth, Massachusetts, and thought the species was bradytictic. Johnson (1970) also believed that the glochidia probably parasitize migratory fish because *L. ochracea* is restricted generally to the lower reaches of streams having direct connections with the Atlantic Slope.

Ligumia nasuta (Say, 1817)

Published Records. Station 15 and Seaford, Nanticoke River System, Sussex Co., DE (Rhoads, 1904).
Museum Materials Examined. Stations 15, 24, 28. Additional materials: Ditch, Choptank River System, near Petersburg, Kent Co., DE, 1939 (ANSP 175862); headwaters of the Choptank River, Medford, Mills, Sussex Co., DE, 1939 (ANSP 174904).
Record from Present Study. Station 45.

While there are historical collections that have placed *Ligumia nasuta* in various streams and ponds of Delmarva, it was encountered at only a single station (45) during our study.

Clarke and Berg (1959) report *Ligumia nasuta* to breed from August to the following June. The host fish species is unknown. The preferred habitat appears to be ponds, lakes, and slack water portions of streams and canals on sand and mud substrata (Clarke and Berg, 1959). The species is usually associated with *Elliptio complanata* and *Lampsilis radiata.*

Strophitus undulatus (Say, 1817)

Published Record. Station 15 (Rhoads, 1904).
Museum Materials Examined. Stations 13, 17, 47.
Record from Present Study: Station 17.

There is some debate as to the life-cycle of *Strophitus undulatus.* Lefevre and Curtis (1912) and Clarke and Berg (1959) report that the species can complete its development in parental marsupia but note that Baker (1928) reported glochidia completed development after attachment to largemouth bass, *Micropterus salmoides* (Lacepede, 1802), and the northern creek chub, *Semotilus atromaculatus* (Mitchill, 1818). Both of these species are found in waters draining into Chesapeake Bay (Lee, 1980; Lee and Platania, 1980; Hocutt *et al.*, 1986).

The habitats reported for *Strophitus undulatus* include small rivers and creeks on substrata of mud, sand, or fine gravel (Clarke and Berg, 1959; Johnson, 1970). *S. undulatus* is reported in association with *Elliptio complanata* and *Alasmidonta undulata* (Clarke and Berg, 1959). Contemporaneous collections at ANSP confirm this association in Andover Creek, Maryland, as do our own collections in Norwich Creek, Talbot Co., Maryland. These collections further indicate associations with *Lampsilis radiata, Anodonta cataracta, A. implicata, E. fisheriana,* and *Alasmidonta heterodon.*

DIVERSITY

Unionid bivalves were found at 56 (18.2%) of the 307 stations examined (Table 1). Of the 13 species of unionids historically reported from waters of the Delmarva Peninsula, 10 are now present (Table 1). The highest number of species present at a single locality was 5 (Station 17) followed by one station (Station 2) with 4 species, 8 stations with 3 species, 10 stations with 2 species, and 36 stations with a single species present (Table 1). When these data are compared with those for the 21 historically identifiable stations represented in museum collections or published in the literature only 2 stations show no change in species composition. Additionally, 14 stations show a decline in the number of species present, 2 stations show an increase in species diversity, and 3 stations have lost species but gained new ones. Therefore, the trend is towards a decrease in unionid species diversity.

A review of historical collections revealed that *Elliptio complanata* was associated commonly with *Anodonta cataracta* and *E. fisheriana* and *E. fisheriana* with *A. cataracta* (Table 1). Collections from our survey indicate that *E. complanata* is commonly associated with *E. fisheriana* and *E. fisheriana* with *A. cataracta* but that *E. complanata* now is associated closely with *Lampsilis radiata* (Table 1).

The three most commonly encountered unionids on the Delmarva Peninsula, both historically and at present, are *Anodonta cataracta, Elliptio complanata* and *E. fisheriana* (Table 2). Neither *E. dilatata, Lampsilis cariosa* nor *Alasmidonta varicosa* were found during our survey. Table 2 summarizes species composition changes for all historical and present collections of unionids on the Delmarva Peninsula.

DISCUSSION

The unionid fauna of Delmarva is composed entirely of species associated with the greater Atlantic Slope fauna (Ortmann, 1919; Clarke and Berg, 1959; Johnson, 1970; Clarke, 1981). The origination of this fauna probably occurred in much the same manner as that of the freshwater fishes of the peninsula. In view of the need for a fish host for the bivalves to complete their development, the population of the peninsula by these two groups should have been simultaneous. Hocutt *et al.* (1986) noted that Chesapeake Bay is the drowned channel of the Susquehanna River and that the lower sea levels associated with interglacial periods facilitated the dispersal of several upland fish species to the peninsula. This process of rising and falling sea levels in the bay occurred many times (Flint, 1957) with the lowest level occurring during the Wisconsonian glaciation (Lougee, 1953). Thus, with the free movement of fishes and unionids during these periods, it is not surprising that Delmarva's unionid fauna is like that of the rest of the Atlantic Slope.

Once established, some isolation of unionid populations in the major drainages of the peninsula could have occurred (Sepkowski and Rex, 1974). Further, extinction of local populations can occur and, given the disjunct populations of such species as *Alasmidonta heterodon,* this has undoubtedly occurred. Given the life cycle and physiological

Table 1. Species present at all stations (A, Species historically present but now absent; B, Species historically present and now present; C, New record for the species).

Taxon	Station Number 1	2	3	4	5	6	7	8	9	10	11	12	13
Elliptio fisheriana	—	—	—	—	A	—	—	A	—	—	C	—	A
E. complanata	C	—	A	A	—	C	C	—	C	C	—	B	B
E. dilatata	—	—	—	—	—	—	—	—	—	—	—	—	—
Alasmidonta undulata	—	—	—	—	—	—	—	—	—	—	—	—	—
A. varicosa	—	—	—	—	—	—	—	—	—	—	—	—	—
A. heterodon	—	—	—	—	—	—	—	—	—	—	—	—	—
Anodonta cataracta	C	C	C	—	—	C	—	A	—	—	B	—	—
A. implicata	—	—	—	A	A	—	—	—	—	—	A	C	B
Lampsilis r. radiata	C	C	A	—	A	—	—	—	—	—	A	B	B
L. cariosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptodea ochracea	C	C	—	—	A	—	—	—	—	—	—	—	—
Ligumia nasuta	—	—	—	—	—	—	—	—	—	—	—	—	—
Strophitus undulatus	—	—	—	—	—	—	—	—	—	—	—	—	A

Taxon	Station Number 14	15	16	17	18	19	20	21	22	23	24	25	26
Elliptio fisheriana	—	A	—	B	A	—	—	—	—	A	A	—	—
E. complanata	A	—	—	B	B	C	—	B	B	A	A	C	C
E. dilatata	—	—	—	—	—	—	—	—	—	A	—	—	—
Alasmidonta undulata	—	A	—	B	—	—	—	—	—	—	—	—	—
A. varicosa	—	—	—	—	—	—	—	—	—	—	—	—	—
A. heterodon	—	—	—	B	—	—	—	—	—	—	—	—	—
Anodonta cataracta	—	A	—	A	—	—	C	—	—	—	B	—	—
A. implicata	—	—	C	—	—	—	—	—	—	—	—	—	—
Lampsilis r. radiata	—	—	—	—	—	—	—	—	—	—	A	—	—
L. cariosa	—	—	—	—	—	—	—	—	—	—	A	—	—
Leptodea ochracea	—	—	—	—	—	—	—	—	—	—	A	—	—
Ligumia nasuta	—	A	—	—	—	—	—	—	—	—	A	—	—
Strophitus undulatus	—	A	—	B	—	—	—	—	—	—	—	—	—

Taxon	Station Number 27	28	29	30	31	32	33	34	35	36	37	38	39
Elliptio fisheriana	—	A	C	C	C	—	—	C	C	C	C	C	C
E. complanata	C	A	—	C	C	C	—	C	—	—	C	—	—
E. dilatata	—	—	—	—	—	—	—	—	—	—	—	—	—
Alasmidonta undulata	—	—	—	—	—	—	—	—	—	—	—	—	—
A. varicosa	—	—	—	—	—	—	—	—	—	—	—	—	—
A. heterodon	—	—	—	—	—	—	—	—	—	—	—	—	—
Anodonta cataracta	—	—	C	C	—	C	—	C	C	—	—	C	—
A. implicata	—	—	—	—	C	—	—	—	—	—	—	—	—
Lampsilis r. radiata	—	—	—	—	—	—	C	—	—	—	—	—	—
L. cariosa	—	—	—	A	—	—	—	—	—	—	—	—	—
Leptodea ochracea	—	A	—	—	—	—	—	—	—	—	—	—	—
Ligumia nasuta	—	A	—	—	—	—	—	—	—	—	—	—	—
Strophitus undulatus	—	—	—	—	—	—	—	—	—	—	—	—	—

Taxon	Station Number 40	41	42	43	44	45	46	47	48	49	50	51	52
Elliptio fisheriana	—	—	—	—	—	—	—	—	—	—	—	—	—
E. complanata	—	—	—	C	—	—	A	—	C	C	—	—	—
E. dilatata	—	—	—	—	—	—	—	—	—	—	—	—	—
Alasmidonta undulata	—	—	—	—	—	—	—	—	—	—	—	—	—
A. varicosa	—	—	—	—	—	—	—	A	—	—	—	—	—
A. heterodon	—	—	—	—	—	—	—	—	—	—	—	—	—
Anodonta cataracta	C	C	C	—	—	—	C	—	—	—	—	C	C
A. implicata	—	—	—	—	—	—	—	—	—	C	C	—	—
Lampsilis r. radiata	—	—	—	—	C	—	—	—	—	—	—	—	—
L. cariosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptodea ochracea	—	—	—	—	—	—	—	—	—	—	—	—	—
Ligumia nasuta	—	—	—	—	—	—	—	A	—	—	—	—	—
Strophitus undulatus	—	—	—	—	—	—	—	—	—	—	—	—	—

(continued)

Table 1. (Continued)

	Station Number												
Taxon	53	54	55	56	57	58	59	60	61	62	63	64	65
Elliptio fisheriana	—	—	—	—	—	—	—	—	—	—	—	—	—
E. complanata	C	C	—	—	—	—	C	—	C	—	C	—	—
E. dilatata	—	—	—	—	—	—	—	—	—	—	—	—	—
Alasmidonta undulata	—	—	—	—	—	—	—	—	—	—	—	—	—
A. varicosa	—	—	—	—	—	—	—	—	—	—	—	—	—
A. heterodon	—	—	—	—	—	—	—	—	—	—	—	—	—
Anodonta cataracta	—	—	B	C	C	C	C	C	B	C	C	A	C
A. implicata	—	—	—	—	—	—	—	C	—	—	—	—	—
Lampsilis r. radiata	—	—	—	—	—	—	—	—	—	—	—	—	—
L. cariosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptodea ochracea	—	—	A	—	—	—	—	C	C	—	—	—	—
Ligumia nasuta	—	—	—	—	—	—	—	—	—	—	—	—	—
Strophitus undulatus	—	—	—	—	—	—	—	—	—	—	—	—	—

requirements of unionids, opportunities for expansion of zoogeographic ranges are limited in these habitats and thus, the observed pattern of distribution of unionids in coastal rivers is not explained easily.

Sepkowski and Rex (1974) offered three hypotheses to explain the distribution of unionid fauna along coastal rivers. The first proposes that gravid mussels could attach to the feet of aquatic birds and are thence transported into neighboring systems. They noted that van der Schalie (1945) rejected this particular statement of the hypothesis but noted that predatory birds can carry the tissues of glochidial-parasitized fish from one stream to another. This form of the hypothesis seems more reasonable given the size and weight of unionid bivalves although the size, depth, and degree of canopy cover of most Delmarva Peninsula streams do not lend themselves to large-scale use by predatory birds.

The second hypothesis hinges on parasitism of secondary and peripheral fishes. Myers (1938, 1951) classified fishes on the basis of their salinity tolerance. Primary fishes have little or no tolerance to sea water; secondary fishes are restricted usually to freshwater but have a salinity tolerance sufficient to cross narrow bands of salt water. Thus, secondary fish hosts could move freely into the bay from one drainage and enter another. Salinity tolerance studies by Musick (1972) and Lee (1976) suggested that primary fishes can tolerate greater salinity concentrations than suggested by Myers. Because of this others (e.g. Hocutt *et al.*, 1986) have suggested that the salinity tolerance classification scheme is invalid. The presumed primary fish host of *Lampsilis r. radiata* and *Strophitus undulatus*, *Micropterus salmoides*, tolerated a salinity of 12.9 ppt and another primary fish host of *L. r. radiata* and *Elliptio complanata*, *Perca flavescens*, tolerated a salinity of 13 ppt. Thus, these fishes could move more freely among the drainage systems of the peninsula than was suspected previously. Unionid glochidia, however, are intolerant of saline conditions (Cvancara, 1970) and their movement on a fish host into saline conditions seems unlikely unless physiological isolation occurs within the fish host's tissues. It seems more likely that the usual mode of movement of unionid species on fish hosts occurred during times of high freshwater input into the system (e.g. rains, etc.). These events would dilute the saltwater barriers between drainages and this seems to agree with the third hypothesis of Sepkowski and Rex (1974) that stream capture and flooding could play a role in dispersal.

This dispersal mechanism could also explain the absence of unionids on the Virginia portion of the Delmarva Peninsula. These streams are short and shallow and most are tidal and brackish. Furthermore, the waters of the Chesapeake Bay on the west side of the peninsula are more saline [22 - 28 ppt (Bashore and Kelly, 1987)] than those observed farther north in Maryland. The extensive use of mill dams that act to sharply demarcate fresh and salt waters are essentially absent from the Virginia portion of the peninsula. Thus, the movement of unionids from one drainage to another in the southern end of the peninsula, even while attached to a host fish species, requires traversing waters of even higher salinities than those farther north. Even major weather events that result in significant amounts of rainfall could not dilute appreciably waters of these salinities to permit the passage of species from one drainage to another. Another factor contributing to the absence of unionid species in this region is the frequency with which the streams dry up during periods of drought. Should a unionid species become established in a southern peninsula stream, it could find itself without water during the summer months. The absence of species usually associated with ponds (*Elliptio complanata, Anodonta cataracta, Lampsilis r. radiata, Leptodea ochracea, Ligumia nasuta*) is puzzling because many of the existing ponds have been stocked with fish.

The collections made during our survey indicate a general trend toward decline in species diversity. While there has not been a historical trend towards development of heavy industry on the Delmarva Peninsula during the past 100 years, there has been an increase in population and an intensification of agricultural production. This has led to the channelization of many streams for both flood control and increased drainage of farm fields. This process could have contributed to habitat loss for some species because several historical localities are now channelized. Furthermore, the increased application of agricultural chemicals could have played a role in diversity decline by acting either directly upon the mussels or upon their fish hosts species. Because many of the fish hosts for the species of unionids on Delmarva are as yet unknown, the extent of this factor is unknown.

The zebra mussel, *Dreissena polymorpha*, has yet to be found along the Delmarva Peninsula. The point at which direct introduction from abroad is likely to occur is the Chesapeake Bay and Delaware Canal. The Maryland Department of Natural Resources is currently monitoring these waters for evidence of this exotic species.

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APPENDIX.

Collection station numbers and localities examined for the presence of unionid bivalves on the Delmarva Peninsula. The geographic locations of stations are identified in figure 1 by station number. Stations are listed from north to south first in the Chesapeake Bay drainage and secondly in the Delaware Bay Atlantic Ocean drainage. Previously reported stations are referenced in parentheses. (DMNH, Delaware Museum of Natural History; ANSP, Academy of Natural Sciences of Philadelphia; UMES, University of Maryland Eastern Shore). Only those stations where unionid bivalves were found are listed. A complete list of all station localities, including those where no naiades were found, is on file at ANSP.

Chesapeake Bay Drainage

SUSQUEHANNA RIVER

1. Susquehanna River, mud flat at Veterans Hospital, Perry Point, Perryville, Cecil Co., MD (UMES 2258, 2259, 2260, 2261)

BOHEMIA RIVER SYSTEM

2. Little Bohemia Creek, Bohemia Mills, Bunker Hill Road, Cecil Co., MD (UMES 2397, 2398, 2399)

SASSAFRAS RIVER SYSTEM

3. Sassafras River, MDSR 299 bridge, Cecil-Kent Co. line, MD (ANSP 358302, 358303, 358304, 358305; UMES 2408)
4. Sassafras River, under US 301 bridge, Cecil-Kent Co. line, MD (Davis, 1984; ANSP 346882, 346889, 347868)

CHESTER RIVER SYSTEM

5. Ratcliff Creek, MDRT 661, Chestertown, Kent Co., MD (Ortmann, 1919; ANSP 65093, 65095, 65096; DMNH 78556)
6. Island Creek, MDSR 213 bridge, north of Centreville Queen Anne's Co., MD (UMES 2402, 2403)
7. Granny Finley Branch, MDSR 213 bridge, Queen Anne's Co., MD (UMES 2409)
8. Southeast Creek, MDSR 213 crossing, Queen Anne's Co., MD (Ortmann, 1919; ANSP 66311)
9. Red Lion Branch, Dudley Corse Road, Queen Anne's Co., MD (UMES 2395)
10. Red Lion Branch, Red Lion Branch Road, Queen Anne's Co., MD
11. Unicorn Branch, Unicorn Community Lake, Queen Anne's Co., MD (ANSP 358299, 358300, 358301; UMES 2378, 2379)
12. Chester River, MDSR 313 bridge, Millington, Kent-Queen Anne's Cos., MD (ANSP A9484, 358297, 358298, 358308; UMES 2307, 2308, 2309)
13. Andover Branch, Peacock Corner Road crossing, east of Millington, Kent Co., MD (ANSP A9482, 355555, 355801, 358291, 358292, 358293; UMES 2480, 2481, 2482)
14. Chester River, US 301 bridge, Kent-Queen Anne's Co. line (ANSP 346890)

CHOPTANK RIVER SYSTEM

15. Choptank River, "Choptank Mills," RT 207 at Mud Mill Pond, Kent Co., DE (Rhoads, 1904; Clarke, 1981; ANSP 85224, 85226, 85264)
16. Tuckahoe Lake, Tuckahoe Creek, Tuckahoe State Park, Crouse Mill Road bridge, Caroline-Queen Anne Cos., MD (UMES 2375)
17. Norwich Creek, RT 404 bridge, Queen Anne's Co., MD (ANSP A9487, A9488, A10261, A10262, 355556, 355802, 358285, 358286, 358287, 358288, 358289, 358290; DMNH 41138; UMES 2471, 2472, 2473, 2474)
18. Mason Branch, Tuckahoe Creek, MDSR 304 bridge, Caroline-Queen Anne's Cos., MD (ANSP 358294, 358295, 358296; UMES 2265)
19. Watts Creek, Legion Road bridge, Caroline Co., MD (UMES 2380)
20. Williston Lake at spillway, Denton Road, Caroline Co., MD (UMES 2400)
21. Hog Creek, Hog Creek Road bridge, Caroline Co., MD (ANSP 358306; UMES 2483)
22. Beaverdam Branch, 1.5 km west of Matthews at MDSR 328 bridge, Talbot Co., MD (ANSP 358309; UMES 2484)

NANTICOKE RIVER SYSTEM

23. Concord Pond, just north of DESR 20, CR 516, 1.6 km east of Seaford, Sussex Co., DE (Davis, 1984; ANSP 345054, 352551, 358277)
24. "Deep Creek," just below Concord Pond spillway, RT 516, east of Seaford, Sussex Co., DE (Davis, 1984; ANSP 346863, 346864, 346865, 346866, 346867, 347863, 347864, 347865, 347866, 347867, 349333, 349337, 349338, 358272, 358273, 358274, 358276, 358278; UMES 2476)
25. Gravelley Branch, Collins Pond, just east of Coverdale Crossroads, Sussex Co., DE (UMES 2243)
26. Marshyhope Creek, DESR 16 bridge, just east of Hickman, Kent Co., DE (UMES 2233)
27. Nanticoke Branch, DESR 18 bridge, just east of junction with CR 533, Sussex Co., DE (UMES 2235)
28. Nanticoke River, US 13 bridge, Seaford, Sussex Co., DE (Rhoads, 1904; ANSP 84837, 88219, 88370, 301003, 301004, 345058; DMNH 75214)
29. Trap Pond, Trap Pond State Park, Sussex Co., DE (UMES 2266, 2267)
30. Chipman Pond, CR 465 bridge at dam, Sussex Co., DE (UMES 2262, 2263, 2264)
31. Meadow Branch, just downstream of Horsey's Pond, DESR 24 bridge, Laurel, Sussex Co., DE (UMES 2276, 2277, 2279)
32. Quantico Creek, Quantico Creek Road, east of Quantico, Wicomico Co., MD (UMES 2469, 2470)
33. Rewastico Pond, Rewastico Creek at dam, Athol Road, Wicomico Co., MD (UMES 2252)
34. Barren Pond, Barren Creek at dam, Wicomico Co., MD (UMES 2249, 2250, 2451)
35. Tyndall Branch, Fleetwood Pond, CR 484 at dam, Sussex Co., DE (UMES 2298, 2297)
36. Record Pond, at dam, Laurel, Sussex Co., DE (UMES 2293)
37. Gales Creek, Galestown Pond, Galestown-Reliance Road at spillway, Galestown, Dorchester Co., MD (UMES 2287, 2289)

38. Butler Mill Branch, Craigs Pond, public boat access at spillway, CR 542A, Sussex Co., DE (UMES 2290, 2291)
39. Nanticoke River, Williams Pond, Tharp Road bridge, Seaford, Sussex Co., DE (UMES 2300)
40. Bucks Branch, Hearn Pond, CR 544A at spillway, Sussex Co., DE (UMES 2299)
41. Smithville Lake, Opossum Hill Road at dam, Caroline Co., MD (UMES 2377)

WICOMICO RIVER SYSTEM

42. Wicomico River, Riverside Boat Ramp Park, Salisbury, Wicomico Co., MD (UMES 2241)
43. Leonard Pond Run, Leonard Pond, Leonard Pond Park, US 13 bridge, Salisbury, Wicomico Co., MD (DMNH 48638)

POCOMOKE RIVER SYSTEM

44. Nassawango Creek, Red House Road bridge, Worcester Co., MD (UMES 2374)
45. Unnamed tributary (A) of Nassawango Creek, Nassawango Road just southeast of Pennewell Road, Worcester Co., MD (UMES 2219)

Delaware River and Bay, Atlantic Ocean Drainage

CHRISTINA RIVER SYSTEM

46. Brandywine Creek, Brandywine Park at Dam near Brandywine Zoo, Wilmington, New Castle Co., DE (DMNH 44090)
47. Red Clay Creek at Yorklyn, New Castle Co., DE (Clarke, 1981; ANSP 85227, 85228)
48. Becks Pond, SR 48 at dam and swimming beaches, New Castle Co., DE (UMES 2269, 2270)

APPOQUINIMINIK RIVER

49. Shallcross Lake at Greylag, CR 428 bridge at dam, New Castle Co., DE (UMES 2282, 2283)
50. Silver Lake, CR 442 bridge at dam, east of Middletown, New Castle Co., DE (UMES 2281)
51. Wiggins Mill Pond, Road 446, below spillway, New Castle Co., DE (UMES 2406)

BLACKBIRD CREEK

52. Pond, Road 463A, below spillway, New Castle Co., DE

SMYRNA RIVER SYSTEM

53. Paw Paw Branch, Road 40 bridge, east of Thomas Corner, New Castle Co., DE (UMES 2396)

LEIPSIC RIVER SYSTEM

54. Massey's Millpond, Road 42 bridge, Kent Co., DE (UMES 2407)

ST. JONES RIVER SYSTEM

55. Silver Lake, Silver Lake Recreation Area, Dover, Kent Co., DE (ANSP 45991, 45992; UMES 2376)
56. Tidbury Creek, Derby Pond, US 13A, south of Wyoming, Kent Co., DE

MURDERKILL RIVER SYSTEM

57. McGinnis Pond, Road 378, southwest of Lexington Mill, Kent Co., DE (UMES 2393)
58. McColley Pond, DESR 15 bridge at dam and spillway, Mordington, Kent Co., DE (UMES 2392)

MISPILLION RIVER SYSTEM

59. Blairs Pond, Road 443, west of Milford, Kent/Sussex Cos., DE (UMES 2382, 2385)
60. Griffith Lake, Road 443 at spillway, west of Milford, Kent/Sussex Cos., DE (UMES 2384, 2386, 2388)
61. Haven Lake, US 113 bridge at spillway, Milford, Kent/Sussex Cos., DE (ANSP 103011; UMES 2389, 2390, 2391)
62. Silver Lake, DESR 36 bridge at spillway, Milford, Kent/Essex Cos., DE (UMES 2401)

CEDAR CREEK SYSTEM

63. Cedar Creek, Cubbage Pond, CR 214 bridge, Sussex Co., DE (UMES 2284, 2285)

INDIAN RIVER SYSTEM

64. Millsboro Pond, DESR 24 at dam, Millsboro, Sussex Co., DE (ANSP 85835)
65. Ingram Pond, Public Fishing Area at dam, CR 328, Sussex Co., DE (UMES 2298)