Harman 1974

Bulletin of the American Malacological Union, Inc.
May 1974

THE EFFECTS OF RESERVOIR CONSTRUCTION AND CANALIZATION ON THE MOLLUSKS OF THE UPPER DELAWARE WATERSHED

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Lakes are ephemeral geological phenomena. The most stable, although dynamic, aquatic biotopes are our major rivers. As would be expected, our greatest diversity of freshwater mollusks occur in these environments. Unfortunately, many of our rivers, including the Delaware, are becoming chains of impoundments. In the Northeast these are constructed primarily for flood control and urban water supplies.

The construction of reservoirs in tropical climates has increased the populations of pulmonates that are vectors of schistosomiasis, causing serious health problems. However, the same impoundments eliminate mollusks specialized for existence in the erosional areas of rivers. Even snails adapted for life in impounded waters are often eliminated from comparatively deep, steep-sided reservoirs typical of those found in the Northeast. In lakes of this character, variable water levels preclude the development of stable shallow water communities. This has been so effective in removing snails that varying the water levels of impoundments has been used as a control measure for snails in tropical areas (Jobin, 1970).

One of the most serious effects of the construction of reservoirs is the destablization of substrates and increased siltation. Canalization, often associated with the construction of highways, has the same effects, and has also been used for snail control (Palmer *et al.*, 1969). As a result of these activities silt is often found in suspension. This has an abrasive action on molluscan shells that erodes the periostracum, allowing carbonic acids to quickly corrode the $CaCO_3$ layers underneath. It also affects light penetration, reducing primary productivity and decreasing the dissolved oxygen levels. When this silt is deposited, it fills the spaces between rocks reducing most of the surface area for the growth of organisms and eliminating many benthic species. Bivalves are quickly buried and gastropod eggs do not develop properly (Chutter, 1969). This same phenomenon also increases the possibility of adsorption and absorption of various toxic chemicals (Cairns, 1968).

These activities have adversely affected more than three-fourths of the Delaware watershed north of the Beaverkill. The major streams exhibit vast reaches practically devoid of mollusks. In these waters, which are used as water supplies for New York City, the water levels fluctuate as much as 20m annually, and daily changes of 2 m have been recorded. Aquatic plants, that provide food and cover for many mollusks, are unable to grow, and adult mollusks and their eggs are often stranded completely out of the water.

Drains from the deeper waters of these reservoirs normally maintain extremely low temperatures throughout the year in the streams below them. This reduces productivity, resulting in extremely low food supplies, very slow growth and inhibition of reproduction. Variable amounts of precipitation, typical of the Northeast, result in ephemerally large flows of water out of these reservoirs (compared to the usual restricted flow) which often flushes snails away in the downstream areas. This technique has also been artificially induced and utilized as a snail control procedure (Jobin and Ippen, 1964).

Figure 1 illustrates a typical situation in which the species of mollusks present in an area increase as one moves downstream from the headwaters. Apparently this is a result of the waters becoming larger, more chemically and physically stable, and therefore more conducive to inhabitation. The example is the relatively undisturbed Chenango River in east-central New York State. The coarse stippling indicates areas where 10 or more species of mollusks are found; the fine stippling indicates from 5 to 9 species; the outlined areas, from 2 to 4; and no pattern indicates 1 or less.

In the Delaware (Figure 2) we see the effects of reservoir construction and canalization. Note the normal increase in species numbers above the impoundments and how the populations are now isolated from each other in tributaries that enter the reservoirs. For 10 to 20 miles below the reservoirs the cold water precludes the development of stable populations although some specimens are found that have presumably washed from the tributaries. Canalization along route 17 (the heavy dark line) has disrupted species along its right of way. It can be seen that where meanders of the river were left undisturbed, greater numbers of species still maintain themselves.

The group most seriously affected appears to be the larger bivalves. The only habitat that retains an apparently normal bivalve fauna is just above the Cannonsville reservoir. In that locality we have collected *Anodonta cataracta*, *Alasmidonta undulata*,

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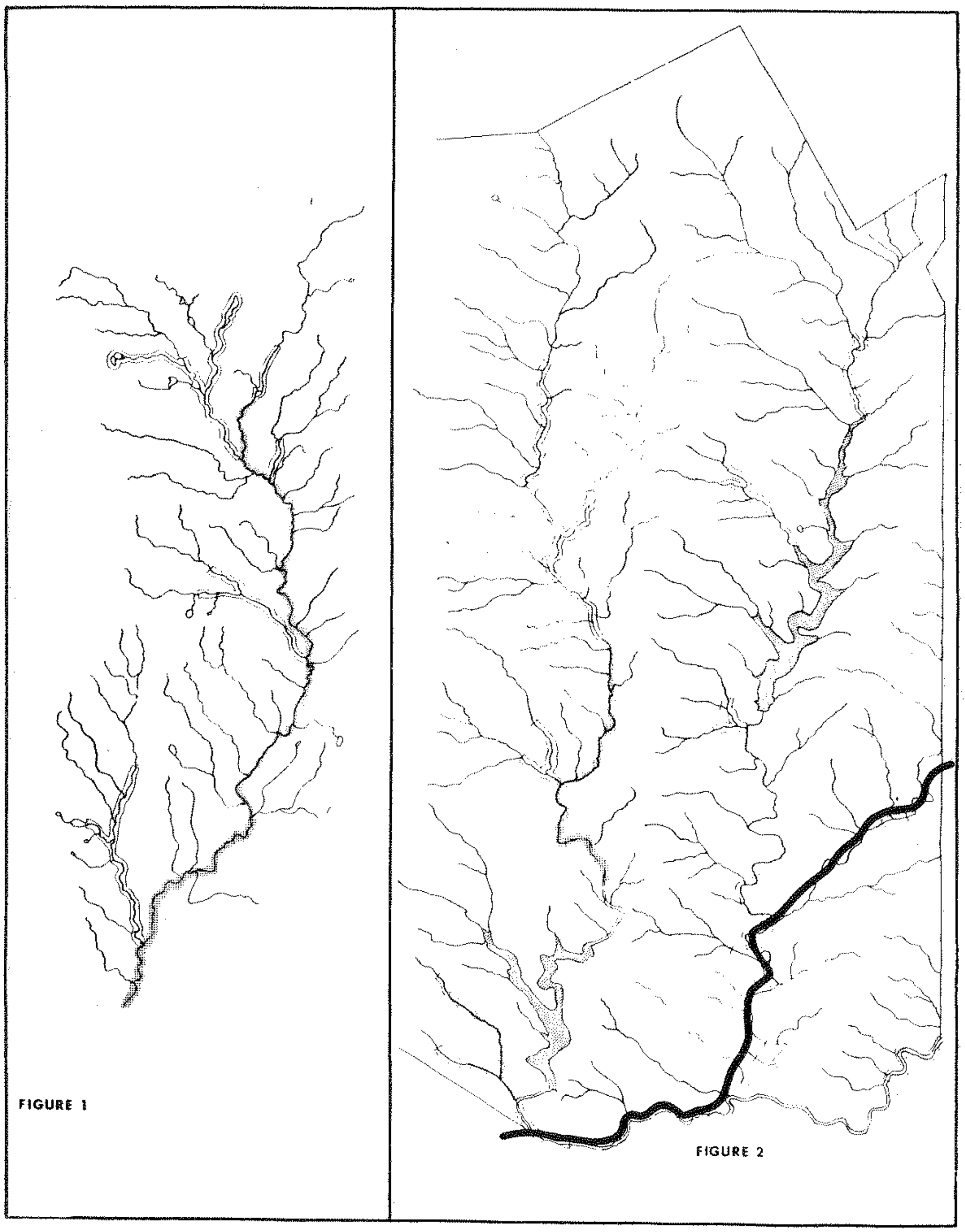

Fig. 1, Chenango River, New York. Fig. 2, Upper Delaware River, New York.
See text for explanation.

A. marginata, *Strophitus undulatus* and *Elliptio complanata*, along with the prosobranchs *Campeloma decisum* and *Amnicola limosa* and several pulmonate snails, including the limpet *Ferrissia rivularis*. In many other localities bivalves are absent and mollusks are represented only by a few tolerant pulmonates such as *Gyraulus parvus*, *Helisoma* spp. and *Physa* spp.

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BIOLOGICAL AND PHYSICAL CAUSES OF MORTALITY IN NEW ENGLAND *CREPIDULA* SPECIES

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Mortality in *Crepidula* species is notable for its seasonal and year-to-year variability (Adam and Leloup, 1934). It is of interest economically since *Crepidula* are attacked by many of the same predators as oysters, yet the two groups differ in susceptibility to physical mortality factors (Korringa, 1946). This present report summarizes preliminary qualitative investigations into causes of death in adult populations of *C. fornicata*, *C. plana*, and *C. convexa*, the three species found in New England.

Table 1 details known causes of death and reduced viability in New England *Crepidula*. Except where a literature citation is given, data were obtained from field observations at Nahant, Woods Hole, Vineyard Haven, and Duxbury, Massachusetts, supplemented by laboratory tests.

Some factors are not by themselves usually fatal, but contribute to mortality in concert with other factors (see asterisks in Table 1). Such synergistic effects have been demonstrated in the laboratory. For example, *C. fornicata* stressed by low oxygen were more adversely affected by a temperature increase from 10°C to 20°C than were animals held under continuous aeration. Oxygen needs increase with temperature in metabolic processes. *Crepidula* maintained on suboptimal food were more easily pried loose by crabs and starfish than well-fed animals. In nature, those animals whose shells are infested by *Cliona* or *Polydora* must put energy into shell repair that they would otherwise use in body maintenance and reproduction. Also, a shell riddled by *Cliona* provides increased surface area for fungal growth.

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Interspecific competition for space is often a factor in death of *Crepidula*. It forces them into marginal habitats, where they are less well protected against physical causes of mortality and more available to predators. Marginal habitats for *C. fornicata* at Nahant are the rocky-shore tidepools surrounded by soft, unsuitable substrate and by submerged rocks covered with algae. Temperature fluctuations and exposure to the air at low tide cause high mortality of spat in these tidepools. Fast-growing barnacles and colonial tunicates sometimes grow over *Crepidula* and kill them outright, as observed on spat collectors put out at Woods Hole.

Crepidula maintained in water tables in the laboratory are often attacked by fungi, bacteria, and protozoa. Only in areas of restricted circulation are these factors expected to be important in nature. *Crepidula* are also attacked by trematode cercaria; they commonly cause resorption of the gonads without killing the adult. Chemicals such as copper sulfate are used commercially to kill *Crepidula* on oyster shells (Walne, 1956). All three New England species thrive in water containing organic pollution and oil scum, although large amounts of oil interfere with respiratory and feeding functions of the gill.

Exact ranking of mortality factors is not yet possible, but different rank orders are expected for different geographical areas and substrate types. Off Vineyard Haven, in 10 to 20 feet of water on a muddy bottom, starfish are very abundant and predacious gastropods are rare. Less than 1% of empty shells examined had been drilled. In Woods Hole, drilling gastropods are relatively unimportant macropredators compared with flatworms, crabs, and starfish, yet about 5% of all *C. fornicata* beach shells collected in one year were drilled. The percentage was less for the other species. The proportion of drilled