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BIOLOGICAL PROBLEMS IN WATER POLLUTION

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USE AND VALUE OF BIOLOGICAL INDICATORS OF POLLUTION:

FRESH WATER CLAMS AND SNAILS

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I. INTRODUCTION

In discussing fresh water clams and snails (mollusks), not enough is known yet about molluscan ecology to name any species a pollution indicator. There are mollusks tolerant to certain effects of pollutants such as septicity, but even these are not pollution indicators. Species that are found associated with domestic sewage in septic reaches of water, as *Musculium transversum*, *Pisidium idahoensis*, *Physa integra*, and *Physa heterostropha*, are also found in high dissolved oxygen areas of lakes and streams unpolluted by domestic sewage or putrescible industrial wastes.

On the other hand certain mollusks, such as the Unionidae[a/], are not associated with near-septic water resulting from pollution. These have an index value in that their presence typically indicates good dissolved oxygen and attendant physical and chemical conditions associated with unpolluted water. Such mollusks can be called clean water index organisms.

Apart from systematic morphological studies, it is not realistic to isolate a single group of organisms such as mollusks from other animals and plants that are associates under similar ecological conditions in clean or polluted water. It is the study of the total biota which tells one most about water conditions.

a/ Members of the family Unionidae have had various common names applied to them: Mussels, fresh water clams, and naiads.

In this respect, the presence of an assemblage of rat-tailed maggots, Eristalis tenax; sewage mosquitoes, Culex pipiens; sludge worms, Tubifex tubifex; blood worms, Chironomus plumosus; physid snails, Physa integra; and finger-nail clams, Musculium transversum, and an absence of Unionidae, mayflies, caddis worms, stoneflies, and shiners would indicate to investigators stream reaches highly degraded by domestic sewage, for example. Thus, certain associations of organisms that tolerate such pollutional conditions as septicity and the absence of intolerant forms can be looked upon collectively to form pollution tolerant biological assemblages, even though any single mollusk species or other members of the assemblage may not be called a pollution indicator. The presence of intolerant mollusks, with other intolerant animals, lend themselves usefully in sanitary science to establishing parameters around areas of septicity and sludge deposits resulting from domestic sewage.

Information is not available that can be presented to indicate that various species of mollusks can be used to indicate varying degrees of water quality, i.e. from high dissolved oxygen values by gradations to septicity, such as can be measured by chemical tests. Also, various species cannot be used to measure variations in fecal contamination as can certain bacteria.

The majority of studies made in United States waterways dealing with the effects of pollution on mollusks are related to domestic sewage. The principal effect of such pollution on water quality, investigated in relation to mollusk survival, is that of lowered dissolved oxygen. Some attention has also been given to the effects on mollusks of bottom deposits attendant to domestic sewage and silt pollution. Little information dealing specifically with the effects of industrial wastes or their components on fresh water mollusks has been found.

The information presented below can assist those working with biological indices of pollution to group mollusks as either pollution-tolerant or clean-water forms. Consideration is given to the following aspects of this subject: references relating mollusks to pollution; structural and life cycle variations relating to survival in polluted water; natural variations in distribution not related to pollution; and identification sources.

II. DISCUSSION OF SELECTED REFERENCES

Selected references that may be readily available to those working in sanitary sciences are cited here that especially deal with waterways of the United States. No attempt is made to present a complete literature review covering pollution and its effects on mollusks. Many of the included references should point out to those studying bottom organisms the importance of recording chemical and physical data that can be analyzed in relation to tolerances of specific mollusks to pollutants.

Available literature relating mollusks to water chemistry is woefully lacking. When the word "pollution" is used, the general inference is to domestic sewage. Except in a few specific studies of industrial wastes, cognizance often is not taken of the effects of such wastes in association with domestic sewage, even though they may have been related to the presence or absence of mollusks.

In order to make data concerning the effects of pollution on mollusks comparable, pollution should be defined both chemically and physically. It is also necessary to identify mollusks to species, if pollution-tolerant ones are to be exactingly separated from intolerant ones. Specific identification is particularly important to those who hope to find indicators of degrees of pollution.

If work, under field conditions, on the relationship of mollusks to physical and chemical factors is contemplated, Boycott (1936) should be consulted early in the planning stages. Even though relatively few of the species he deals with are found in North America, the information he presents associating mollusks with water chemistry should provide valuable background information for North American studies.

(1) References Relating Mollusks to Pollution in General

The following references relate mollusks to pollution in general without consideration of chemical and physical data. Such papers are valuable, in that they contain references to mollusks already identified to genera or to species by outstanding authorities in Conchology. By being aware of such references aquatic biologists working on water pollution problems have mollusk names available from certain areas, that may give them a lead to identification of current collections.

In relation to water pollution in general with special reference streams in western Pennsylvania, Ortman (1909) wrote that the nionidae are the first to be eliminated from polluted waters. Further, states that the genera Pleurocera, Goniobasis, and Anculosa are sually absent in polluted rivers, but were found surviving when the nionidae and fishes were, for the greater part, gone from the llegheny River in Venango County, Pennsylvania. The genera ymnaea, Physa, and Planorbis are noted to be more resistant because ey are air-breathers. Physa is the hardiest and is stated to be a enus "... which represents in certain instances the only remaining fe in certain rivers. But there also seems to be a limit to its power endurance, and in very badly polluted streams also Physa is absent."

Baker (1911), in quoting French investigators, states that naerium, Pisidium, and Planorbis resist the effects of water contam-ted with sewage, oil, and chemicals better than Lymnaea. Baker (1911) ports, from his own observations made at Rochester, New York, that Genesee River into which sewage has been discharged for the past"... or fifteen... years is ... at the present time ... of the consistency dirty, greasy dish water, yet Galba catascopium and Planorbis lis live and thrive by thousands in this seemingly unfavorable ronment. The writer's observations have been that chemicals and oil deadly to molluscan life, while sewage does not materially affect em." In a footnote to this statement, Baker comments that since writ-ng the above, sewage in the Genessee River has become "...of such a ghly concentrated form that the mollusks have all disappeared in the iver for a mile or two below the point of discharge into the river."

In a second report on the pollution of the Genessee River at ochester, New York, Baker (1922) states that he has studied its ollution for 27 years, from 1892 to 1919. He mentions that pollutants re "... sewage ... discharged into the river in a crude condition ...," nd that "refuse and other waste matter, both liquid and solid, also nter the stream from gas works, tanneries, and manufacturing plants... ." ollusk collections that he made in 1892, before pollution became appar-nt, represented 9 species: Musculium transversum, M. partumeium, ythinia tentaculata, Planorbis trivolvis, Physa gyrina, P. sayii, P. oneida, Galba caperata, and G. catascopium. In 1907 the above pecies of Musculium and Bythinia had disappeared, with the air-reathers Planorbis, Physa, and Galba still present but reduced in numbers. n 1910 all mollusks had disappeared and none were found in subsequent ollecting trips from 1910 to 1913. Baker (1922) describes studies that G. C. Whipple made on the river in 1912 after molluscan life had disap-peared. He reports that Whipple found the dissolved oxygen varying rom 5 to 41 per cent of saturation in August.

On one day in this month saturation did not exceed 5 per cent in a 3 mile reach from the surface to bottom in a depth of about 26 feet. He states that in 1917 a large part of the Rochester sewage, 32 million gallons a day, was diverted from the river to a sewage treatment plant, the effluent of which was discharged into deep water of Lake Ontario. In 1919 Baker reports the following mollusks occupying the reach of stream that had become devoid of them before sewage treatment was installed: Musculium transversum, Bythinia tentaculata, Galba catascopium, Planorbis trivolvis, Physa integra, and P. oneida.

According to the study by Wilson and Clark (1912) on the mussel fauna of the Kankakee Basin in relation to destruction by dredging operations, "The most fatal condition is the constant movement of the fine sand and silt along the bottom of dredged channels." They further state, "Portions of the basin which were dredged 15 or 20 years ago show no signs of restocking with mussels, though there are thousands of them close at hand in old channels."

Considering the effects of pollution on the mussel fauna of the Big Vermilion River and its tributaries in Illinois Baker (1922) states that, "sewage pollution has killed all clean water life for a distance of fourteen miles below Urbana and has made the stream an unfavorable environment for a distance of twenty miles. Below this point the fauna is normal and is not affected by sewage pollution." He observed that of that large species of Unionidae, Amblema undulata and Lasmigona complanata resisted pollution conditions better than others. In a pre-liminary paper to this report, Baker and Smith (1919) also wrote on the same subject.

Baker (1928), in the pelecypod part of his monograph on Wisconsin fresh water snails and clams, mentions that stream pollution by sewage and manufacturing wastes produces unfavorable conditions for mollusks. In reference to industrial wastes, he writes that coal tars and oils in particular quickly make a stream totally unfit for any kind of animal life.

In his work on the mollusca of Michigan Goodrich (1932) states that Lymnaea stagnalis appressa are being reduced by drainage enter-prises and pollution. He adds that this gastropod probably disappeared from great areas in a few years because waterways were used for logging purposes and sawdust disposal.

Van der Schalie (1936) notes that over the years domestic sewage and industrial wastes in general, along with other factors, have had a detrimental effect on the naiad fauna of the St. Joseph River Drainage in [illegible] Michigan. Effects of pollution on specific mollusks are not discussed.

Van der Schalie (1936a), when discussing factors contributing to the depletion of naiades in the eastern United States in relation to the fauna of the Mississippi River, states, "[illegible], particularly [illegible] the several large cities located on the river and its tributaries [illegible], was responsible for a heavy mortality in glochidia [illegible] by bacteria and infusoria." In discussing [illegible] relating to the effects of silt on the [illegible] of the Mississippi River he further states that "The river is practically devoid of mussels from the region of St. Louis, Missouri to its mouth, a condition accounted for by the [illegible] of silt carried to the stream and [illegible] of the Missouri River which enters the [illegible] near St. Louis. . . . ." Writing about the "South Atlantic Coastal drainage" he mentions that mine wastes from coal mines in the [illegible] of the [illegible] have damaged the fauna of this stream. With reference to the mussel fauna of the Great Lakes [illegible] rivers in Michigan he comments that industrial wastes and sewage are particularly damaging to mussels in the Saginaw drainage, St. Joseph, the Kalamazoo, the Grand, and Rouge Rivers; wastes from beet sugar refineries are felt to be responsible for "unproductive" areas in the Raisin and Pine Rivers. In reference to the above drainage area he states, "[illegible] action has been taken by the State to curtail such destructive [illegible] (pollution), though usually much [illegible] before preventive action has become [illegible]." [illegible] the effects of factors affecting mussels [illegible] van der Schalie writes, ". . . silting, pollution by sewage and industrial wastes, power dam developments and [illegible] mussel gathering for the pearl button industry have resulted in the [illegible] depletion of the formerly abundant Naiad fauna."

In writing about the depletion of the mussel resources of Michigan van der Schalie ([illegible]) mentions that among the outstanding factors are pollution in streams by sewage and industrial wastes and the [illegible] program of power dam developments. He further comments that mussels are among the most sensitive of organisms to pollution and are among the first to perish where pollution is in evidence.

Van der Schalie ([illegible]) points out that the Cahaba River in [illegible] Alabama, as of 1938, was [illegible] but that there are several potential dangers to Cahaba [illegible]

the possibility of acid pollution from the Cahaba coal fields, [illegible] and sewage from [illegible], and dam construction. He writes, "In view of these possible changes, studies of [illegible] conditions are highly desirable."

[illegible] ([illegible]) [illegible] that the lumber industry has affected mussels [illegible] and rafting. However, he does not assess damages.

From several studies of the Grand and [illegible] Rivers in Michigan van der Schalie (1941) writes that many [illegible] are causing the depletion of the indigenous fauna. Thus, it becomes increasingly important [illegible] and distributional data about them before [illegible]. Factors in addition to [illegible] in the Grand River, are many kinds of [illegible] and sewage in reaches below Jackson, Lansing and [illegible]. Gathering [illegible] with [illegible] in relation to the Muskegon River, he lists power dams and pollution as being detrimental to mussels and hindering their distribution through obstructing fish, the ". . . . . . . carrying agents for fresh-water mussels."

Van Horn (1946) associates the air-breathing snails *Physa* and *Planorbis* with [illegible] of recent pollution, and states, "In this zone also, as the oxygen [illegible] is decreased, one may find sewage fungi . . . such as *Sphaerotilus*, *Leptomitus*, *Thiothrix*, and others."

According to van der Schalie and van der Schalie (1950), reporting on the mussels of the Mississippi River, "The several surveys of the Mississippi [illegible] that the changes brought [illegible] in this drainage through adverse conditions, such as silting, pollution, intensive exploitation of the mussel fauna, power dam construction, etc., are all tending to alter decidedly, as well as to reduce, the original fauna."

Beck (1954), in his ecological classification of the streams of Florida [illegible] in water pollution surveys, refers [illegible] of the genera *Physa* and *Planorbis* and the [illegible] to a "Class III" which include [illegible] have been found in heavily polluted areas. He [illegible] no organism in this class may be considered [illegible] of pollution, since organisms contained therein may be found in clean, [illegible], or greatly polluted water. Conversely, [illegible] "Class I" containing organisms that have been found to tolerate [illegible] organic pollution, [illegible] the more sensitive forms." He states that, "The presence of class I organisms is considered to indicate that the water in which they are found is clean

Carlander (1954) writes about the general effects of pollution, including silt, on the mussels of the upper Mississippi River using material published by the U. S. Fish and Wildlife Service as a basis for her discussion.

In presenting his list of mollusks (Table-1) that can survive "....at least to some degre..." in zones of degradation and recovery, Wurtz (1956) points out that "....we are woefully lacking in knowledge on this subject." He further writes that the exact tolerance limits of the mollusks he lists are not known, and that as far as he can ascertain no mollusks are able to withstand protracted gross pollution. From among the 34 species and subspecies of mollusks he has considered, he states that Physa heterostropha is the most tolerant species that has been found.

TABLE I[*]

Mollusks Reported to Survive "at least some degree" in Zones of Degradation and Recovery

GILL-BREATHING SNAILS	Family - Physidae	FRESH WATER CLAMS
(Ctenobranchiata)	1. Physa gyrina	Family - Sphaeriidae
Family - Viviparidae	2. P. heterostropha	1. Sphaerium rhomboideum
1. Campeloma integrum	3. P. integra	2. S. corneum
2 C. rufum	4. Aplexa hypnorum	3. S. striatinum
Family Amnicolidae	Family - Planorbidae	4. S. sulcatum
1. Bulimus tentaculatus	1. Helisoma anceps	5. S. (Musculium) securis
	2. H. trivolvis	6. S. (Musculium) tranversum
LUNG-BREATHING	3. Gyralus arcticus	7. Pisidium amnicum
(Pulmonata)	4. Menetus dilatatus	8. P. casertanum
Family - Lymnaeidae	Family - Ancylidae	9. P. compressum
1. Lymnaea caperata	1. Ferrissia fusca	10. P. fallax
2 L. humilis	2. F. tarda	11. P. henslorvanum
3. L. obrussa		12. P. subtruncatum
4. L. polustris		Family - Dreissenidae
5. L. stagnalis		1. Mytilopsis leucophaeatus[x]
6 L. auricularia		Family - Mactridae[x]
7 Pseudosuccinae columella		1. Rangia cuneata

* Mollusks of Wurtz (1956) that can survive "... at least to some degree ..." in zones of degradation and recovery. Wurtz's data have been organized to form this table by W. M. Ingram.

x Only one species in each family in the United States; the former with a range from Maryland to Florida, and the latter with a range from Alabama to Texas.

(2) References Relating Mollusks to Specific Aspects of Water Quality Associated with Pollution.

The following investigators have presented varying amounts of physical and chemical data that relate mollusks to certain aspects of water quality.

Tuday (1909 and 1921) reports a Sphaeriid clam, Corneocyclas [Pisidium] idahoensis, from septic water in Lake Mendota, Wisconsin; [illegible] he does not mention specific pollutional conditions. From laboratory observations he concluded that this clam may remain quiescent with its valves closed for as long as three months each summer in the septic bottom zone of the lake. He found that clams occurring in septic water with their valves tightly closed became active when placed in aerated water. Shelford (1913) has [illegible] Juday's (1909) [illegible] to survival of Pisidium idahoensis under anaerobic conditions.

[illegible] and Turner (1917) [illegible] [illegible] [illegible] Serpentina [illegible], and [illegible] [illegible] below a sewage treatment plant outfall where [illegible] dissolved oxygen values in October, June, July, and August were between 1 and 2 p.p.m. These writers do not present D.O. figures other than in monthly averages. The gastropod Campeloma decisum was not taken in any stream reaches where the [illegible] [illegible] 5 p.p.m.

[illegible] (1930) discusses mollusks and other organisms associated with clean water and polluted water reaches of the Sangamon River, Illinois. This author mentions that there is some domestic sewage pollution from the effluent of a septic tank in the town of Monticello entering the clean water area, but such pollution only affects the water in a restricted area. Chemical conditions of clean water reaches are stated to be, "...alkalinity to methyl orange of 222 p.p.m. and a pH of 8... transparent to a depth of a foot or more." Bottom materials are said to consist of gravel. Close to shore it was observed that a "...layer of organic deposit covered the bottom .... " Mollusks associated with pools in such water were the Unionidae species, [illegible] Quadrula pustulosa, Q. [illegible], Q. [illegible], [illegible], [illegible], [illegible], and Anodonta grandis. [illegible] species of Sphaeriidae, [illegible] species of [illegible], and Campeloma subsolidum.

Below the reach of the Sangamon described above, sewage of Decatur is discharged. Bottom animals were stated to disappear immediately and "...not until Monticello is reached about 30 miles below

[Decatur] do the first [illegible] appear." No mollusks are listed in [illegible] list for 75 miles below Decatur. In this distance figures are listed showing variations in chemical and physical conditions: D.O. [illegible] to [illegible] p.p.m., alkalinity from 249 to 348 p.p.m., pH [illegible], odor [illegible] and [illegible] to not pronounced, appearance from sewage to [illegible] to milky to gray to turbid to green gray. At the 75-mile [illegible] the first [illegible] reappear, chemical and physical [illegible] show D.O. of 7.8 p.p.m., an alkalinity of 227 p.p.m. [illegible] The mollusks occurring at [illegible] [illegible] Quadrula [illegible], Q. lachrymosa [illegible] [illegible] Anodonta [illegible] [illegible] 15, [illegible] [illegible] [illegible] gastropods, Pleurocera elevatum and Campeloma [illegible]. Unionidae and gill-breathing snails at [illegible] station [illegible] that [illegible] with dissolved oxygen [illegible] that were not less than 5 p.p.m.

R[illegible] [illegible] a number of papers relating [illegible] of the Illinois River to bottom fauna, among which his 1921, 1925, 1925a, and [illegible] [illegible] as being of special interest to those studying mollusks. Richardson's 1925 paper [illegible] an attempt by [illegible] dissolved oxygen [illegible] [illegible] from Chillicothe into Spring Bay [illegible] few [illegible] that he presents under the [illegible] Three species of [illegible], M. [illegible], and Pisidium [illegible] D.O. of 0.2 p.p.m. The gill-breathing snail, Valvata tricarinata can be associated with a minimum D.O. of 1.4 p.p.m. The [illegible] Campeloma subsolidum, which Richardson stated as being a surviving [illegible] [illegible] conditions, can be associated with dissolved oxygen figures between 0.5 to 3.0 p.p.m.

Baker (1927) presents a review of Richardson's 1925 papers on the effects of pollution on bottom organisms in the Illinois River. Data from the review state, "It is shown prior to 1915 there have disappeared from Peoria Lake (a widening of the Illinois River) about forty species of river mussels (only three or four species are left), all of the small snails belonging to the water breathing [sic. = gill-breathing] family Amnicolidae, all but one species of the large water snails belonging to the Viviparidae, the remaining species being recorded as Campeloma subsolidum, and a varied insect fauna. There remains certain species [illegible] more tolerant of pollutional conditions. These are Musculium transversum

Pisidium compressum, P. pauperculum crystalense, Campeloma subsolidum, and Sphaerium stamineum. Several species less tolerant to sewage conditions were observed in peculiarly favorable conditions, usually in strong current in midchannel or elsewhere where oxygen conditions were good. These included Anodonta imbecillis, an insect Corixa, a caddis-fly larva (Leptocerid), Goniobasis livescens, Pleurocera elevatum lewisii, Quadrula plicata (= peruviana), Hyalella, a sponge, and a Hydropsyche. These species, however, were observed to vary in presence during different years."

Suter and Moore (1922) state that Physa heterostropha may be found in septic regions and list it with Pisidium abditum, Goniobasis virginica, and Campeloma decisum as an organism tolerant of pollution; they do not mention that the latter three species can survive septicity.

Turner (1927) lists Physa heterostropha as found in septic water and Planorbis panus from stagnant water and the vicinity of sewer outlets. Campeloma decisum is described as being more sensitive than the other species since ". . . . it seems to thrive under clean water conditions."

Wiebe (1928), in his paper on the effects of pollution on the upper Mississippi River, collected Helisoma trivolvis, Musculium transversum and Campeloma integrum on August 27 at his Red Wing station with the D. O. at 2.83 p. p. m.; of 22 D. O. measurements made in August the average at this station was 2.25 p. p. m. with a minimum of 1.12 p. p. m. and a high of 4.01 p. p. m. Individuals of Musculium (near) transversum were collected at his Jackson Street station on August 17 with the D. O. at 0.87 p. p. m.; of 22 D. O. measurements made in August the average at this station was 0.87 p. p. m. with a range from 0 to 2.52 p. p. m. His data on tables 4 and 5 indicate that mussels (not identified) were taken in September at the Jackson Street station when the D. O. was 5.73 p. p. m. with the range of 20 readings for September varying from 0.44 to 8.14 p. p. m. He records collections of Anodonta imbecillis on September 17 at the Red Wing Station with the D. O. on this date being 4.39 and a range of 21 readings for September varying from 2.89 to 6.44 p. p. m. Campeloma rufum was taken at two stations where the D. O. was always above 5 p. p. m. for 61 measurements; Wiebe nevertheless comments in relation to this species, ". . . . very likely it is one of the more tolerant forms;" this conclusion is based on the fact that 1,600 specimens per square yard of bottom were taken some 50 yards below a sewage outfall at one station and were associated with 15,120 Tubificidae and 54 Sphaerium notatum per square yard. Pleurocera acuta is reported from two stations where the D. O. was always above 4.30 p. p. m. for 65 measurements.

Purdy (1930), in summarizing pollution data on organisms other than plankton in his Illinois River work, states that the Sphaeriidae are often very numerous in moderately polluted water. He further writes that these mollusks cannot stand "extreme" conditions that Tubificid worms can and that they will die when oxygen becomes largely depleted. He states that, "Apparently their Sphaeriidae large numbers in places where water is polluted is a question of their abundant food supply of microscopic organisms normally found there." Purdy's data for the Illinois River, as correlated by Ingram with those of Hoskins et. al. (1927), show that unidentified Sphaeriidae were collected at Chillicothe where the dissolved oxygen was recorded as low as 1.23 p. p. m. in August. The highest D. O. at this station was 7.79 p. p. m. in February. Unidentified air-breathing snails collected by Purdy (1930) at Lockport, as correlated with Hoskins's et. al. (1927) data, were taken at this station where septicity existed in August and the D.O. was 9.11 in February. The pollution in the Illinois River at the time the above data were collected was from numerous industrial wastes and domestic sewage.

Ellis (1931a) writes that juvenile and young mussels are quite sensitive to oxygen reduction and that adult mussels ". . . usually become inactive when the oxygen tension of the water is reduced to 20 per cent saturation or less." He emphasizes the detrimental effect of erosion silt on clams. In relation to the general effect of industrial wastes on mussels, he writes, "Whenever concentrated industrial wastes are poured into the streams the fresh-water mussels suffer because of their inability to change location quickly and because of the ease with which the blood of fresh-water mussels takes up the various substances in the surrounding waters. . . ."

Van der Schalie (1938) has presented chemical and physical data associated with unpolluted water and water polluted by domestic sewage in relation to the distribution of Unionidae in the Huron River, Michigan. Referring to the effect of pollution on mussels, he states, "Below Ann Arbor, sewage has been very detrimental to the fauna. It is true that sewage may, if not too concentrated, increase the productivity of sections of a stream by increasing the dissolved organic compounds, but below Ann Arbor and as far as the backwaters of Geddes dam, pollution is so concentrated that it has killed all Naiades. Furthermore, there is such a heavy deposit of sludge in this zone that it will be many years before bottom conditions will permit the re-establishment of a fauna even though the discharge of sewage into the river be discontinued."

Goodrich (1945), in his monograph on the gilled-snail Goniobasis livescens in Michigan, associates water chemistry with its occur[illegible] and with Pleuroceridae in general. He writes that this species has disappeared from the heavily polluted Huron River. He a[illegible] massive kills of Pleuroceridae in western Lake Erie with [illegible] of oxygen under ice cover. G. livescens has been found in streams with the alkalinity ranging from [illegible] p.p.m. He [illegible] that a drop in pH much below 7.0 does not permit survival of pleurocerid life [illegible] by studies made by C. E. Shoup in the Obey River in 1944, [illegible] with a pH above 7.0 were [illegible] mollusks were absent in water with a pH of 6.1. Members of the genus Goniobasis in general endure periodic [illegible] streams that [illegible]. Certain ones, G. virginica for example, may live in tidal reaches of streams where the salinity [illegible] per cent of that of sea water.

Whipple, Fair, and Whipple (1947) [illegible] of mollusk species that they have associated with the pollution zones of Kolkwitz and Marsson (Table 2). They list no mollusks [illegible] polysaprobic zone that they partially characterize by the [illegible] accumulations on the bottom and a lack of oxygen. They [illegible] that life in the mesosaprobic zone is commonly [illegible] or imperfectly purified sewage and its products [illegible] and state that "Many bacteria are still present [illegible] the oligosaprobic zone they write, "This is a zone of cleaner water in which mineralization has been completed [illegible] the water is practically saturated with oxygen, [illegible]" It should be noted from Table 2 that many mollusks associated with the mesosaprobic zone are also associated with the oligosaprobic. One Unionid clam and certain gill breathing snails [illegible] Campeloma, Viviparus, and Valvata [illegible] associated with the [illegible].

Patrick (1949) associated Physa heterostropha with [illegible] conditions at a station [illegible] Chemical data are presented in [illegible] such information presented for August, [illegible] be "[illegible] water" for this station, shows a [illegible] alkalinity 19.8 p.p.m.; Nitrogen (N as NH[illegible]) [illegible] (N as NO_2), 0.[illegible]; Nitrogen (N as NO_3) [illegible].

TABLE 2

Mollusks Related by Whipple, Fair, and Whipple to Pollution Zones of Kolkwitz and Marsson*

Mollusca	Oligo-saprobic	Poly-saprobic	Mesosaprobic: No sub-designation	Mesosaprobic: Alpha	Mesosaprobic: Beta		
FAMILY - SPHAERIIDAE						CLAMS	
Pisidium amnicum	x						
" compressum			x				
" fossarinum	x						
" pauperculum			x				
Sphaerium corneum				x	x		
" [illegible]	x				x		
" [illegible]	x				x		
" stamineum			x				
" [illegible]			x				
Musculium [illegible]			x				
" [illegible]			x				
FAMILY - UNIONIDAE							
Unio [illegible]	x						
" [illegible]	- - -	- - -					
" [illegible]					x		
Anodonta [illegible]	- - -	- - -					
FAMILY - MARGARITANIDAE							
Margaritana margaritifera	x						
FAMILY - PHYSIDAE						Lung Breathing Snails	SNAILS
Aplexa hypnorum	x				x		
Physa [illegible]	x				x		
" fontinalis	x				x		
FAMILY - LYMNAEIDAE							
Lymnaea [illegible]					x		
" [illegible]					x		
" palustris	x				x		
" [illegible]	x				x		
" [illegible]	x						
FAMILY - HELISOMIDAE							
Planorbis [illegible]	x						
" [illegible]	x				x		
" [illegible]	x						
FAMILY - ANCYLIDAE							
Ancylus [illegible]	x				x		
" [illegible]	x				x		
FAMILY - VALVATIDAE						Gill Breathing Snails	
Valvata [illegible]					x		
" tricarinata	x						
FAMILY VIVIPARIDAE							
Viviparus [illegible]				x	x		
" [illegible]					x		
Campeloma [illegible]				x	x		

* Not all species are presented here (arranged by W.M. Ingram)

Gaufin and Tarzwell (1952) reported Physa integra from all stations on Lytle Creek, Ohio, during studies conducted in May and August, and list it as abundant at a station where D.O. was recorded as low as 0.2 p.p.m. Sphaerium solidulum, as reported, was not collected at stations where the D.O. was less than 4.5 p.p.m. as based on diurnal sampling.

On the basis of collections from Lytle Creek Ingram, Ballinger, and Gaufin (1953) report Sphaerium solidulum intolerant of pollution from domestic sewage including septicity and sludge deposits, and tolerant of bottom areas covered with zoogleal organisms. Certain literature relating to the tolerance of the sphaeriidae to pollution is discussed.

Gaufin and Tarzwell (1955) show that during January and February of 1952 Ferrissia rivularis, Sphaerium solidulum, and Pisidium casertanum were not taken in Lytle Creek reaches that had had a septic record in August of 1951, even though the minimum winter D.O. was above 7.0 p.p.m. They present data for October of 1951 showing that Ferrissia rivularis, Musculium transversum, Pisidium casertanum, and Lymnaea humilis modicella also were not collected from reaches that had a septic record in August of 1951. A few Sphaerium solidulum were collected from a station that had had an August septic record

(3) References Relating Mollusks to Wastes from Specific Industrial Operations

Few available references discuss mollusks in relation to specific wastes from industrial operations in natural waters.

In Culter's (1930) work concerning the blanketing effect of pulp and paper mill wastes in Ticonderoga Creek, New York, he states that Campeloma decisum was abundant where pulp was the thickest. In addition, the following mollusks are listed in a table as being associated with "a pulpy bottom 8 inches thick ... " Amnicola limosa, Planorbis antrosus, Calyculina hirsutus, Lymnaea decidiosa and Sphaerium fabale. Sphaerium striatinum is listed as occuring on a stream bottom covered by pulp up to one inch thick. Cutler states that at a station in Lake Erie at the mouth of the creek there was no molluscan life; by inference, he attributes this to the drifting action of pulp. At a second station in Lake Erie, also at the mouth of the creek but protected from pulp deposits, he reports the occurrence of the following mollusks: Valvata tricarinata, Amnicola limosa,

Bythinia tentaculata, Calyculina securis, Planorbis campanulatus, Planorbis hirsutus, Lymnaea (Acella) haldemanni, Lymnaea decidiosa, Sphaerium stiratinum, and Sphaerium fabale. No consideration was given to possible effects of toxicity on mollusks

Henderson (1949) has observed that mollusks once killed by wastes from certain viscose operations do not re-inhabit sections of streams rapidly. Through bioassays, he found that quantities of zinc proportional to quantities in the Shenandoah River from a viscose operation proved fatal to snails, daphnia, and bass fry.

Bartsch and Churchill (1949), in studying the effects of waste sulphite liquor on the biota of the Flambeau River, Wisconsin, made observations relating such a waste to mollusks. They state that Campeloma integrum, with three unnamed snail species, apparently resist high concentrations of waste sulphite liquor, although they are not found immediately below the industrial sewer outfall. The sphaeriid clam, Sphaerium rhomboideum, was likewise noted to be absent from such an area.

Neel (1953), in pollution studies relating to oil refineries of the North Platte River below Casper, Wyoming, writes that absence of larger benthic forms below "...the refinery area may be laid to periodic releases of large quantities of toxic wastes." He comments that a dearth of bottom organisms, including unnamed snails, is probably to be associated with blackish oil rather than to any lethal phenol concentrations. Conducted bioassay tests showed oil to be deadly to benthic snails.

(4) Low Hydrogen Ion Concentration not Associated with Pollution, Under Which Mollusks Have Been Reported Living

Mollusks have been reported living in natural waters where low pH values have not been associated with pollution. Data are presented to illustrate low pH values that many might not suspect mollusks could tolerate.

Based on Morrison's (1932) Wisconsin studies that do not associate with pollution the low pH values recorded therein, various mollusks are shown to live in natural waters with a pH as low as 5.6 (Table 3). Figures indicate that many mollusks live in waters with a pH as high as 8.3; no figure is cited above this pH value. Hydrogen ion figures taken from this work and shown in Table 3, are ones cited under each species in Morrison (1932).

Such a range of pH val[illegible] [illegible] by [illegible] that which [illegible] [illegible] to most fresh water than without lethal [illegible]. [illegible] state, "It appears that under [illegible] pH values above 5.0 and ranging upward [illegible] are [illegible] for most fully developed [illegible]. [illegible] these investigators [illegible] in relation to pH. [illegible] more extreme pH values, [illegible] 10.0, also can be tolerated in [illegible]. However, regardless of the nature of [illegible], such extreme [illegible] [illegible] are evidently [illegible] and [illegible] in waters which are naturally so acid." Most [illegible] (1933) and [illegible] upon fish for [illegible] of their life-cycles, were found in a pH range [illegible] 4.9. However, one member of the genus [illegible] [illegible] reported [illegible] a pH of 6.3.

Jewell (1922) has [illegible] in the Big Muddy River, Illinois, a stream characterized [illegible] naturally acid [illegible], with a pH range stated to be from 5.8 to 7.? Jewell presents [illegible] identification [illegible] Unionidae from the stream. In relation to [illegible] found in this river she writes, "Abundant as were mussels in the Big Muddy River [illegible] were found: one a living Pleurobema [illegible], the other a [illegible] subsolidum taken near [illegible]. No dead shells [illegible] to indicate that [illegible] present." This writer states that fish were "... everywhere [illegible]," and that [illegible] native [illegible] minnows, and fingerlings (at one time a school of [illegible]), and unidentified fry were seen [illegible]. [illegible] in length, were seen in [illegible] increasing numbers [illegible] the mouth of the [illegible]."

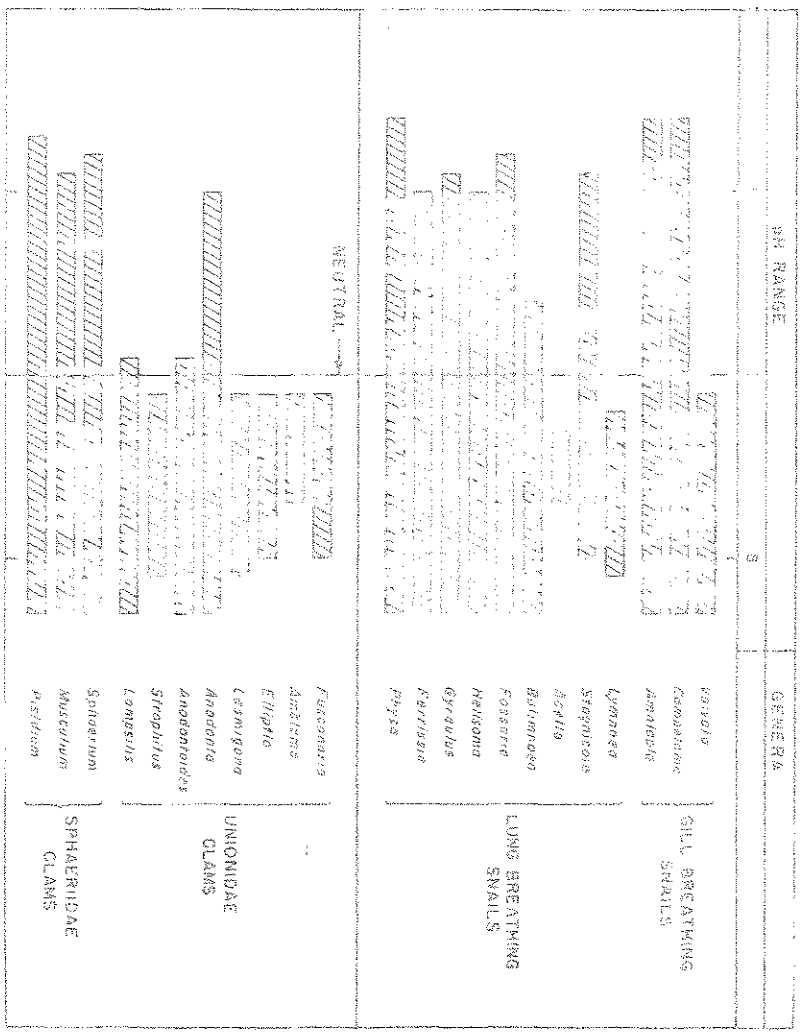
The writer has found Physa [illegible] Ohio, where the pH range [illegible] 4.1 to 7.5.

(5) Mollusks [illegible]

The [illegible] of [illegible] in trickling filter [illegible] domestic [illegible]. A number of [illegible] stated that the [illegible] snails in trickling filter beds [illegible], very little [illegible] in the literature to [illegible]

Table 3

pH RANGES ASSOCIATED WITH SELECTED MOLLUSK GENERA (AFTER MORRISON 1932)



which snails live in such situations. Study of snails in trickling filters offers ready access to those who wish to obtain data relating snails to water not completely purified from the effects of pollution. Certain chemical and physical tests, kept routinely at many secondary sewage treatment plants employing trickling filters, can be used to relate snails living in filters to specific ranges of water quality.

Brown (1937) studied Physa anatina living in sprinkling filters in sewage treatment plant at Urbana Champaign, Illinois, during parts of the years 1932-35. Brown writes that the plant has Imhoff tanks and sprinkling filters, ". . . where jets of the sewage are forced into the air for aeration.", and a secondary settling tank. Part of the final effluent is diverted into an experimental lagoon and part into the Saline Drainage Ditch, a tributary of the Big Vermilion River. Except for bacterial numbers no operational data are presented in the paper. In reference to bacteria it states, "At the time crude sewage enters the plant it contains 2, 100, 000 bacteria per cubic centimeter, but when finally treated, the number has been reduced to 700 per cubic centimeter." Brown (1937) believes that snails play a part in the reduction of numbers of bacteria. In addition to collecting Physa anatina in the rock beds of sprinkling filters, individuals were taken from the secondary settling tank and from the Saline Drainage Ditch and experimental lagoon receiving the final effluent. During the course of the study, in addition to Physa, 8 individuals of the snail Fossaria modicella were reported from the secondary settling tank, but from no other structures.

It is mentioned that in maintenance operations from 25 to 30 bushels of empty shells are removed each year in July and November from a conduit of the secondary settling tank. Brown believes that the majority of snails in the sprinkling filter beds die each winter. Reported observations based on shell size present evidence to indicate that life cycles of snails are completed in the sprinkling filter beds. Whether snails occur through the depth of the beds is not indicated.

A 1929 Annual Report of the Urbana-Champaign Sanitary District, as quoted by Brown (1937), mentions that passage of snails from the sprinkling filters into the secondary settling tank, ". . . proves beyond doubt the presence of a high amount of dissolved oxygen in the lower part of the filters." Associated with this quotation is the statement by Brown that Physa anatina breathes atmospheric oxygen. Referring to other records of snails reported from sewage treatment plants Brown mentions that Physa halei has been reported from a Fort Worth, Texas, installation.

Lohmeyer (1955) has written about the occurrence of an unidentified Physa in a high-rate trickling filter of the University of Florida's sewage treatment plant at Gainesville. In March of 1956 snails from this plant were sent to the writer; they were forwarded to W. J. Clench of the Museum of Comparative Zoology of Harvard University, who identified them as Physa cubensis, a species of wide distribution in Florida and the West Indies. Lohmeyer does not give operational data relative to the character of water that is applied to the filter. He mentions that dosing the filter for three days with a chlorine residual of approximately 3 p. p. m. resulted in snail control for eight months before operational difficulties were experienced. Mechanical difficulties relating to high-rate filter operation, resulting from Physa cubensis snails, are described in detail.

In May of 1955, individuals of varying sizes of Physa intergra were collected by the writer from the rock beds of both standard and high-rate trickling filters at the Dayton, Ohio, sewage treatment plant. Egg masses were present on the undersides of stones in the top three inches of the beds. Such information would seem to indicate that this species successfully carries on its life cycle in these trickling filter beds. The following operational data represent extremes that were recorded for water going onto the filters for two weeks preceding snail collections: B. O. D. 59 to 131 p. p. m.; total nitrogen 24.4 to 24.8 p. p. m.; ammonia nitrogen 13 to 17.9 p. p. m., chlorides 122 to 128 p. p. m., and D. O., 0. 0 p. p. m. The dissolved oxygen in water leaving the filters varied from 2. 7 to 4. 9 p. p. m. Hydrogen ion concentrations were not available for the stated period but for the month of April they were about 7. 1

III. SOME STRUCTURAL AND LIFE CYCLE VARIATIONS RELATING TO MOLLUSCAN SURVIVAL ABILITY IN ASSOCIATION WITH DOMESTIC SEWAGE POLLUTION

Some structural and life cycle variations that relate to differing molluscan abilities to survive septic conditions and a substrate of sludge may consist of differences in: the type of respiratory organs, ability to close the shell for extended periods, weight of shell, and life cycle. Because of such differences among mollusks when associated with domestic sewage pollution, certain of the lung-breathing snails survive better than gill-breathers and certain fingernail clams are more resistant than are the mussels.

(1) Survival of Lung-Breathing Versus Gill-Breathing Snails

Snails possessing lungs can generally be expected to survive under low dissolved oxygen or septic conditions because they typically rely on atmospheric oxygen in breathing. It is important for the aquatic biologist to become familiar with snail morphological characteristics in order to separate readily gill-breathing from air-breathing snails. An obvious character revealing whether the gastropod being dealt with is a gill-breather or a lung-breather is the presence of an operculum in the aperture of the former. Families and common genera of gill-breathing fresh-water snails are listed in Table 4 for convenience in separating them from those that typically breathe atmospheric oxygen.

Table 4

FAMILIES AND GENERA OF GILL-BREATHING SNAILS	
Family	Genera
Amnicolidae*	Amnicola
	Pyrgulopsis
	Hydrobia
	Somatogyrus
	Lyogyrus
	Bythinia (Bithynia)
Pleuroceridae	Pleurocera
	Goniobasis
Valvatidae	Valvata
Viviparidae	Vivipara
	Campeloma

* Amnicolidae genera listed from Berry, 1943; other families and genera from Baker, 1902.

It is important to point out to those conducting investigations in lakes or deep rivers that the presence of a lung in a snail does not necessarily mean that atmospheric oxygen will serve as the only source for respiration in all seasons. Periodic movement of lung-breathing snail, from shallow to deep water, may be induced by a lowering of water temperature to 10°C. as fall merges into winter and may be an annual occurrence as is reported by Cheatum (1934) in Douglas Lake, Michigan. A change in temperature from 10°C. to 21°C. is accompanied by an ascent from deeper water to marginal lake areas. Cheatum presents data indicating that when pulmonate snails are submerged, the lung functions as a gill in taking dissolved oxygen from water. Lung-breathing snails may remain submerged for three [illegible] of every twelve in areas where winter months are climatically similar to Michigan.

Experimental work conducted by Cheatum indicates that lung snails are not completely dormant when submerged, but rather are in a state of suspended animation [illegible] they actively respire using dissolved oxygen. [illegible] the following [illegible] survival and submergence of [illegible] breathing snails [illegible] by Cheatum [illegible] rather than atmospheric oxygen for a part of each year when submerged in Douglas Lake, Michigan: [illegible]

In summer, an experimental [illegible] individuals of each of the species named above survived [illegible] days with the water temperature varying between [illegible] 6°C. [illegible] experiments indicated that mortality was greatest [illegible] whose oxygen requirements were the highest. The [illegible] that submerged pulmonate snails can live under conditions of [illegible].

In writing [illegible] of life cycles, by certain pulmonate snails, when submerged, Cheatum (1934) states, "In all probability many individuals of the species H. campanulatum [illegible], H. antrosum percarinatum, [illegible] complete their life cycles and reproduce [illegible] come [illegible] for air."

[illegible] (1934) writes that pulmonate snails of the genus Ancylus ". . . are said to take water into their lung and thus do not need to come to the surface for air."

It is especially pertinent to point out literature, like the above, concerning lung-breathing snails that can obtain oxygen from either the atmosphere or from water, because in deep water during submerged living conditions in winter certain pulmonates could be killed by oxygen-consuming pollutants that could lower oxygen to asphyxial levels.

Thus, it may not be advisable to always include pulmonate snails with sludge worms, certain blood worms, rat-tailed maggots, and household or sewage mosquitoes as being tolerant to pollutional conditions involving septicity.

Of all snail genera, members of the genus Physa, especially, may occur in great abundance in septic zones of streams. Two species, Physa interga and Physa anatina, are commonly associated with septic zones in shallow streams in the mid-west during summer and fall months.

The writer has not collected any of the gill-breathing snails in polluted water where the dissolved oxygen, as measured during daylight hours was less than 2 p.p.m. Even though these mollusks possess an operculum which, if tightly sealed, should enable them to close themselves away from low dissolved oxygen waters, the fact that such snails are not reported from septic or near septic water would indicate that low dissolved oxygen may be one of several factors denying such water to them.

(2) Survival Relating to Shell Closure in the Sphaeriidae and Unionidae

The fact that certain of the Sphaeriidae can survive low dissolved oxygen conditions and a shifting bottom of sludge, as related to domestic sewage, and that the Unionidae do not points somewhat speculatively to the ability of certain fingernail clams to close the shell and survive until stream conditions improve.

Allen (1923), in studying reactions of certain Unionidae under low dissolved oxygen conditions writes, "When under conditions of deficient oxygen not only to the siphons widen to bring in more water, but also additional spaces between the mantle edges are thrown open." He does not mention whether all of the Unionidae that he studied opened the valves as indicated under the stated circumstances. The following Unionidae are listed as being used in general experiments: Anodonta grandis, Lampsilis luteolus, L. ligamentinus, L. altus, Quadrula [illegible], Q. pustulosa, Q. [illegible], Q. undulata, Unio [illegible], [illegible], Plagiola elegans, and others." If the Unionidae, in general, have a response to open their valves under low dissolved oxygen conditions resulting from pollution by domestic sewage and industrial wastes, they are most vulnerable to destruction. If they do open their valves as described by Allen, their bodies are vulnerable to any number of substances in polluted water that may be toxic enough to destroy them. Also, in an open position they could be covered by settable solids.

It is known that the Sphaeriidae can live under septic conditions and on sludge-cover[ed] bottoms as discussed earlier. Apparently, when living under conditions of septicity the valves remain tightly closed. Thus, the Sphaeriidae would not be subjected to toxic materials as they would if they lived under such conditions with their valves opened. Juday (1908) has written about the behavior of Cornocyclas [Pisidium] idahoensis under laboratory conditions in water containing and devoid of dissolved oxygen, and has related such data to field conditions. In water without dissolved oxygen, individuals remained quiescent with their valves tightly closed without activity being observed in the mud of the experimental jars. When individuals were placed in aerated water they became active. He states that his experiments seemingly indicate that this mollusk remains quiescent or dormant in Lake Mendota, Wisconsin, when the muddy zone at the bottom of the lake contains no dissolved oxygen, a period of about three months each summer. Juday (1921), in further studying Pisidium idahoensis in lake Mendota, writes that there is no free oxygen below a depth of 20 meters from about the middle of July until early October, and again in March for two or three weeks in some years. He mentions that organisms living under such conditions must be "... facultative anaerobes.", and includes in this category, in addition to Pisidium idahoensis, worms of the genera Tubifex and Limnodrilus, and three dipterous larvae: Corethra punctipennis, Chironomus tentans, and Protenthes choreus.

Baker (1928) writes about Sphaeriidae being able to live in the mud bottom of pools where the water has dried up, and Ingram (1941) has reported Pisidium abditum living out of water on the beach of a lake from at least June 15 to September 1.

(3) Survival Relating to Weight of Shell

The entombment effect of heavy sludge or silt pollution may relate to the absence of heavy Unionidae and presence of certain light Sphaeridae, other factors being favorable. In Dawley's (1947) study of the distribution of aquatic mollusks in Minnesota, she comments on the survival of mollusks on varying substrates. "A mussel [Unionidae] is more exacting in its requirements than a snail, being heavier and less mobile. The bottom in which it lives may be sand, gravel, or mud, but not rock or soft muck because its foot cannot penetrate rock and it sinks too far into the muck and is smothered." Based upon commonly finding certain Sphaeriidae on a sludge bottom, such a physical substrate may not deter the existence of certain species of this family. General observations, based upon reconnaissance of flocculent bottoms in rivers and streams polluted by domestic sewage, indicate that the Unionidae do not seem to favor such areas.

In studies of erosion silt as a pollutant under laboratory conditions, Ellis (1936) found that certain mussels were unable to maintain themselves, in either sand or gravel bottoms, when a layer of silt from one-fourth to an inch in depth was allowed to accumulate over such, other conditions being favorable to survival. The yellow sand-shell, Lampsilis teres, a sand species, most readily succumbed; the species least readily killed were: Obliquaria reflexa, Quadrula quadrula and Q. metanevra.

Coker et. al. (1922) compiled data of various investigators on types of bottoms on which mussels were reported to be living. From his analysis of such data he concluded, "It appears that the preferred bottom for the majority of species is mud (but not deep, soft mud, to which type of bottom few species are adapted) and gravel, including sand and gravel. Sand ranks next and sandy clay last; but few species of mussels exhibit a preference for sand or sandy clay, and only two are recorded (by one observer) as finding the most favorable environment in a bottom of clay mixed with sand." Baker (1928), in writing about fresh-water clams of Wisconsin, discusses types of bottoms that mussels prefer: gravel, sand, mud, and clay; he says that they are common or abundant in the first three and rare in the latter. A shifting bottom, whether it consists of mud or sand, is stated to be usually devoid of mussels. Fine silt bottoms are always avoided by mussels, and Baker (1928) doubts if mussels could live in such a bottom environment. He states that mussels are usually absent or rare where great quantities of silt are carried into streams. Ingram (1948) reported Anodonta wahlamatensis by the thousands in the soft mud bottom of Stow Lake, San Francisco, California.

Many fresh-water snails are heavy enough to sink into the sludge covering stream bottoms to become buried and suffocate. The writer has observed areas of streams where sludge deposits were two to three feet in thickness, such as reaches of the Mahoning below Warren and Youngstown, Ohio, where Physa intergra used higher aquatic plants as a substrate rather than the flocculent sludge deposits. In sludge filled sections of streams without higher aquatic plants, snails may be found on rock islands protruding from the sludge, and may be absent or rarely occur on sludge. In weight, adult fresh-water snails are much more comparable to the Sphaeriidae than to the Unionidae.

(4) Survival Relating to Type of Life Cycle

Of clams, the Unionidae are especially vulnerable to pollution which may eliminate species by affecting larval stages. It is well known that after being released from the female the immature glochidial stage of the Unionidae must parasitize various fish in order to assure life cycle completion, Lefevre and Curtis (1912), Coker et. al. (1922), van der Schalie (1938), and Jones (1950).

After spending from 10 to 14 days as an external fish parasite, the glochidium drops off the fish and continues its life as a free living form. If a fish is not parashtized, the glochidium dies. No information is available on the direct effects of pollution on the glochidium or on sperm cells which pass freely in water from male to female clam.

Because it is necessary that a part of any Unionid's life cycle be spent as a fish parasite, there is a direct relationship between the effects of pollution on fish and perpetuation of succeeding generations of Unionidae in any stream. If adult Unionidae are more resistant to various pollutional affects than fish, they may survive to die of old age, without succeeding generations developing to replace them. If glochidia-carrying fish are denied areas of streams by pollutants, expanded distribution of the Unionidae is hindered. A number of fish have been reported in the literature as carrying glochidia of various Unionidae, Coker et. al. (1922), Danglade (1922), Murphy (1942), Ingram (1948), Jones (1950). The following fish are examples of some that have been associated with glochidia, and are noted so that those working in water pollution might be aware of them if it is ever desired to correlate mussel-fish relationships relative to pollution: black bullhead, common bullhead, bowfin, eel, sheepshead, gizzard shad, mooneye, pike, spotted catfish, yellow catfish, long and short-nosed gars, red-ear sunfish, orange-spotted sunfish, blue-gill sunfish, small-mouth black bass, largemouth black bass, striped bass, river herring, yellow perch, white crappie, black crappie, sand sturgeon, madtom, sauger, and drum.

The Sphaeriid's sex cells are not subjected to any possible pollutional effect outside of the adult's body. They are hermaphrodites, fertilization is internal, and the young may be carried in the adult for as long as a year, Goodrich and van der Schalie (1944). The growth stage that leaves the parent to fend for itself is a small mirror-image of the adult. Such protected reproduction and shielding of the very young, when compared with the haphazard early life cycle stages of the Unionidae, should enhance survival of fingernail clams over mussels.

Gastropods that one would encounter in water pollution investigations copulate with resulting internal fertilization. Most lay eggs that are attached to submerged objects and, on occasion, to each other's shells; the Viviparidae are ovoviviparous. Thus, the eggs and very young stages of most are exposed to external changing environmental conditions at all times.

IV. NATURAL VARIATIONS IN DISTRIBUTION OF MOLLUSKS NOT RELATED TO POLLUTION

In studying the effects of pollution on bottom organisms, with emphasis on mollusks, cognizance should be taken of natural phenomena affecting distribution not related to pollution. Normal variations in kinds, size, and abundance of mollusks, unrelated to pollution, make inventories of species of little value in pollution studies unless those interested in delineating indicator organisms include chemical, physical, and bacteriological descriptions of water quality so as to establish tolerances of mollusks to pollutants.

It has been shown by Baker (1918) that in lakes the numbers of molluscan species decrease with depth. In further writings about the increase of mollusk abundance in relation to depth, with reference only to mussels, Baker (1928) states that "The great majority of naiades live in comparatively shallow water from a foot to six feet in depth. More rarely they descend to depths as great as 25 feet. Records of fresh water mussels from greater depths than 25 feet are to be viewed with suspicion." Thus, in studying the effects of pollution on benthonic organisms in a lake, one should always be aware that paucity of a variety of mollusks may naturally be related to water depth and not to pollutional effects. In such studies chemical, physical, and bacteriological tests could be most important in presenting data to indicate whether a reduction of molluscan variety was a natural phenomenon of depth or whether it could be attributed to pollution.

In streams, it is known that Unionidae and Gastropods tend to increase in numbers of species from headwaters to the stream mouth, Goodrich and van der Schalie (1944), Baker (1928). For example, Baker (1928) lists on increase of Unionidae from three species upstream to 28 downstream in a 27 mile reach of the Big Vermilion River, Illinois. Certain pollution sources on the headwaters of a stream may be suspect in relation to a dearth of mollusks such as the Unionidae; however, a small number of species may represent a natural condition rather than a relationship to pollution.

There may be a greater number of species and individual gastropods living in stream areas where higher aquatic plants are present and usable as a substrate in addition to the stream or lake bed. Thus, it is important to select stations to include sampling of higher aquatic plants in studies designed to provide data on indicator organisms. For example, in certain reaches of the Mahoning River, Ohio, in 1952, the writer made collections of bottom organisms in sludge deposits two to three feet in thickness and found no mollusks. In those reaches the river had a water temperature of 96°F., pH of 4.1, and D.O. of 0.2 An initial conclusion from these meager chemical and physical analyses could have been that mollusks were unable to stand such conditions in this stream. However, Physa integra was present by the hundreds in various growth stages as well as in egg masses, using higher aquatic plants as a

substrate. Thus, some data were collected to show certain conditions under which Physa integra can survive and carry out its life cycle. If higher plants present had not been searched for organisms, one might not have associated this snail at all with such a low pH or high temperature. On the basis of collections limited to the stream bottom, this pulmonate snail would have been associated only with waters having more favorable pH and temperature and with but little sludge.

V. IDENTIFICATION SOURCES FOR FRESH WATER MOLLUSKS

To assist those interested in the relationship of mollusks to water pollution, certain publications which may serve as examples of aids to their identification are cited. Also, certain museums having collections available for comparison of species or personnel that can assist in identification of specimens are presented. Much additional information relative to identification can be obtained by literature searches, or by consulting State and municipal museums and natural history societies.

A great deal of information concerning fresh water mollusks is contained in various numbers of "The Nautilus," a quarterly journal devoted to the interests of conchologists. This journal is edited by Dr. H. B. Baker of the University of Pennsylvania's Zoological laboratories, Philadelphia, Pennsylvania.

The foremost museums housing collections of fresh water mollusks are: the United States National Museum, Washington, D.C., with Drs. Harald Rehder as Curator of Mollusks and Dr. J. P. E. Morrison as Associate Curator; the Academy of Natural Sciences of Philadelphia, Pennsylvania, with Dr. Henry A. Pilsbry as Curator of Mollusks and Dr. R. Tucker Abbott as Curator of the Pilsbry Chair of Malacology; Museum of Comparative Zoology of Harvard University, Cambridge, Massachusetts, with William J. Clench as Curator of Mollusks; Chicago Museum of Natural History, Chicago, Illinois, with Dr. Fritz Haas as Curator of Mollusks; Museum of Zoology, University of Michigan, Ann Arbor, Michigan, with Dr. Henry van der Schalie as Curator of Mollusks; California Academy of Sciences, San Francisco, California, with Dr. G. Dallas Hanna as Curator of Mollusks and Dr. Leo George Hertlein as Associate Curator; and the Carnegie Museum, Pittsburgh, Pennsylvania. Smith's (1943) directory of malacologists can be useful to those interested in having mollusks identified, because it lists in alphabetical order, malacologists who are specialists in mollusk identifications.

The following are cited as examples of keys and faunal lists developed from studies limited geographically that can serve to provide species names as a base for specific identification in future studies of fresh water mollusca: Baker (1922) on mollusks of the

Big Vermilion River, Illinois; Eddy and Hodson (1950) on mollusks of the North Central states; Goodrich and van der Schalie (1939) on mollusks of the upper peninsula of Michigan; Morrison (1932) on mollusks of the northeastern Wisconsin lake area; Strecker (1931) on the Unionidae of Texas; and a series of papers by van der Schalie on the Unionidae bearing the following dates from the stated geographical areas: (1940) St. Joseph River, southwest Michigan; (1938b) Cahaba River in north-central Alabama and (1938) Huron River in southeastern Michigan; (1940) Chipola River in northwestern Florida; (1939) [illegible] valuable mussels of the Grand River, Michigan, and (1939) of the Mississippi River.

Examples of regional fresh water mollusk identification guides are: Baker (1898) on clams of the Chicago area and (1902) on gastropods of the same area; Baker (1928) [illegible] of Wisconsin; Chamberlin and Jones (1929) on [illegible] of Utah; Goodrich (1932) on mollusca of Michigan; Goodrich and van der Schalie (1944) on mollusca of Indiana; Henderson (1924, 1927) on mollusca of Colorado, Utah, Montana, Idaho and Wyoming; Henderson (1929 and 1936a) on mollusca of Oregon and Washington; Ingram (1948) on the larger fresh water clams of California, Oregon and Washington; and Strecker (1935) on the mollusca of Texas.

The following are monographs, papers, and catalogues of varying degrees of comprehensiveness that deal with fresh water molluscan classification: Baker (1911) on the Lymnaeidae of North and Middle America; Berry (1943) on the Amnicolidae of Michigan; Brooks and Herrington (1944) on a preliminary survey of the Sphaeriidae; Ortmann (1919), a monograph of the naiades of Pennsylvania; Pennak (1953), a key to the families and genera of North American fresh water mollusks; Sterki (1916), a catalogue of North American Sphaeriidae; and Walker (1918), a synopsis of fresh water mollusca of North America north of Mexico; and (1918), keys to fresh water mollusca of the United States.

VI. SUMMARY

1. Presented literature affirms that little specific information is available relating one species of mollusk or a group of species to a set of well-defined water quality conditions, and another species to different degrees of water quality.

No information is available to be found in selecting from molluscan species that may be called pollution-tolerant. Several species are tolerant to low dissolved oxygen [illegible] conditions resulting from pollution of water by [illegible]. However, such species cannot be considered [illegible] pollution as related to septicity, for they are also found in [illegible] and lakes.

2. Most specific data available relating mollusks to certain effects of pollution on water quality deal with survival under septicity. Other such data relate to survival in relation to blanketing bottom deposits and acid water.

a. In relation to survival under conditions of septicity resulting from domestic sewage pollution, general conclusions that have been apparent for many years, can be reaffirmed here. Certain genera that are collected under such conditions, while Unionidae are not, and certain pulmonate snails are commonly found in septic water, while gill-breathers typically are not.

b. In relation to survival on bottoms blanketed by sludge from domestic sewage and by silt, certain Sphaeriidae and Physidae are most often collected.

3. Information on the hydrogen ion concentration is presented indicating that a number of genera of mollusks may live normally in acid water conditions not associated with pollution.

4. Variations in molluscan structure and types of life cycle are discussed, as such variations may result in enhancing survival under pollutional conditions relating to dissolved oxygen, sludge and silt deposits.

5. Natural variations in the distribution of mollusks in streams and lakes are considered in order to make those working in water pollution aware that variations in numbers of species may be a natural phenomenon not related to pollution.

Selected literature and general [illegible] as well as a list of guides and lists are presented to assist those who are not authorities on mollusks [illegible] with identification.

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