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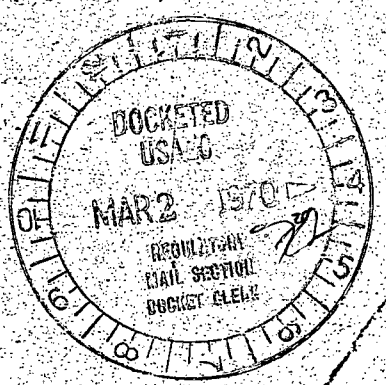
ECOLOGICAL SURVEY OF THE HUDSON RIVER

Progress Report Number 3

September 30, 1968



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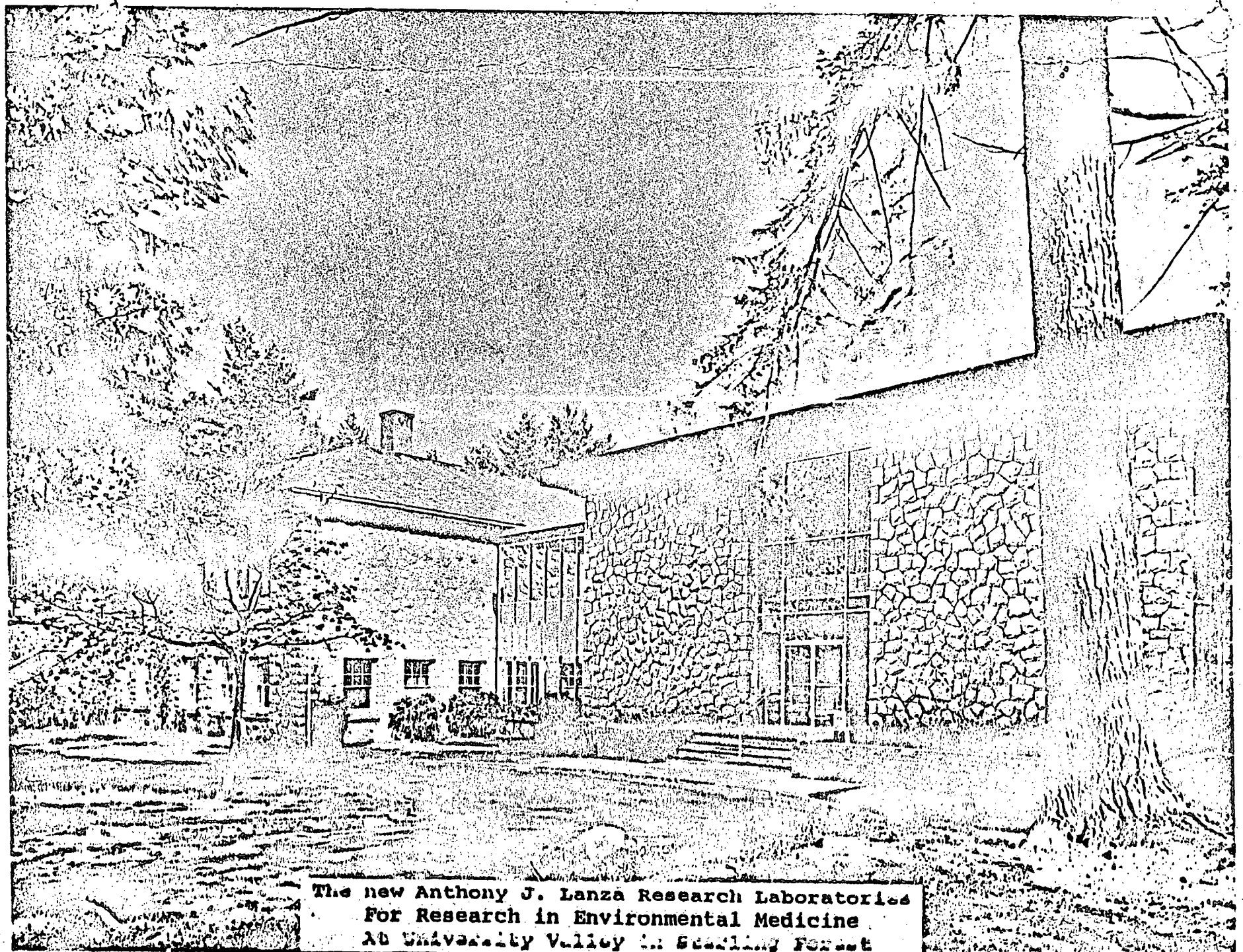

The new Anthony J. Lanza Research Laboratories
For Research in Environmental Medicine
At University Valley in Standing Forest

ECOLOGICAL SURVEY OF THE HUDSON RIVER

Progress Report Number 3

Period Covered February 1, 1966 - January 31, 1968

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Department of Environmental Medicine

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Department of Environmental Medicine

September 30, 1968

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ACKNOWLEDGEMENTS

This investigation was variously supported by a number of agencies: Public Health Service (contract No. PH-86-65-102), and by Grant No. UI00461-02 from the National Center for Urban and Industrial Health (part of a center program supported by the Division of Environmental Health Sciences, National Institute of Health, Grant No. ES00260). Substantial support has also been received from the New York State Department of Health (contract No. C-19560). A gift has also been received from Consolidated Edison, New York. Appreciation for advice, encouragement, and for support in some practical matters is also due to the Hudson River Valley Commission, and to Mr. and Mrs. Glunt, of Saugerties, New York.

THE BIOLOGY OF THE HUDSON RIVER

By: G. Parry Howells

Introduction

The efficient exploitation of water resources depends on the co-operation of industrialists, engineers, scientists, conservationists but above all, of people, who create the demand for, both clean water and its use as a carrier for wastes. The delicate balance of biological, chemical and physical factors in an aquatic ecosystem is always changed, and the natural developmental changes accelerated, as a result of man's activities.

The development of an area in terms of population and industrial growth, or of intensified agriculture, or river "development", is always accompanied by the enrichment of water bodies by nutrients, and sometimes by heat. This accelerates the natural aging of waters which is called "eutrophication". This process frequently interferes with the multiple uses of water, reduces its aesthetic value, and threatens to destroy the water source.

Eutrophication is still imperfectly understood and difficult to measure in quantitative terms, although we recognize some

aspects such as the reduction in clarity of the water, the development of plant growths, and even the production of undesirable odors or tastes. Eutrophication may or may not be a desirable development. It is a process which increases the productivity of natural waters and this is utilized in the establishment of fertilized, artificial fish ponds and of shellfish hatcheries in some countries. However, because chemical enrichment of the water generally favors those species that naturally accompany eutrophication, the resulting fish or shellfish may be valuable only in places where the criterion for success is measured in terms of protein weight (for food) rather than quality. The most successful species cultured in this way are rarely those prized by fishermen or epicures, or even by biologists.

One of the obvious results of advancing eutrophication is the excessive production of phytoplankton and of rooted shore plants. The growth of these organisms interferes with the recreational uses of the water; it may impede shipping; it may produce filtration problems in industrial water use. It may also develop unacceptable tastes or odors to drinking water which may carry through to food fish or shellfish living in this environment. The algal growth may even proceed so far that it creates a biological oxygen demand in place of oxygen production in

conditions of low light intensity, and may, by blanketing the surface, prevent natural gaseous equilibration of lower waters with oxygen in air. In addition, some algae can produce substances which are directly toxic to fish or other animals.

Understanding the development of eutrophication of any natural body of water requires information about physical and chemical properties of the primary water supply, and of any organic material or toxic materials which are added to it. It is also advantageous to have some knowledge about the whole of the drainage basin and of its geology and geochemistry and of its land use. Then, it is most important to identify biologically the biota of the water body and to study their nutrient requirements, their behavior to toxic materials, and their relationships to one another (as in a food web), as well as the dynamics of the whole ecosystem in terms of nutrients. This is a requirement of perfection and it is doubtful if we will ever gain as much knowledge as we need about even a few small and dynamically simple bodies of water. Usually it will be necessary to make decisions about water use and water treatment on the basis of grossly inadequate knowledge and we have to trust that our generalizations will suffice for predictions about most waters. However, the Hudson River is of such importance for navigation, domestic and industrial water

use, as well as for recreation, that it is imperative that we know more about its specific problems.

Specific Problems in the Hudson River

I would like to put forward the view that a large part of the lower Hudson River has the characteristics of a eutrophic brackish lake; the hydrographic conditions may prove critical in the biological sense. At a time when increasing population, increasing industrialization and the concomitant rising demand for water for all purposes is an inevitable course in the Hudson River area, it is clear that our understanding of the situation and its possible remedies in the river are all too inadequate.

This laboratory between 1964 and the present, has been following changes in water quality and biota over a 100 mile stretch of the river roughly between the Tappan Zee Bridge and Inwood in the south, and Coeymans in the north (1, 2, 3). This study has the purpose of establishing an inventory of plant and animal species, of documenting the biological history of the region in a time of change, and of identifying indicator species of eutrophication or pollution and also those which might be used as monitors of potentially toxic pollutants. Concurrent studies have been made of stable and radioactive contaminants as well as pesticides, in

the river water, sediments and biota.

The stretch of the river investigated has the physical characteristics of a "drowned river" and its channel can be traced well out into the Atlantic. At the northern limit of the estuary (at Troy) the river bottom is still 4 feet below sea level. In the region studied, the lower part may be termed "mesohaline" with salinities varying from about 23 °/oo to 10 °/oo, (2/3-1/3 SW) and then "oligohaline" from 10 °/oo to 2 or 3 °/oo (1/3-1/10 SW). As the sea water pushes up the river at flood tide it tends to form a wedge of denser saline water at the bottom of the river bed. Since the Hudson River is deep (>100 feet in some parts), this saline water should remain near the bottom, but in fact only relatively slight (< 1-2 °/oo) differences have been seen and our conclusion is that the water gets well mixed in this part of the river.

The freshwater inflow into the river at Troy varies from 25,000 cfs during the spring runoff (e.g. May 1966) to a minimum 1600 cfs recorded during the summer of 1965 in a drought period (Ref. 4). Super-imposed on this, dwarfing the fresh water flow is a massive tidal flux. The flux is so massive that at the flood of "spring tides" in the summer there appears to be no downstream

flow in the river at all. This has been demonstrated by dye studies where the distribution of added dye in the river was followed for 14 tidal cycles (1 week). At the head of the tide at Troy, the tidal excursion was only 3 miles, while the velocity of net movement of the dye mass downstream was 1.4 miles/tidal cycle. However, at Kingston and stations south of this, while the tidal excursion was 8 or 9 miles for each tide, there was no net movement of the dye mass (Ref. 5). On the other hand, the relatively uniform salinities seen in the river (with depth) and the fairly low salinities recorded at Inwood (from 1 °/oo during spring to about 10 °/oo during the summer) suggests that the net inflow of sea water through the Verrazano Narrows is also small. What we appear to have is a seiche-like movement of brackish water, impelled by the ocean tides. The implication for pollution and eutrophication are clear: this large volume of water (at a guess, 150 miles x 1/4 mile x 30 feet) is behaving as a brackish water lake rocked north and south by the influence of the tide. The inflow is sufficient for only 1/2 to 7% to be exchanged each day, assuming no evaporation or rain and no appreciable volume of inflow from tributary streams. Hence effluents and nutrients discharged into this brackish lake

will, as in a true lake, be recirculated between the water and the biota until irreversible eutrophic conditions are reached, with little opportunity for this volume of water to be cleansed by either a freshwater or sea water inflow.

The freshwater inflow at Troy already carries a relatively high concentration of nitrogen and phosphorus into the lower Hudson River. A large quantity of treated and untreated organic sewage is added daily, the peak being from Albany to Hudson, and near Manhattan. A study of the total phosphorus in the Hudson shows that there is a maximum concentration of 12 μg-atoms/l at the southern tip of Manhattan. Of this total, 70% is present as inorganic phosphate, 16% is present as particulate material (incorporated into plankton) and 14% is present as dissolved organic phosphorus (Ref. 6). In general, it is reported that the total phosphorus in river water is higher than that of lakes but this value is high by any measure. Lake Washington (Seattle), where eutrophication is slowly being reversed by a costly sewage diversion, has a phosphorus concentration of 7.5 μg atoms/l, and it has been stated that 2.8 μg atom/l is the approximate upper limit of unpolluted water. A theoretical relationship has been deduced that oxygen demand = oxygen supply from photosynthesis

when there are concentrations of 2.6 µg atoms/l in winter, and 1.7 µg atoms/l in summer (Ref. 7). On this basis, we might expect that in the Hudson River, at least in the stretch south of Albany, and around Manhattan, where phosphorus levels are high, there will be net oxygen depletion. This has been demonstrated in field studies.

Similarly, nitrogen levels are high, although all of this nutrient is not so clearly derived from domestic sewage. Complete analysis of the nitrogen cycle is considerably more difficult than the phosphorus cycle because the nitrogen is present as nitrate, nitrite, and ammonia nitrogen, and the effects of nitrogen fixation or denitrification by bacteria also complicate the picture. Nitrate in water can act as a reserve of oxygen, even with appreciable concentrations of dissolved oxygen; in anaerobic conditions nitrogen compounds are reduced to ammonia or even to nitrogen. The cycle is complex and related to dilution, oxygen and temperature. Similarly sulphate is reduced to sulphides by bacteria in anaerobic or near anaerobic conditions.

The relatively high sulphate from sea water intrusion and nitrate both from added sewage and feeder tributaries in the Hudson River means that anaerobic or near anaerobic conditions may tip

the balance between a healthy river and a noxious one producing hydrogen sulphide and ammoniacal gases.

Biological Developments in the Hudson River

The Hudson River is potentially rich in biological resources. It has a large population of endemic fishes and a tremendous migrant population of diadromous fishes i.e., those species that live in both the sea and fresh water. It is unlikely that the river was ever a salmon spawning ground, but there are records of Atlantic salmon being caught in the river, and a serious attempt was made to introduce both Pacific salmon (in 1873) and Atlantic salmon (from 1882 to 1896) (Ref. 8, 9). However, these attempts were not successful and the adults never established a spawning run. The Hudson in the past has been famed for commercial shad and sturgeon fishing.

Again, there was once a flourishing oyster fishery, now destroyed by pollution, and while clams are still plentiful in appropriate areas, they are unfit for human consumption because of pollution (Ref. 9). On a much more personal level, many sport fisherman who use the Hudson for their recreation say they cannot eat the catch because of its unpleasant oily flavor. What are the reasons for this decline? First, the growth of population and industry has changed the physical conditions of the river by impoundments, dams, dredging and similar works. Then the use

of river water for industrial purposes has added some pollutants. A large and growing population in the area uses the river as a drain for untreated or primary treated sewage. Development of agricultural lands adds sewage as well as agricultural fertilizers, pesticides, herbicides. These influences may increase the fertility of the river as well as adding toxic materials; however, the changes are not always those sought by fisherman, anglers or water engineers.

Fish in the Hudson River

We have some historical accounts of the abundance of fish in the Hudson, as well as records of commercial catches over a long period, but the bulk of our previous scientific knowledge is from a survey published in 1936 by the New York State Conservation Department (Ref. 8). This report lists 67 species of fish for the lower Hudson. In 1965-1967, however, 14 species were most commonly caught and about 20 other species were found occasionally.

The commonest species found in the earlier survey were judged to be the common sunfish (Lepomis gibbosus), the common sucker (Catostomus commersonnii), the golden shiner (Notemigonus crysoleucas) and the Johnny darter (Etheostoma nigra). In our survey during the summer of 1965 to 1967, however, the

commonest species, overall, were the blueback herring (Alosa aestivalis), freshwater killifish (Fundulus diaphanus), the northern silverside (Menidia menidia) and the spot-tail shiner (Notropis hudsonius). Some caution is needed in the comparison: the 1936 (June) survey used seine nets on shore and gill nets midstream, as well as other fishing methods using lines and traps. Our survey (July and August) was restricted to shore seining on the west bank of the river and these collections were principally of young fish in their first year. Another difference may lie in the slight seasonal differences since many of the young fish sampled by shore seining belong to migratory species whose presence and abundance in the river is seasonal, and variable (in time) from year to year.

With caution, the changes to be seen in 30 years seem to be a tendency for carp and goldfish to be seen more frequently, together with more migratory "herrings", namely silverside and alewife. However, the latter may reflect the slightly later season of our collections, rather than a changing environment. Freshwater and brackish water killifish also seem more frequently caught in our samples, but the predominance of either species at any specific site seems to reflect their distribution in

relation to the salinity gradient in the river in each year. In general, the number of species found in our survey is less than in 1936 and this, if real, may reflect increasing pollution.

Commercial aspects of the fisheries in the Hudson River presents an alternate view. The Hudson River has been exploited for its fish since the area first became populous. The catches varied naturally year by year, but in recent years, 1945 may have been a peak year (in terms of total catch). The fishing effort (in terms of boats and men employed) continued to increase until 1945, beyond which there is a decline. A part of this is attributed to the general tendency of a wealthy community to consume less fish, but is also partly due to a decline in the quality of the fish, and a decline in the catch per unit of effort. The shad has been an important food fish in the river since the first settlers arrived in the area. In the long history of the shad fishery, there were two periods of peak abundance, 1877-1901 and 1936-1949. The decline may be attributed to over-fishing or to other causes such as the restriction of the spawning grounds, the deleterious effect of dredging (which destroys spawning sand banks), and pollution, especially in the Albany-Hudson stretch. Of all these changes, the most significant seems to be over-exploitation of the fishery since the

abundance of the fish is more closely related to the proportion of time when nets are fishing, than to any other factor.

Striped bass is a fish native to the Hudson, but while some are resident in the river, others move out to sea and migrate up and down the coast. This species spawns between Bear Mountain and Kingston. The population is underexploited in the commercial sense although it is popular as a sport fish and the adults are well able to tolerate the highly nutrient, low oxygen waters of the Hudson. It deserves to be conserved; however, little is known about the optimum breeding and nursery conditions for this fish.

Sturgeon are represented in the Hudson by two species, the short-nosed and Atlantic sturgeons. The latter spawns in the Hudson and spends its juvenile life there (to 12 years) and is often needlessly destroyed when it is caught in commercial gill nets. The other species is resident in the river throughout its life and grows more slowly. At one time there was a flourishing fishery for both sturgeon and caviar but the abundance of the fish began to decline about 1875. Attempts to propagate the fish by artifical spawning methods have been unsuccessful. While sturgeon fishing is now restricted by a size limit, there is little evidence of a

return of the early abundance of these fish. In addition, almost nothing is known about the effects of pollution on the development of the eggs and larvae, or of the statistics of population growth of the sturgeon and it seems that this valuable biological asset may be lost to the Hudson by neglect.

Alewife and Blueback Herring are also migratory fish coming into the Hudson seasonally. These fish are also unexploited although a good food source.

A parallel decline in the commercial shellfish industry is seen. The bulk of shellfish beds in the Hudson lie in the Raritan Bay area and most of this has been destroyed by domestic sewage pollution. The stretch of the river between Hastings and Ossining is thought to have some potential for oyster culture, but salinity here is fairly critical for the commercial oyster species and a year of more than average rainfall can reduce the river salinity at this point to less than the critical level.

Invertebrates and Microorganisms

While most non-biologists consider only the fish population of a river, this represents only the top of a broad-based pyramid of animal and plant life. Nutrients in the water are converted by photosynthetic activity to single-celled algae and diatoms, or by

bacteria and these support a population of plankton which in turn, provides the food for young fish and larger invertebrate animals. The waters of the Hudson are always turbid to some degree; while some of its brown color is due to sediments suspended in the water, much is due to the presence of plankton. The plankton is characterised by a dominance of copepod species and their nauplii, grazing on a population of bacteria, ciliates, diatoms and algae. There is a relative abundance also of rotifers and other microcrustaceans. The density of the zooplankton at various stations in the river during the summer ranges from 200 to 1200 organisms/liter water.

Collections mid stream (from the water and the benthos) and along shore have shown two contrasting environments inhabited by different populations of animals and plants. Our shore collection sites are characterised by snails such as Lymnaea and Physa and brackish water shellfish; by larger crustaceans such as Gammarus and isopods, and inshore shallow waters by shrimps, prawns, and crayfishes. But they are also prolific in a number of organisms considered as indicators of domestic sewage pollution. Among these are nematode worms, Tubifex, filamentous algae such as Phormidium and Oscillatoria. In

addition, large bacterial and fungal masses have been observed at many sites, especially in the northern reaches. The mid-stream samples on the other hand, are characterised by abundant algae and diatoms, including some species indicating eutrophic conditions, and by a rich fauna of copepods and other small crustacea. We also find many species of rotifers; other polluted waters (such as the Delaware River, Lake Erie, or the Raritan River) appear to have a more restricted rotiferan fauna. The protozoan fauna is also rich, with about 30 identified species, fewer from shore collections.

Our studies of the main stream (by following sectors across the width of the river at four stations at Inwood, Indian Point, Cornwall and Saugerties) have shown that the micro-organisms, like temperature and salinity, are relatively uniform with depth and across the channel. Moving from the most southerly site at Inwood to the most northerly at Saugerties, there is a natural succession from brackish water species to freshwater ones; the distribution varies a little from year to year. But a number of species in the plankton are collected over many miles of the 100 mile stretch of the river studied and appear tolerant of the salinity differences seen.

What will the future be?

Our studies have been undertaken to give us the information needed to make predictions of the future course of the river. We can safely predict an increasing use of the river for industrial and domestic purposes, and also the increasing use of its water to augment existing drinking water supplies. There is also projected a pumped storage scheme at Cornwall, and an increased use of water for cooling nuclear reactors. The changes we can postulate are then: First, physical ones: a diminution in water flow due to increased use, and the diversion of large volumes through pumps and turbines. Secondly, an increase in nutrient materials derived from agricultural expansion and from an enlarging population. A reduction in water flow will accentuate this. Thirdly, an increase, overall and in specific localities, in the water temperature, as more water is used for industrial cooling. Lastly, we might postulate an increased outfall into the river of toxic pollutants such as pesticides and trace metals.

How will these changes affect the biota of the river? The physical effect of pumps and turbines in the river system has been compared to that of a giant predator, eating up, rather indiscriminately, a proportion of the population. The effects of a predator

are not always bad, as every fishman, who is frustrated by a large population of undersized fish, well knows. The removal of a part of the population often allows the survivors to attain more rapid growth. But if predation exceeds the natural recovery rate, then the productivity (in terms of fish weight/unit water volume) must decline. While protective grids at water inflows can save larger fish, young fish, or fish eggs, along with the plankton of the river on which fish larvae feed, will be entrained. Water treatment (such as chlorination) and heating, as well as pressure damage in turbines, may damage these entrained organisms. Hence, the proportion of the river flow which can be used for such purposes is limited, unless some successful remedial measures are applied to repopulate the waters with young fish and their food plankton.

The increase in nutrient materials in the river will necessarily increase the process of eutrophication. As the waters become richer, algae (especially Oscillatoria) and some objectionable diatoms, will bloom with increasing explosiveness, as in other polluted waters such as Lake Washington, Lake Erie, the southern part of Lake Michigan. The abundance of a few of these species

produces dense crops generally considered a public nuisance. Mats and floating masses of algae may be produced, and if the process continues, deoxygenation of deeper waters occurs. The only remedies for such a situation (as has been demonstrated recently with Lake Washington) is to direct sewage out-falls to alternative water systems, or to remove chemically and biologically, at least a proportion of the nutrient material in the sewage. If eutrophic conditions persist for a number of years the saturated mud may act as a reservoir of nutrient material.

The third change, of increasing temperature, also brings far-reaching effects. In the classic studies in the Potomac and Patuxent rivers [10] it has been shown that as environmental water temperatures change from $<90^{\circ}$ to $>90^{\circ}$, the species making up the micro fauna and flora will change. There is a reduction in the variety of organisms as the less heat tolerant cannot survive in competition with the others. There is a loss of protozoa and an increase in microbial growth, perhaps because the reduced protozoan population no longer browses on them.

There are changes in fish populations also as more heat tolerant species dominate the others. Fish tend to move into the warmer dischage areas near effluents, but they become very

active and cannot feed since there are few insect larvae in these areas. However, this tends to increase the sport fishing potential of such an area.

The planktonic copepod Acartia (present in the Hudson) shows a critical dependence on temperature in relation to egg hatching (11). A reduction in the abundance of larval nauplii would deplete the food supply for young fish, and it would also remove the population responsible for cropping algae and diatoms. Again, many invertebrates such as soft-shelled clams, oysters and crabs are directly or indirectly affected by temperature changes.

The effects of increased temperature need not all be bad ones. The warm effluent water from power stations, together with nutrients derived from sewage can be used for fish or shellfish culture, since growth can be stimulated. Experimental and field studies of such projects are being carried out in Japan and the United Kingdom, and other countries, including the United States.

Conclusions

In conclusion, the lower Hudson River should be regarded as rich in potential for industry and recreation as well as in biological resources. Because of its hydrological characteristics

and because it flows through a relatively densely populated area, it is important that there be available a body of biological and chemical data, so that future changes may be predicted. It is hoped that the report following will provide some of this information.

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DISTRIBUTION AND ABUNDANCE OF FISH ALONG THE SHORES OF THE LOWER HUDSON RIVER DURING THE SUMMER OF 1967

By: A. Perlmutter, E.E. Schmidt, R. Heller, F.C. Ford and S. Sininsky

Introduction

A study of the distribution and abundance of fish along the west shore of the lower Hudson River was carried on in the summer of 1967 following a standard procedure (Perlmutter et al., 1967). Sampling stations (Appendix A) were the same as in previous years, and ranged from Nyack near the Tappan Zee Bridge, to Cementon south of Catskill. The method of sampling employed a 50 ft. nylon shore seine (3/8 inch mesh) up to a depth of about 5 feet, along the shore. The area seined was estimated following a standard procedure (Perlmutter et al., 1967). The number of tows made at each station and the computed total area seined are shown in Table I. The average total area seined per station for the sampling period was about 60,000 square feet and ranged from about 20,000 square feet at Station II-W-2 to 90,000 square feet at Station I-W-3. The average number of tows made at the individual stations was 14 with a range of 7 to 19.

As in previous years the lengths of the specimens of each species was taken at Stations I-W-3, II-W-1, II-W-2 and III-W-2

were pooled, and the composite length frequency was considered indicative of the size composition for that species in the river below Poughkeepsie. Similarly, lengths of fish taken at Stations IV-W-1, IV-W-2, IV-W-3, and IV-W-4 were combined, and the pooled frequency was taken as indicative of size in the river north of Poughkeepsie. Furthermore the combined frequencies by species for the areas below and above Poughkeepsie were determined, when possible, for two time periods, June-July (Period 1) and August (Period 2).

From these length-frequencies, together with information on length-age distributions obtained in the 1964 study (Eisenbud et al., 1965), the catch of most species could be divided into two age categories: a 0 + (young of the year) group and a 1 + year or older group. This information was then correlated with the extent of area seined. An arbitrary relative catch-per-unit-area value, i.e., the number of fish caught in each of the two age categories per 100,000 square feet of shore area seined, was calculated for each station during each collection interval throughout the season. The measure of relative abundance and availability was also calculated for each species for the collecting period by taking the average of the catch per 100,000 square feet of shore area seined for all nine stations.

Results

Fourteen species were most common in the catch. These were Roccus americanus (white perch), Roccus saxatilis (striped bass), Alosa sapidissima (shad), Alosa pseudoharengus (alewife), Alosa aestivalis (blueback herring), Fundulus diaphanus (freshwater killifish), Fundulus heteroclitus (saltwater killifish) Menidia menidia (northern silverside), Menidia beryllina (tidewater silverside) Carassius auratus (goldfish), Notropis hudsonius (spottail shiner) Notemigonus crysoleucas (golden shiner), Lepomis gibbosus (common sunfish), Etheostoma nigrum (Johnny darter).

Length-frequency Distribution:

The length-frequency distributions of these species are given in Tables 2-13. Where sufficient data are available, the length-frequency distribution has been given independently for the areas above and below Poughkeepsie both for Period 1 and Period 2. Where the data are less complete the length-frequency information for the two areas or two periods, or both, was combined. An examination of this data indicates that the fish sampled were principally of the smaller sizes and in the 0 + age group for most species.

For white perch during Period 1, the fish caught ranged in length from 10 to 184 mm. The 0 + age group, ranging from 10 to 29 mm in length comprised 19 per cent of the catch of that species

and most of them were caught in the southern area. In Period 2, the 0 + age group ranged from 10 to 54 mm and comprised 90 per cent of the catch. During the same period the modal length in the northern area was 40 to 44 mm compared with 15 to 19 mm in the southern area (Table 2 and Figure 2). The 1 + fish in Period 1 ranged in length from 45 to 89 mm. As we have demonstrated in previous years, white perch caught in the northern area had more fish in the larger size groups.

Striped bass in the 0 + age group ranged from 10 to 44 mm in Period 1 and from 15 to 69 mm in Period 2 (Table 3 and Figure 2). As for white perch, striped bass in the northern area appear to be larger than those in the southern area.

Among the herrings, only 15 shad in the 0 + age group and 2 in the 1 + age group were caught (Table 4). Alewives and blueback herring were taken in considerably larger numbers. Most of the alewives taken were 0 + fish and in Period 1 ranged in size from 15 to 54 mm and in Period 2 from 30 to 64 mm (Table 4 and Figure 5). For this species, the fish in the northern area appear to be smaller than those in the southern area. As with the alewives, most of the blueback herring were 0 + fish ranging in size from 15 to 39 mm in Period 1 and from 20 to 54

mm in Period 2 (Table 5 and Figure 3).

Among the killifishes, the freshwater killifish in the 0 + age group during Period 1 had a modal length of 15 to 19 mm in the southern area where most of these fish were taken. During Period 2 the modal lengths were 5 to 29 mm in the southern area and 20 to 24 mm in the northern area (Tables 4 a and b and Figure 7). The saltwater killifish, like the related freshwater species, was found mostly below Poughkeepsie during Period 1. The 0 + fish had a modal length of 20 to 24 mm during Period 1 and 25 to 29 mm during Period 2 (Tables 7a and b and Figures 8 and 9).

The northern silverside and tidewater silverside were caught only below Poughkeepsie and those taken were all 0 + fish. The modal length of the northern silverside in Period 1 was 30 to 34 mm and in Period 2, 40 to 44 mm. The modal length of the tidewater silverside was 50 to 54 mm in both Periods 1 and 2 (Table 8 and Figure 6).

Young-of-the-year goldfish were taken both above and below Poughkeepsie. Fish caught in the northern area appear larger in size. Their modal length in Period 1 was 25 to 29 mm and in Period 2, 30 to 34 mm, compared with modal lengths of fish in the southern area of 15 to 19 mm in Period 1 and 20 to 24 mm

in Period 2 (Table 9 and Figure 10).

For the spottail shiner, 0 + fish ranged in size from 10 to 39 mm in Period 1 and 10 to 54 mm in Period 2. Fish in the northern area were larger than those in the southern area. In the northern area, the modal length in Period 1 was 25 to 29 mm and in Period 2 35 to 39 mm compared with the modal length in the south in Period 1 of 15 to 19 mm and in Period 2 of 20 to 24 mm (Table 10 and Figure 9).

The golden shiner in the 0 + age group also appears to be larger in the northern area than in the southern area. Young-of-the-year fish range in size from 20 to 89 mm (Table 2 and Figure 11).

The common sunfish in the 0 + age group ranges in length from 10 to 24 mm in Period 1 and 10 to 49 mm in Period 2. Most of this age group was taken in Period 2. During this period the fish in the northern area were found to be smaller than those in the south with a mode for the former of 15 to 19 mm compared to a mode for the latter of 25 to 29 mm (Table 12 and Figure 10).

Young-of-the-year Johnny darters ranged in size from 10 to 39 mm in Period 1 and from 15 to 54 mm in Period 2. In this species, the 0 + fish appeared to be smaller in the northern area

than in the southern area (Table 13 and Figure 12).

Relative Abundance:

On the basis of both the length-frequencies observed, and the age-length-frequencies computed for 1964 (Eisenbud et al., 1965), the comparative catches of 0 + and 1 + or older fish were computed for the entire collection period for each species and for all species, both for individual stations and for all stations combined (Table 14). As has been explained, these comparative figures were computed for measured areas seined at the different stations and converted to an arbitrary unit of catch per 100,000 square feet of shore area seined. This unit of catch is designated "p.u.a." (per unit area) throughout the remainder of this paper.

The relative abundance of all species taken at each station through the period studied varied from 852 to 6572 p.u.a. The highest levels of abundance were seen at Station III-W-2 (6572 p.u.a.), and Station IV-W-4 (5215 p.u.a.).

Of the 14 species considered, the blueback herring was the most abundant, averaging 594 fish p.u.a. at all stations. The alewife averaged 102 p.u.a. at all stations while the shad averaged only 3 p.u.a.

The second most abundant species was the freshwater killifish with an average catch of 576 p.u.a. The spottail shiner, Johnny darter, common sunfish and white perch were closely grouped as the next most abundant species with respective average catches of 232, 219, 218 and 206 p.u.a. The average catch of the saltwater killifish was 119 p.u.a.

Goldfish averaged 47 p.u.a. Golden shiner, striped bass and northern silverside averaged 22, 20 and 19 p.u.a. respectively, while the tidewater silverside averaged 3 p.u.a.

Discussion:

A comparison of the levels of abundance in 1967 with the preceding two years of the 0 + age groups of the 14 species predominant in the catch during all three years is shown in Table 14 and Figure I. The white perch appeared to increase in abundance over the previous year but did not attain the 1965 level of abundance. This was also true for the Johnny darter. The striped bass, shad, spotted shiner, goldfish, saltwater killifish and both species of silverside were lower in abundance than in either of the preceding two years. The golden shiner was less abundant in 1967 than in the previous year, but slightly more abundant than in 1965. The freshwater killifish was somewhat less abundant than in 1966 but more abundant than in 1965. Only the alewife and common sunfish were more abundant in 1967 than in the previous two years.

The drastic drop in abundance of the silversides and relatively high levels of abundance of the freshwater killifish and common sunfish in 1967 may reflect the reduced salinity of the river resulting from an increased annual rainfall in the early part of that year.

The apparent size difference observed in individuals of species taken in the northern areas as compared with individuals of the same species taken in the southern areas may be attributed a number of possible factors. One factor may be a relative difference in the availability of food in the areas studied. Another factor may be a relative difference in the spawning time for members of the same species in the areas studied, earlier spawning manifesting itself as the size observed differences. A third possibility may involve both availability of food and early spawning leading to the relative size differences observed. Relative productivity and water chemistry studies of the areas sampled may shed some light on the reason or reasons for this size difference phenomenon.

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TABLE I

Number of Tows and Computed Area (In Square Feet) Seined at each Station

Station (Miles) from Battery	June 20-21 26-27	July 3-4 10-11	July 17-18 24-25	July-Aug. 31-1 7-8	August 14-15 21	Total
South of Poughkeepsie						
IW3 (26.6)						
No. of Tows	5	3	3	4	4	19
Total Area	20,000	15,000	15,000	20,000	20,000	90,000
Av. Area/Tow	4,000	5,000	5,000	5,000	5,000	4,737
IIW1 (41.4)						
No. of Tows	4	4	2	3	4	17
Total Area	9,375	15,000	10,000	10,000	10,000	54,375
Av. Area/Tow	2,344	3,750	5,000	3,333	2,500	3,199
IIW2 (45.2)						
No. of Tows	1	1	1	2	2	7
Total Area	2,500	1,250	5,000	5,000	5,000	18,750
Av. Area/Tow	2,500	1,250	5,000	2,500	2,500	2,679
IIW2A (56.5)						
No. of Tows	4	4	2	2	2	14
Total Area	20,000	20,000	10,000	10,000	10,000	70,000
Av. Area/Tow	5,000	5,000	5,000	5,000	5,000	5,000
IIIW2 (67.3)						
No. of Tows	5	2	2	2	3	14
Total Area	18,750	10,000	10,000	10,000	7,500	56,250
Av. Area/Tow	3,750	5,000	5,000	5,000	2,500	4,000
North of Poughkeepsie						
IVW1 (86.1)						
No. of Tows	2	3	2	2	3	12
Total Area	7,500	15,000	7,500	10,000	10,000	50,000
Av. Area/Tow	3,750	5,000	3,750	5,000	3,333	4,167
IVW2 (95.1)						
No. of Tows	4	3	2	3	3	15
Total Area	20,000	15,000	10,000	10,000	10,000	65,000
Av. Area/Tow	5,000	5,000	5,000	3,333	3,333	4,333
IVW3 (100.5)						
No. of Tows	2	2	2	3	4	13
Total Area	10,000	10,000	10,000	10,000	7,500	47,500
Av. Area/Tow	5,000	5,000	5,000	5,000	1,875	3,654
IVW4 (104.7)						
No. of Tows	3	4	2	3	4	16
Total Area	15,000	20,000	10,000	10,000	15,000	70,000
Av. Area/Tow	5,000	5,000	5,000	3,333	3,750	4,375

TABLE 2

Length-Frequency Distribution Recorded for White Perch

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	1	0.5	-	-	1	0.3	63	16.3
15-19	-	-	-	-	42	12.6	103	26.6
20-24	3	1.6	3	1.5	46	14.1	98	25.3
25-29	-	-	6	2.9	3	0.9	59	15.2
30-34	-	-	24	11.7	-	-	16	4.1
35-39	-	-	51	24.9	-	-	9	2.3
40-44	-	-	53	25.9	-	-	1	0.3
45-49	1	0.5	38	18.5	1	0.3	1	0.3
50-54	1	0.5	8	3.9	3	0.9	-	-
55-59	2	1.1	-	-	12	3.7	-	-
60-64	3	1.6	-	-	12	3.7	-	-
65-69	14	7.6	-	-	35	10.7	3	0.8
70-74	8	4.3	1	0.5	34	10.4	4	1.0
75-79	18	9.8	-	-	24	7.3	3	0.8
80-84	6	3.3	5	2.4	4	1.2	1	0.3
85-89	1	0.5	3	1.5	5	1.5	2	0.5
90-94	3	1.6	4	2.0	4	1.2	3	0.8
95-99	10	5.4	1	0.5	5	1.5	1	0.3
100-104	19	10.3	1	0.5	8	2.4	2	0.5
105-109	18	9.8	2	1.0	7	2.1	1	0.3
110-114	20	10.9	2	1.0	3	0.9	2	0.5
115-119	12	6.5	-	-	7	2.1	2	0.5
120-124	14	7.6	1	0.5	3	0.9	2	0.5
125-129	12	6.5	1	0.5	6	1.8	3	0.8
130-134	9	4.9	-	-	8	2.4	2	0.5
135-139	4	2.2	-	-	7	2.1	1	0.3
140-144	-	-	1	0.5	12	3.7	-	-
145-149	-	-	-	-	8	2.4	1	0.3
150-154	2	1.1	-	-	13	4.0	3	0.8
155-159	1	0.5	-	-	7	2.1	-	-
160-164	1	0.5	-	-	4	1.2	1	0.3
165-169	-	-	-	-	2	0.6	-	-
170-174	-	-	-	-	1	0.3	-	-
175-179	-	-	-	-	-	-	-	-
180-184	1	0.5	-	-	-	-		
TOTALS	184	99.6	205	100.2	327	99.3	387	100.2

TABLE 3

Length-Frequency Distribution Recorded for Striped Bass

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	-	-	-	-	3	5.3	-	-
15-19	-	-	-	-	9	15.8	3	8.6
20-24	-	-	-	-	1	1.8	1	2.9
25-29	-	-	-	-	10	17.5	7	20.0
30-34	1	12.5	-	-	5	8.8	3	8.6
35-39	4	50.0	2	4.4	5	8.8	5	14.3
40-44	-	-	10	22.2	1	1.8	2	5.7
45-49	-	-	13	28.9	-	-	3	8.6
50-54	-	-	6	13.3	-	-	4	11.4
55-59	-	-	7	15.6	-	-	2	5.7
60-64	-	-	3	6.7	-	-	3	8.6
65-69	-	-	-	-	1	1.8	1	2.9
70-74	-	-	-	-	4	7.0	-	-
75-79	-	-	-	-	2	3.5	-	-
80-84	-	-	-	-	2	3.5	-	-
85-89	-	-	2	4.4	5	8.8	-	-
90-94	-	-	-	-	1	1.8	-	-
95-99	1	12.5	-	-	-	-	-	-
100-104	-	-	-	-	-	-	-	-
105-109	-	-	-	-	2	3.5	-	-
110-114	-	-	1	2.2	2	3.5	-	-
115-119	-	-	1	2.2	1	1.8	1	2.9
120-124	-	-	-	-	-	-	-	-
125-129	1	12.5	-	-	1	1.8	-	-
130-134	-	-	-	-	1	1.8	-	-
135-139	-	-	-	-	-	-	-	-
140-144	-	-	-	-	-	-	-	-
145-149	-	-	-	-	-	-	-	-
150-154	-	-	-	-	-	-	-	-
155-159	1	12.5	-	-	-	-	-	-
160-164	-	-	-	-	1	1.8	-	-
165-169	-	-	-	-	-	-	-	-
TOTAL	8	100.0	45	99.9	57	100.4	35	100.2

TABLE 4

Length-Frequency Distribution Recorded for Shad and Alewife

Standard Length (Millimeters)	Shad								Alewife							
	N. of Poughkeepsie				S. of Poughkeepsie				N. of Poughkeepsie				S. of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2		Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
10-14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15-19	-	-	-	-	-	-	-	-	9	3.1	-	-	-	-	-	-
20-24	-	-	-	-	-	-	-	-	22	7.5	-	-	-	-	-	-
25-29	-	-	-	-	-	-	-	-	21	7.1	-	-	2	4.2	-	-
30-34	-	-	1	8.3	-	-	-	-	136	46.2	2	2.7	12	25.0	1	0.7
35-39	-	-	-	-	-	-	-	-	80	27.2	20	27.4	11	22.9	2	1.5
40-44	-	-	1	8.3	-	-	-	-	15	5.1	29	39.7	11	22.9	7	5.2
45-49	-	-	3	25.0	-	-	-	-	5	1.7	16	21.9	12	25.0	29	21.5
50-54	-	-	-	-	-	-	1	33.3	1	.3	5	6.9	-	-	59	43.7
55-59	-	-	5	41.7	-	-	1	33.3	-	-	1	1.4	-	-	32	23.7
60-64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	3.7
65-69	-	-	1	8.3	-	-	1	33.3	-	-	-	-	-	-	-	-
70-74	-	-	1	8.3	-	-	-	-	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80-84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85-89	1	50.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90-94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95-99	-	-	-	-	-	-	-	-	3	1.0	-	-	-	-	-	-
100-104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105-109	1	50.0	-	-	-	-	-	-	2	.7	-	-	-	-	-	-
TOTAL	2	100.0	12	99.9	-	-	3	99.9	294	99.9	73	100.0	48	100.0	135	100.0

TABLE 5

Length-Frequency Distribution Recorded for Blueback Herring

	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	-	-	-	-	-	-	-	-
15-19	31	9.3	-	-	14	13.5	-	-
20-24	147	44.1	49	8.7	72	69.2	4	1.3
25-29	122	36.6	218	38.8	15	14.4	37	12.0
30-34	28	8.4	155	27.6	2	1.9	107	34.7
35-39	2	0.6	101	18.0	-	-	113	36.6
40-44	-	-	32	5.7	-	-	30	9.7
45-49	-	-	4	0.7	-	-	15	4.9
50-54	-	-	1	0.2	-	-	2	0.6
55-59	-	-	-	-	-	-	-	-
60-64	-	-	-	-	-	-	-	-
65-69	-	-	-	-	-	-	-	-
70-74	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-
80-84	-	-	-	-	-	-	-	-
85-89	1	0.3	-	-	-	-	-	-
90-94	-	-	-	-	-	-	-	-
95-99	-	-	-	-	1	1.0	-	-
TOTAL	331	99.3	560	100.7	104	100.0	308	99.8

TABLE 6a

Length-Frequency Distribution Recorded for Freshwater Killifish

North of Poughkeepsie

Standard Length (Millimeters)	Period 1						Period 2					
	Immature		Mature				Immature		Mature			
			Male		Female				Male		Female	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
10-14	-	-	-	-	-	-	-	-	-	-	-	-
15-19	-	-	-	-	-	-	4	1.8	-	-	-	-
20-24	1	100.0	-	-	-	-	74	32.4	-	-	-	-
25-29	-	-	-	-	-	-	73	32.0	-	-	-	-
30-34	-	-	-	-	-	-	49	21.5	-	-	-	-
35-39	-	-	-	-	1	1.5	23	10.1	-	-	2	2.9
40-44	-	-	4	6.6	2	3.0	4	1.8	-	-	6	8.8
45-49	-	-	10	16.4	4	6.0	1	0.4	1	5.6	-	-
50-54	-	-	12	19.7	13	19.4	-	-	2	11.1	1	1.5
55-59	-	-	13	21.3	10	14.9	-	-	5	27.8	7	10.3
60-64	-	-	15	24.6	19	28.3	-	-	4	22.2	15	22.1
65-69	-	-	3	4.9	7	10.4	-	-	5	27.8	22	32.3
70-74	-	-	2	3.3	8	11.9	-	-	-	-	12	17.6
75-79	-	-	2	3.3	1	1.5	-	-	-	-	1	1.5
80-84	-	-	-	-	2	3.0	-	-	-	-	1	1.5
85-89	-	-	-	-	-	-	-	-	1	5.6	1	1.5
90-94	-	-	-	-	-	-	-	-	-	-	-	-
95-99	-	-	-	-	-	-	-	-	-	-	-	-
100-104	-	-	-	-	-	-	-	-	-	-	-	-
105-109	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	1	100.0	61	100.1	67	99.9	228	100.0	18	100.1	68	100.0

TABLE 6b

Length-Frequency Distribution Recorded for Freshwater Killifish

South of Poughkeepsie

Standard Length (Millimeters)	Period 1						Period 2					
	Immature		Mature				Immature		Mature			
			Male		Female				Male		Female	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
10-14	6	4.4	-	-	-	-	7	1.6	-	-	-	-
15-19	55	40.1	-	-	-	-	44	9.9	-	-	-	-
20-24	47	34.3	-	-	-	-	140	31.4	-	-	-	-
25-29	27	19.7	-	-	-	-	155	34.7	-	-	-	-
30-34	2	1.5	-	-	4	0.8	58	13.0	-	-	-	-
35-39	-	-	4	0.8	18	3.6	25	5.6	-	-	-	-
40-44	-	-	28	5.8	36	7.1	14	3.1	2	1.3	-	-
45-49	-	-	89	18.5	49	9.7	3	0.7	8	5.3	1	0.6
50-54	-	-	106	22.0	107	21.2	-	-	43	28.6	34	19.9
55-59	-	-	101	21.0	96	19.0	-	-	58	38.6	69	40.3
60-64	-	-	74	15.4	88	17.4	-	-	21	14.0	33	19.3
65-69	-	-	41	8.5	31	6 1	-	-	10	6.7	14	8.2
70-74	-	-	26	5.4	30	5.9	-	-	2	1.3	9	5.3
75-79	-	-	4	0.8	27	5.3	-	-	3	2.0	6	3.5
80-84	-	-	5	1.0	8	1.6	-	-	3	2.0	3	1.8
85-89	-	-	1	0.2	8	1.6	-	-	-	-	-	-
90-94	-	-	-	-	2	0.4	-	-	-	-	1	0.6
95-99	-	-	-	-	1	0.2	-	-	-	-	1	0.6
100-104	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	137	100.0	479	99.4	505	99.9	446	100.0	150	99.8	171	100.1

TABLE 7a

Length-Frequency Distribution Record of Saltwater Killifish

North of Poughkeepsie

Standard Length (Millimeters)	Period 1						Period 2					
	Immature		Mature				Immature		Mature			
			Male		Female				Male		Female	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
25-29	-	-	-	-	-	-	1	8.3	-	-	-	-
30-34	-	-	-	-	-	-	4	33.3	-	-	-	-
35-40	-	-	-	-	-	-	4	33.3	-	-	-	-
40-44	-	-	-	-	-	-	2	16.7	-	-	-	-
45-49	-	-	-	-	-	-	1	8.3	-	-	-	-
50-54	-	-	-	-	-	-	-	-	-	-	1	100.0
55-59	-	-	1	100.0	1	100.0	-	-	-	-	-	-
60-64	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	1	100.0	1	100.0	12	99.9	-	-	1	100.0

TABLE 7b

Length-Frequency Distribution Record of Saltwater Killifish

South of Poughkeepsie

Standard Length (Millimeters)	Period 1						Period 2					
	Immature		Mature				Immature		Mature			
			Male		Female				Male		Female	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
10-14	5	8.8	-	-	-	-	-	-	-	-	-	-
15-19	13	22.8	-	-	-	-	4	2.3	-	-	-	-
20-24	20	35.1	-	-	-	-	21	11.9	-	-	-	-
25-29	15	26.3	-	-	-	-	61	34.6	-	-	-	-
30-34	4	7.0	1	0.5	-	-	51	29.0	-	-	-	-
35-39	-	-	8	3.8	4	1.4	20	11.4	-	-	-	-
40-44	-	-	32	15.3	13	4.6	16	9.1	1	2.6	-	-
45-49	-	-	38	18.2	30	10.6	2	1.1	5	12.8	1	2.4
50-54	-	-	48	22.9	52	18.4	1	0.6	13	33.3	6	14.3
55-59	-	-	35	16.7	58	20.5	-	-	16	41.0	18	42.9
60-64	-	-	26	12.4	64	22.6	-	-	2	5.1	13	31.0
65-69	-	-	11	5.3	25	8.8	-	-	1	2.6	2	4.8
70-74	-	-	5	2.4	16	5.6	-	-	-	-	1	2.4
75-79	-	-	1	0.5	8	2.8	-	-	1	2.6	1	2.4
80-84	-	-	3	1.4	3	1.1	-	-	-	-	-	-
85-89	-	-	1	0.5	3	1.1	-	-	-	-	-	-
90-94	-	-	-	-	4	1.4	-	-	-	-	-	-
95-99	-	-	-	-	-	-	-	-	-	-	-	-
100-104	-	-	-	-	1	0.4	-	-	-	-	-	-
105-109	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	57	100.0	209	99.9	283	99.3	176	100.0	39	100.0	42	100.2

TABLE 8

Length-Frequency Distribution Recorded for Northern and Tidewater Silversides

South of Poughkeepsie

Standard Length (Millimeters)	Northern Silverside Period 1 No.	%	Northern Silverside Period 2 No.	%	Tidewater Silverside Period 1 No.	%	Tidewater Silverside Period 2 No.	%
10-14	-	-	-	-	-	-	-	-
15-19	-	-	-	-	-	-	1	.6
20-24	1	4.0	1	0.8	-	-	7	4.5
25-29	2	8.0	6	4.6	-	-	14	9.0
30-34	8	32.0	18	9.9	-	-	2	1.3
35-39	7	28.0	23	17.5	-	-	2	1.3
40-44	1	4.0	26	19.8	2	2.9	3	1.9
45-49	3	12.0	18	13.7	4	5.7	15	9.6
50-54	3	12.0	22	16.8	35	50.0	58	37.1
55-59	-	-	12	9.2	23	32.8	47	30.1
60-64	-	-	2	1.5	6	8.6	6	3.8
65-69	-	-	8	6.1	-	-	2	1.3
70-74	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-
80-84	-	-	-	-	-	-	-	-
85-89	-	-	-	-	-	-	-	-
90-94	-	-	-	-	-	-	-	-
95-99	-	-	-	-	-	-	-	-
100-104	-	-	-	-	-	-	-	-
TOTAL	25	100.0	131	99.9	70	100.0	157	100.5

TABLE 9

Length-Frequency Distribution Recorded for Goldfish

Standard Length (Millimeters)	North of Poughkeepsie Period 1		North of Poughkeepsie Period 2		South of Poughkeepsie Period 1		South of Poughkeepsie Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	-	-	1	1.4	5	10.6	2	2.6
15-19	2	9.5	4	5.4	15	31.9	13	17.1
20-24	2	9.5	12	16.2	13	27.7	24	31.6
25-29	3	14.3	15	20.3	1	2.1	20	26.3
30-34	2	9.5	20	27.0	-	-	5	6.6
35-39	-	-	16	21.6	-	-	5	6.6
40-44	-	-	2	2.7	-	-	-	-
45-49	-	-	3	4.1	-	-	3	3.9
50-54	-	-	-	-	-	-	-	-
55-59	-	-	-	-	-	-	1	1.3
60-64	-	-	-	-	-	-	-	-
65-69	-	-	-	-	-	-	1	1.3
70-74	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-
80-84	1	4.8	-	-	-	-	-	-
85-89	1	4.8	-	-	1	2.1	-	-
90-94	-	-	-	-	1	2.1	-	-
95-99	1	4.8	-	-	2	4.2	-	-
100-104	-	-	-	-	-	-	-	-
105-109	1	4.8	-	-	1	2.1	-	-
110-114	-	-	-	-	-	-	-	-
115-119	1	4.8	-	-	1	2.1	1	1.3
120-124	1	4.8	1	1.4	-	-	-	-
125-129	-	-	-	-	1	2.1	-	-
130-134	-	-	-	-	-	-	-	-
135-139	1	4.8	-	-	-	-	-	-
140-144	-	-	-	-	-	-	-	-
145-149	-	-	-	-	-	-	-	-
150-154	-	-	-	-	-	-	-	-
155-159	1	4.8	-	-	-	-	-	-
160-164	2	9.5	-	-	1	2.1	-	-
165-169	-	-	-	-	1	2.1	-	-
170-174	1	4.8	-	-	1	2.1	-	-
175-179	-	-	-	-	-	-	-	-
180-184	-	-	-	-	-	-	1	1.3
185-189	-	-	-	-	-	-	-	-
190-194	1	4.8	-	-	1	2.1	-	-
195-199	-	-	-	-	-	-	-	-
200-204	-	-	-	-	1	2.1	-	-
205-209	-	-	-	-	-	-	-	-
210-214	-	-	-	-	-	-	-	-
215-219	-	-	-	-	-	-	-	-
220-224	-	-	-	-	-	-	-	-
225-229	-	-	-	-	1	2.1	-	-
230-234	-	-	-	-	-	-	-	-
TOTAL	21	100.3	74	100.1	47	99.3	76	99.9

TABLE 10

Length-Frequency Distribution Recorded for Spottail Shiner

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	5	1.2	-	-	2	0.4	2	3.0
15-19	34	8.4	-	-	95	18.3	6	8.9
20-24	68	16.8	4	1.4	60	11.6	30	44.7
25-29	88	21.7	29	10.2	7	1.4	14	20.9
30-34	20	4.9	46	16.2	-	-	6	8.9
35-39	9	2.2	70	24.6	-	-	1	1.5
40-44	-	-	37	13.0	5	1.0	1	1.5
45-49	1	0.2	8	2.8	29	5.6	-	-
50-54	8	2.0	4	1.4	56	10.8	-	-
55-59	30	7.4	-	-	63	12.2	-	-
60-64	38	9.4	3	1.1	66	12.7	1	1.5
65-69	53	13.1	14	4.9	71	13.7	4	6.0
70-74	34	8.4	30	10.6	36	6.9	2	3.0
75-79	6	1.5	31	10.9	13	2.5	-	-
80-84	6	1.5	4	1.4	7	1.4	-	-
85-89	4	1.0	4	1.4	3	0.3	-	-
90-94	1	0.2	-	-	2	0.4	-	-
95-99	-	-	-	-	1	0.2	-	-
TOTAL	404	99.9	284	99.9	516	99.9	67	99.9

TABLE 11

Length-Frequency Distribution Recorded for Golden Shiner

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	-	-	-	-	-	-	1	1.4
15-19	-	-	-	-	-	-	-	-
20-24	-	-	1	5.9	1	.9	23	32.9
25-29	-	-	4	23.5	-	-	31	44.3
30-34	2	1.6	3	17.6	-	-	2	2.9
35-39	-	-	4	23.5	2	1.9	-	-
40-44	3	2.3	-	-	7	6.6	-	-
45-49	11	8.5	-	-	18	17.0	-	-
50-54	25	19.4	-	-	16	15.1	2	2.9
55-59	25	19.4	-	-	23	21.7	-	-
60-64	31	24.0	1	5.9	14	13.2	2	2.9
65-69	6	4.7	1	5.9	7	6.6	3	4.3
70-74	7	5.4	-	-	4	3.8	2	2.9
75-79	5	3.9	-	-	2	1.9	-	-
80-84	1	0.8	-	-	-	-	1	1.4
85-89	1	0.8	1	5.9	-	-	-	-
90-94	2	1.6	1	5.9	-	-	-	-
95-99	1	0.8	1	5.9	-	-	-	-
100-104	-	-	-	-	-	-	-	-
105-109	-	-	-	-	-	-	-	-
110-114	-	-	-	-	2	1.9	-	-
115-119	-	-	-	-	1	0.9	-	-
120-124	-	-	-	-	-	-	-	-
125-129	-	-	-	-	-	-	-	-
130-134	-	-	-	-	-	-	1	1.4
135-139	-	-	-	-	1	0.9	-	-
140-144	2	1.6	-	-	1	0.9	-	-
145-149	-	-	-	-	-	-	1	1.4
150-154	3	2.3	-	-	3	2.8	-	-
155-159	3	2.3	-	-	-	-	-	-
160-164	-	-	-	-	2	1.9	-	-
165-169	-	-	-	-	-	-	-	-
170-174	-	-	-	-	-	-	-	-
175-179	1	0.8	-	-	-	-	-	-
180-184	-	-	-	-	1	0.9	-	-
185-189	-	-	-	-	-	-	-	-
190-194	-	-	-	-	1	0.9	1	1.4
TOTAL	129	100.2	17	100.0	106	99.8	70	100.1

TABLE 12

Length-Frequency Distribution Recorded for Common Sunfish

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	12	12.0	49	15.9	1	0.4	8	2.8
15-19	10	10.0	121	39.3	-	-	29	10.3
20-24	12	12.0	54	17.6	-	-	43	15.3
25-29	2	2.0	25	8.1	-	-	67	23.8
30-34	1	1.0	26	8.5	3	1.1	43	15.3
35-39	2	2.0	14	4.6	15	5.4	10	3.5
40-44	2	2.0	5	1.6	6	2.2	4	1.4
45-49	1	1.0	1	0.3	23	8.3	-	-
50-54	1	1.0	-	-	28	10.2	3	1.1
55-59	4	4.0	-	-	31	11.3	3	1.1
60-64	3	3.0	1	0.30	39	14.2	7	2.5
65-69	4	4.0	2	0.70	30	10.9	10	3.5
70-74	9	9.0	1	0.30	21	7.6	5	1.8
75-79	5	5.0	-	-	11	4.0	7	2.5
80-84	2	2.0	-	-	4	1.5	5	1.8
85-89	1	1.0	-	-	3	1.1	12	4.3
90-94	3	3.0	2	0.70	7	2.5	1	.4
95-99	3	3.0	-	-	16	5.8	1	.4
100-104	1	1.0	1	0.3	14	5.1	3	1.1
105-109	6	6.0	-	-	12	4.4	5	1.8
110-114	3	3.0	2	0.7	5	1.8	9	3.2
115-119	4	4.0	2	0.7	2	0.7	3	1.1
120-124	5	5.0	1	0.3	2	0.7	2	0.7
125-129	1	1.0	-	-	2	0.7	1	.4
130-134	2	2.0	-	-	-	-	-	-
135-139	1	1.0	-	-	-	-	-	-
TOTAL	100	100.0	307	99.9	275	99.9	281	99.8

TABLE 13

Length-Frequency Distribution Recorded for Johnny Darter

Standard Length (Millimeters)	North of Poughkeepsie				South of Poughkeepsie			
	Period 1		Period 2		Period 1		Period 2	
	No.	%	No.	%	No.	%	No.	%
10-14	4	2.2	-	-	-	-	-	-
15-19	19	10.6	-	-	5	7.7	-	-
20-24	63	35.2	11	3.2	11	16.9	-	-
25-29	35	19.5	64	18.4	13	20.0	2	2.8
30-34	22	12.3	151	43.3	-	-	9	12.7
35-39	2	1.1	100	28.7	1	1.5	27	38.0
40-44	1	0.6	10	2.9	7	10.8	26	36.6
45-49	12	6.7	2	0.6	4	6.2	5	7.0
50-54	11	6.1	4	1.1	7	10.8	-	-
55-59	6	3.3	4	1.1	16	24.6	2	2.8
60-64	3	1.7	2	0.6	-	-	-	-
65-69	1	0.6	-	-	-	-	-	-
70-74	-	-	-	-	1	1.5	-	-
TOTAL	179	99.8	348	99.9	65	100.0	71	99.9

TABLE 14

Average Catch* at Each Station for the 14 Species Taken Most Frequently

Age Group	Station									Average
	IW3	IIW1	IIW2	IIW2A	IIIW2	IVW1	IVW2	IVW3	IVW4	
Tidewater Silverside										
0+	21	10	0	0	0	0	0	0	0	3
1+ or older	180	22	0	0	0	0	0	0	0	22
Total	201	32	0	0	0	0	0	0	0	25
White Perch										
0+	54	1424	4	0	0	246	98	2	26	206
1+ or older	230	218	28	9	0	20	76	168	114	96
Total	284	1642	32	9	0	266	174	170	140	302
(Series 1 and 2 Combined) Alewife										
0+	77	112	24	68	4	170	88	44	327	102
1+ or older	0	0	0	0	0	0	0	10	0	1
Total	77	112	24	68	4	170	88	54	327	103
Blueback Herring										
0+	8	356	432	378	6	560	504	318	2786	594
1+ or older	0	0	2	1	0	0	0	2	0	1
Total	8	356	434	379	6	560	504	320	2786	595
Common Sunfish										
0+	0	0	0	492	54	72	0	1344	2	218
1+ or older	0	161	460	177	129	63	2	76	9	120
Total	0	161	460	669	183	135	2	1420	11	338

*Per unit area (see text)

TABLE 14 (Cont'd.)

Average Catch* at Each Station for the 14 Species Taken Most Frequently

(Series 1 and 2 Combined)

Age Group	Station									Average
	IW3	IIW1	IIW2	IIW2A	IIIW2	IVW1	IVW2	IVW3	IVW4	
Freshwater Killifish										
0+	8	98	448	1744	2261	126	8	38	454	576
1+ or older	6	291	1186	236	2569	120	38	54	171	519
Total	14	389	1634	1980	4830	246	46	92	625	1095
Golden Shiner										
0+	0	18	84	0	76	0	4	20	0	22
1+ or older	0	2	0	22	157	20	106	16	33	40
Total	0	20	84	22	233	20	110	36	33	62
Goldfish										
0+	6	34	0	82	84	58	0	68	90	47
1+ or older	0	17	8	8	22	0	0	44	16	13
Total	6	51	8	90	106	58	0	112	106	60

*Per unit area (see text)

TABLE 14 (Cont'd.)

Average Catch* at Each Station for the 14 Species Taken Most Frequently

Age Group	Station									Average
	IW3	IIW1	IIW2	IIW2A	IIIW2	IVW1	IVW2	IVW3	IVW4	
Johnny Darter										
0+	1	28	296	13	4	430	5	990	206	219
1+ or older	0	35	64	6	21	30	1	4	31	110
Total	1	63	360	19	25	460	6	994	237	329
Northern Silverside										
0+	160	12	0	0	0	0	0	0	0	19
1+ or older	0	2	0	0	0	0	0	0	0	0
Total	160	14	0	0	0	0	0	0	0	19
Saltwater Killifish										
0+	14	20	360	89	572	0	0	0	19	119
1+ or older	38	290	2064	110	190	0	0	0	4	300
Total	52	310	2424	199	762	0	0	0	23	419
Shad										
0+	0	6	0	0	0	2	16	6	1	3
1+ or older	0	0	0	0	0	0	0	4	0	0
Total	0	6	0	0	0	2	16	10	1	3
Spottail Shiner										
0+	1	108	644	4	126	248	149	0	812	232
1+ or older	4	691	156	0	297	64	352	0	82	183
Total	5	799	800	4	423	312	501	0	894	415

*Per unit area (see text)

TABLE 14 (Cont'd.)

Average Catch* at Each Station for the 14 Species Taken Most Frequently

Age Group	Station									Average
	IW3	IIW1	IIW2	IIW2A	IIIW2	IVW1	IVW2	IVW3	IVW4	
					Striped Bass					
0+	26	74	0	2	0	4	58	4	12	20
1+ or older	18	63	0	6	0	0	1	0	20	12
Total	44	137	0	8	0	4	59	4	32	32
					TOTAL					
Total	852	4092	6260	3447	6572	2233	1506	3212	5215	3797

*Per unit area (see text)

Figure 1 Relative abundance of the O + age group of the various species in 1965, 1966 and 1967.

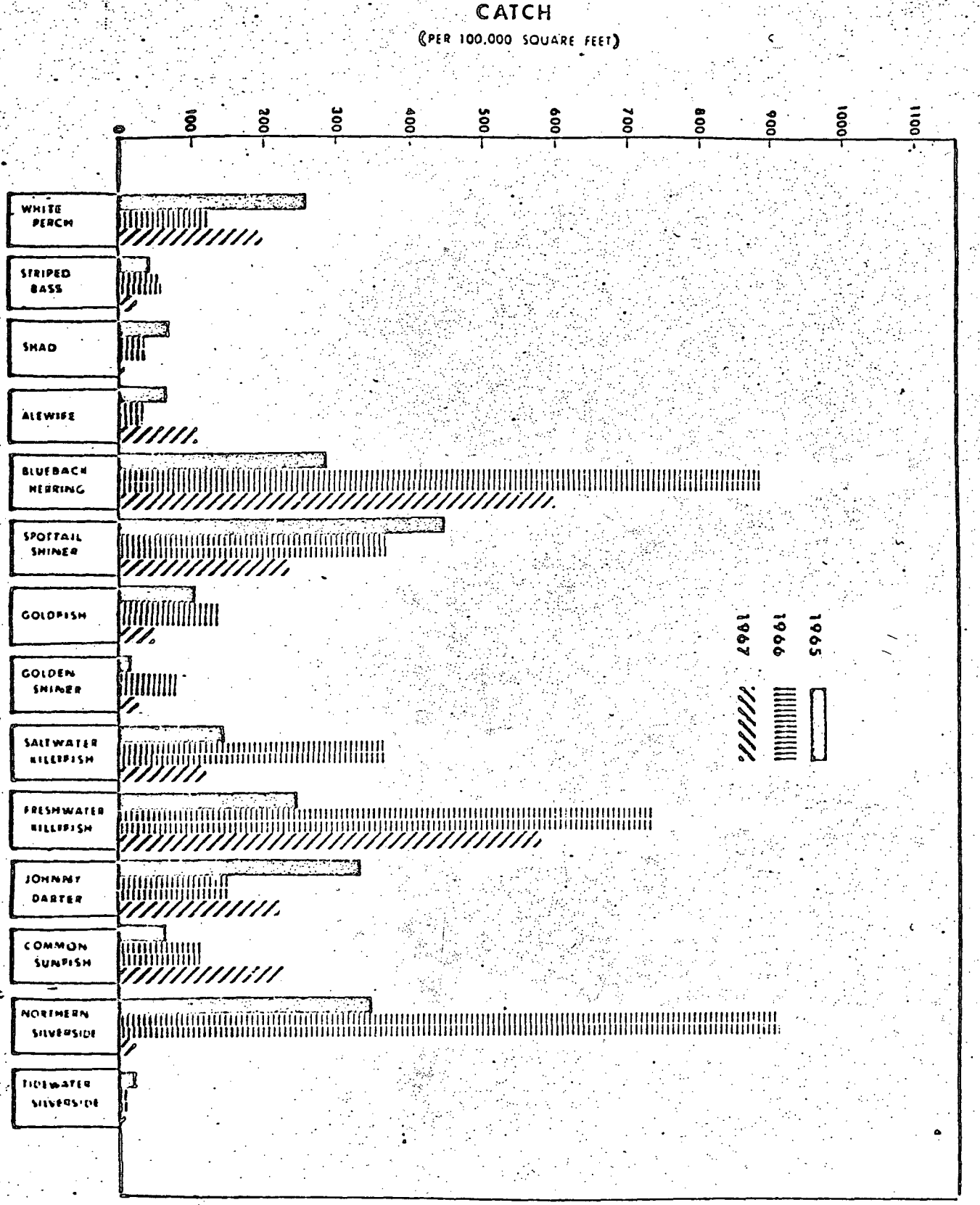


Figure 2 Length frequency distribution of the White Perch and Striped Bass.

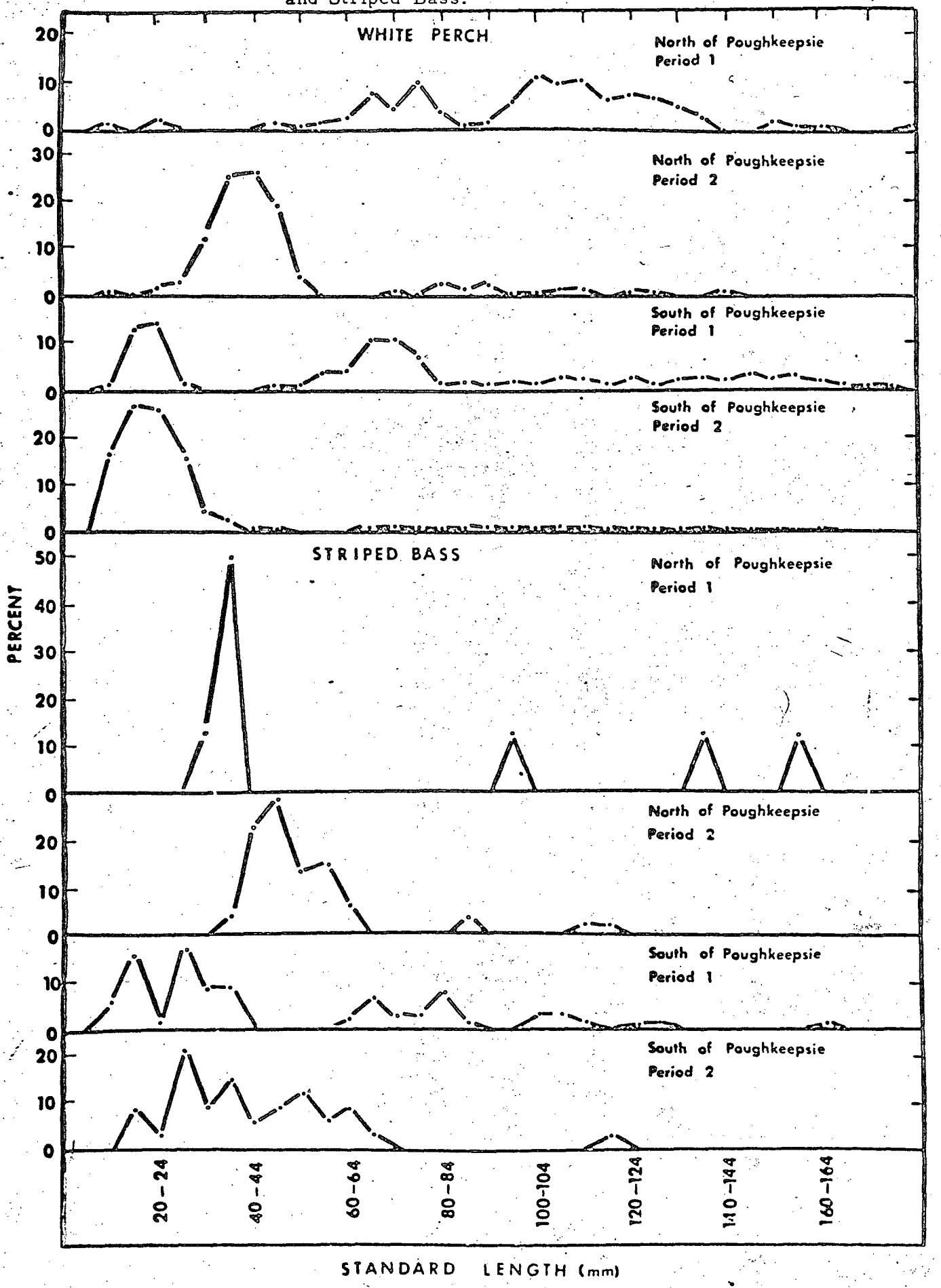


Figure 3 Length frequency distribution of the Blueback Herring.

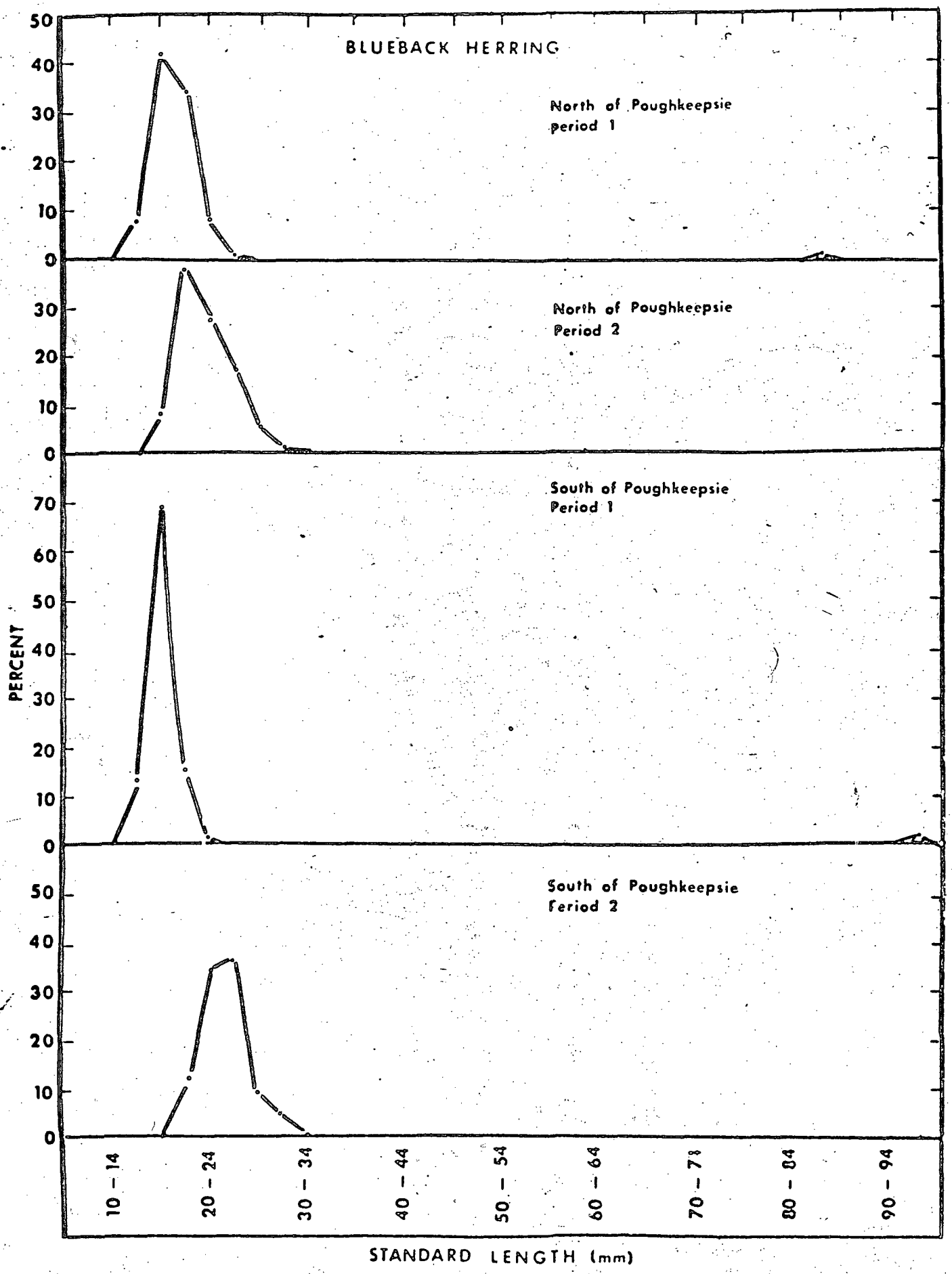


Figure 4 Length frequency distribution of the Shad.

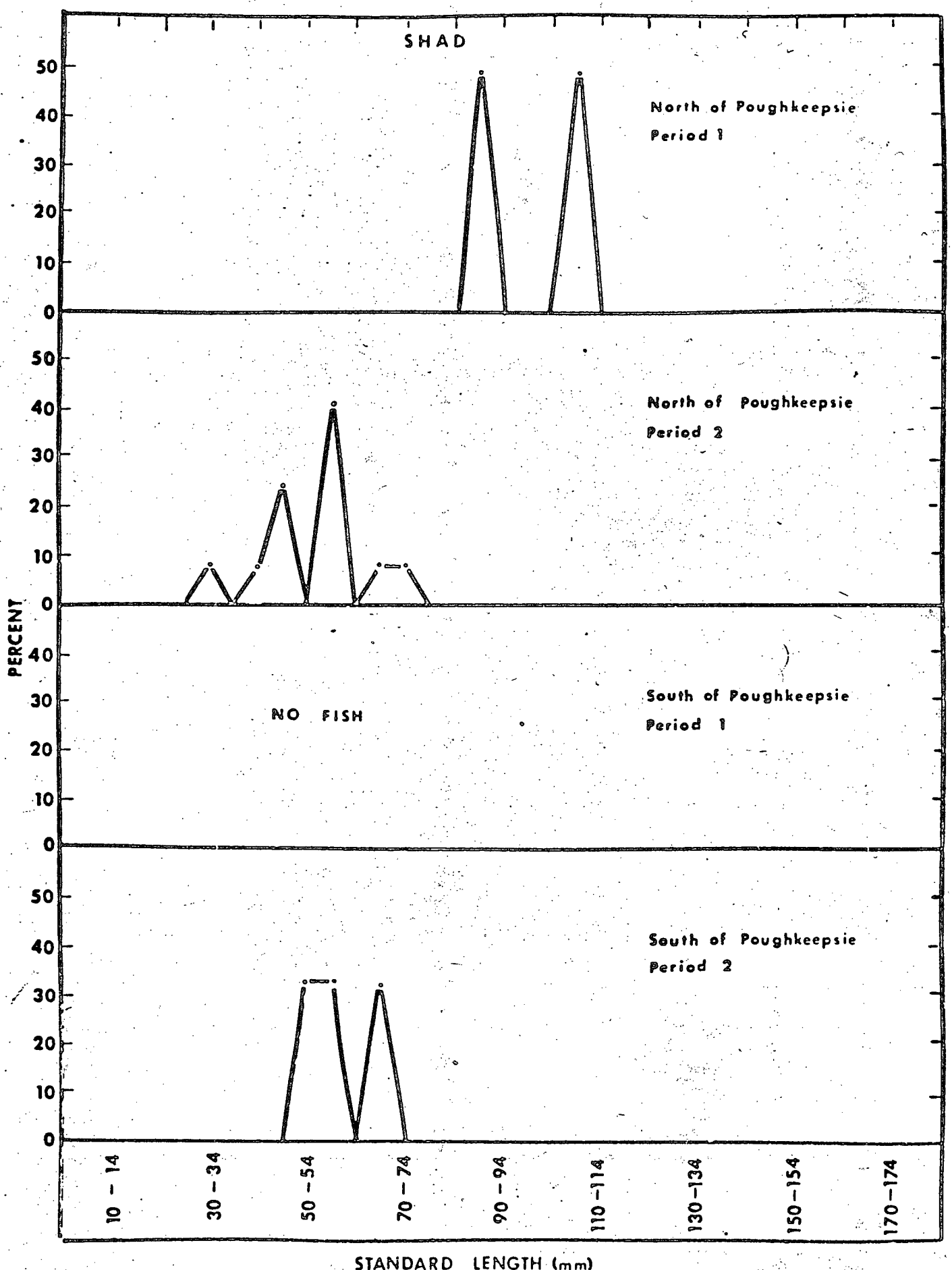


Figure 5 Length frequency distribution of the Alewife.

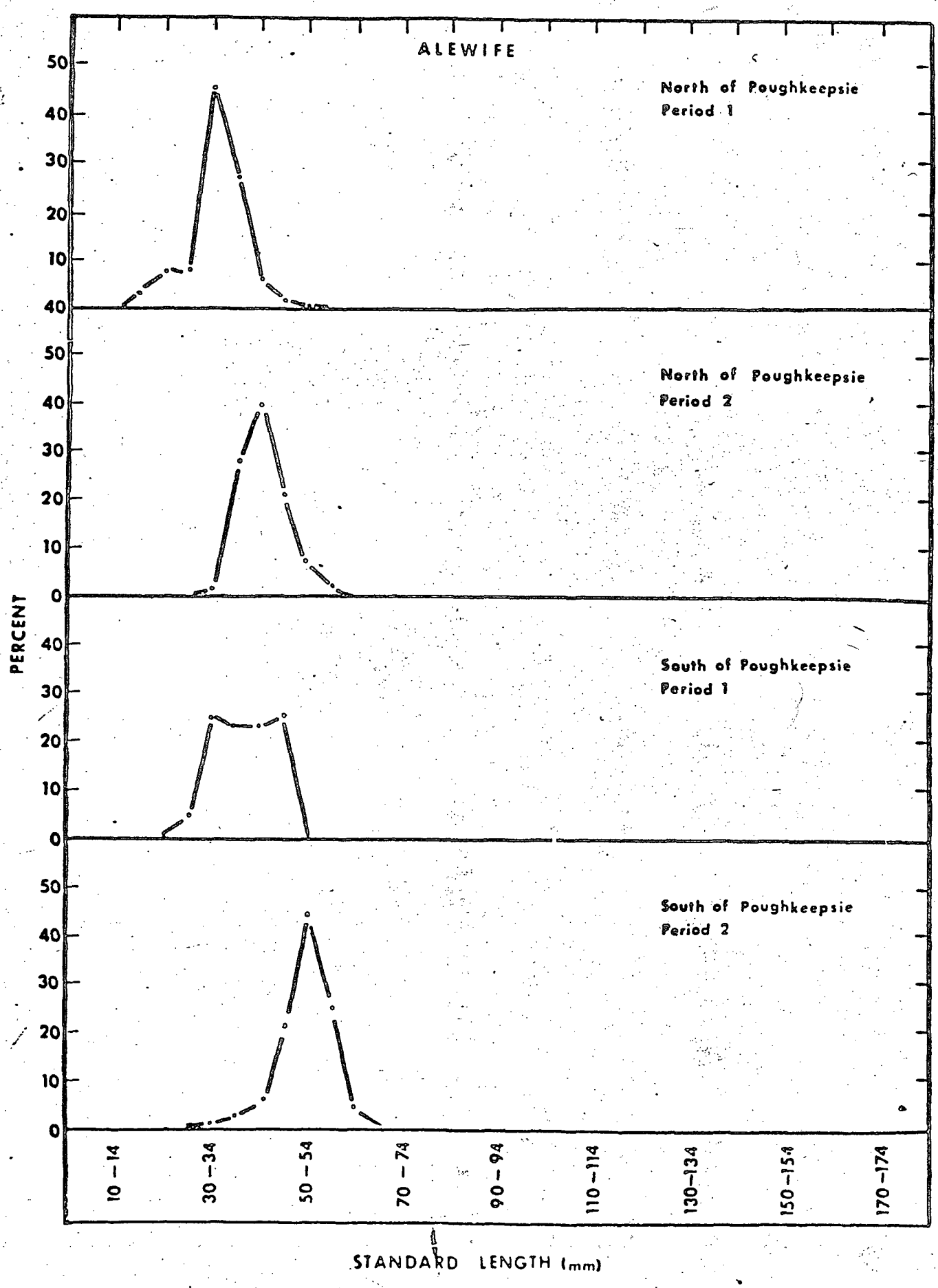


Figure 6 Length frequency distribution of the Northern and Tidewater Silversides.

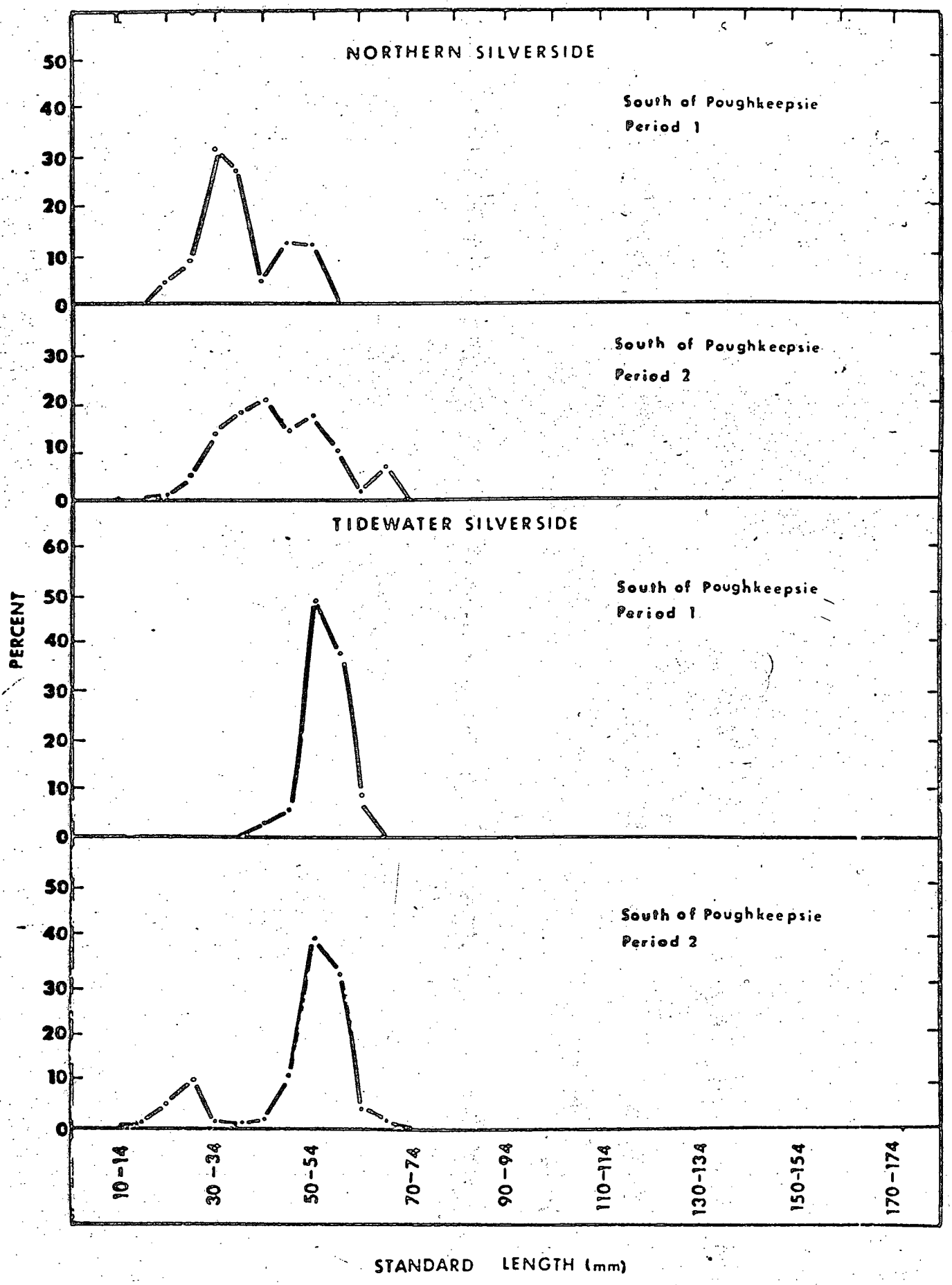


Figure 7 Length frequency distribution of the freshwater Killifish.

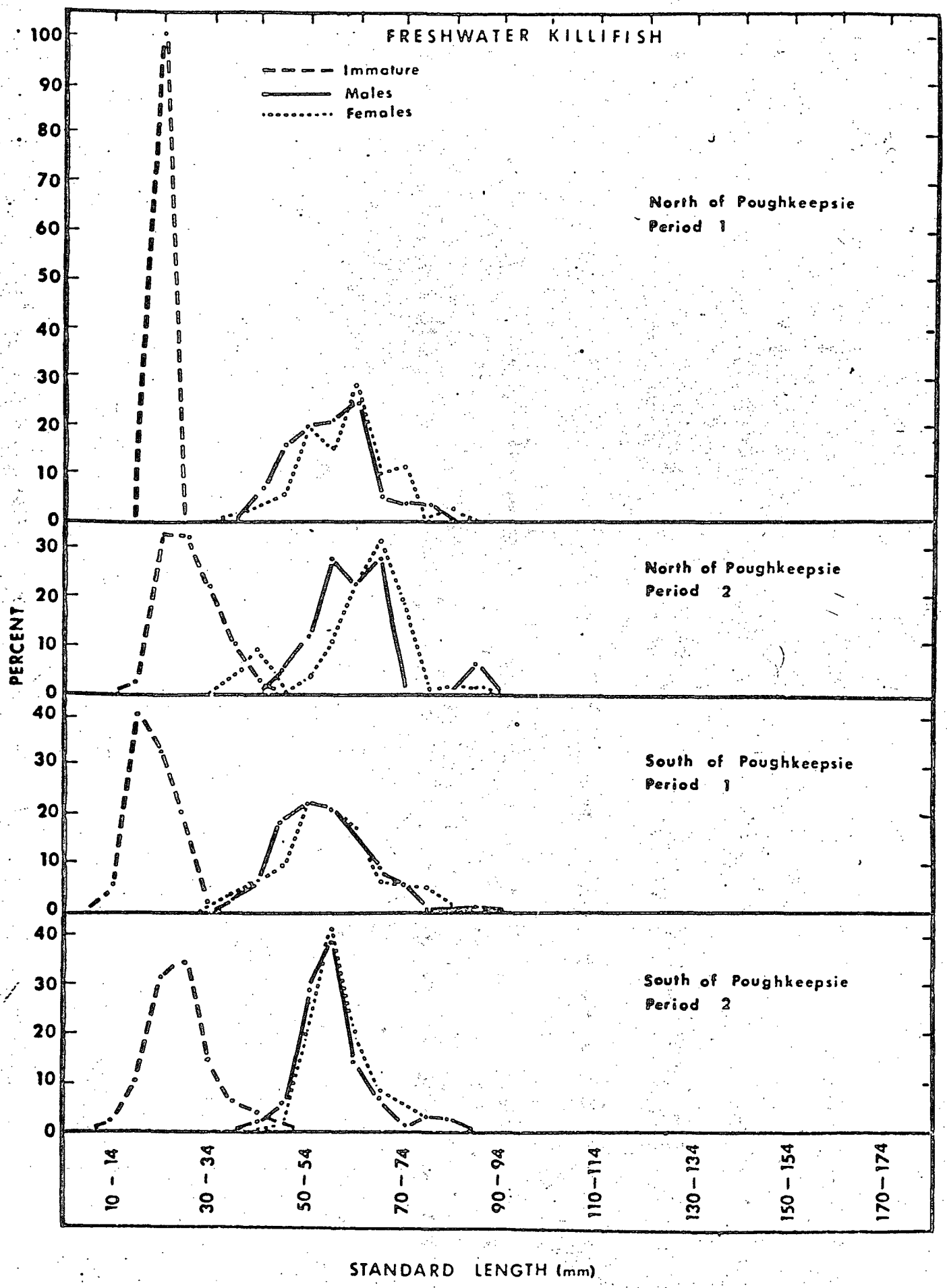


Figure 8 Length frequency distribution of the saltwater Killifish north of Poughkeepsie.

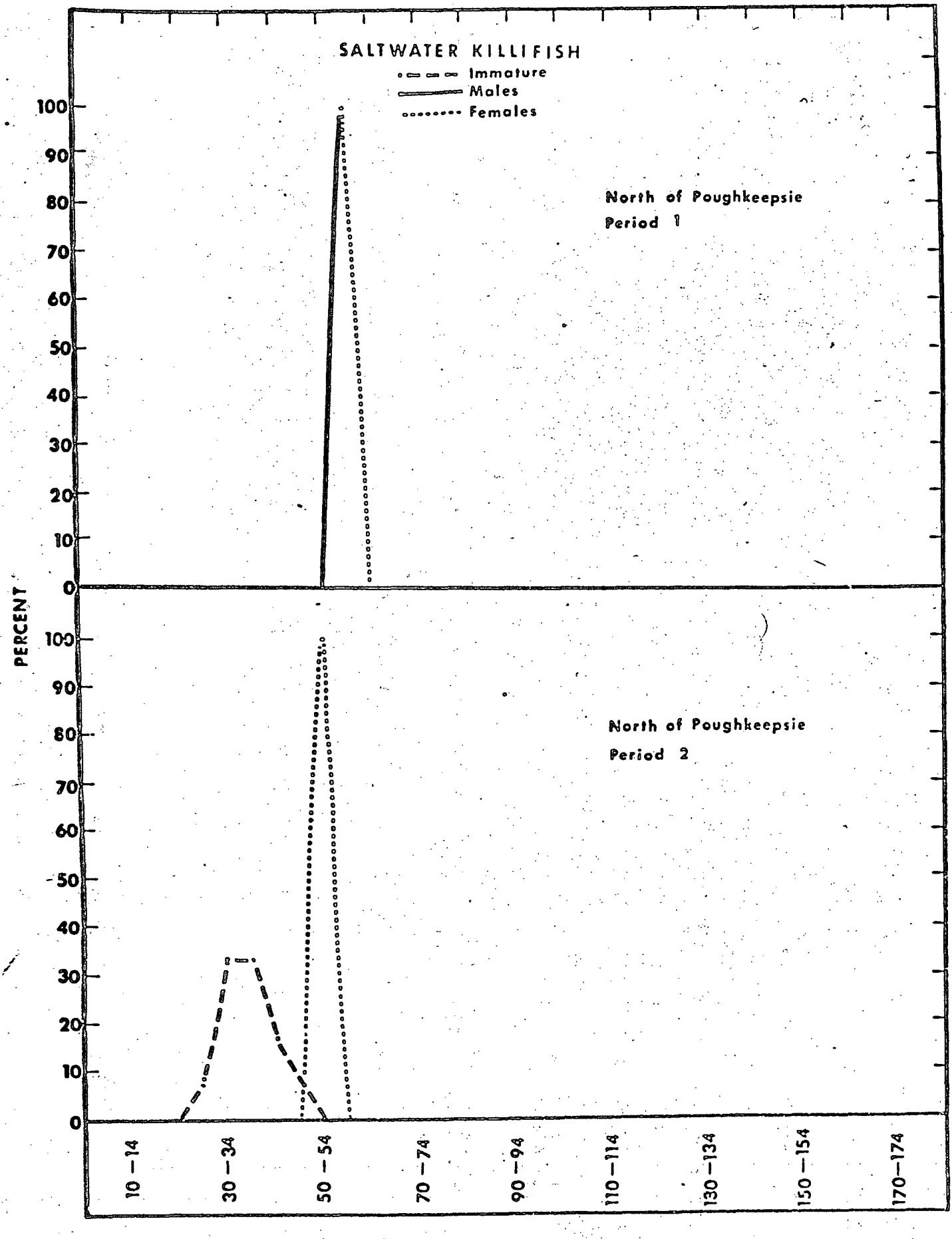


Figure 9 Length frequency distribution of the saltwater Killifish south of Poughkeepsie.
Length frequency distribution of the Spottail Shiner.

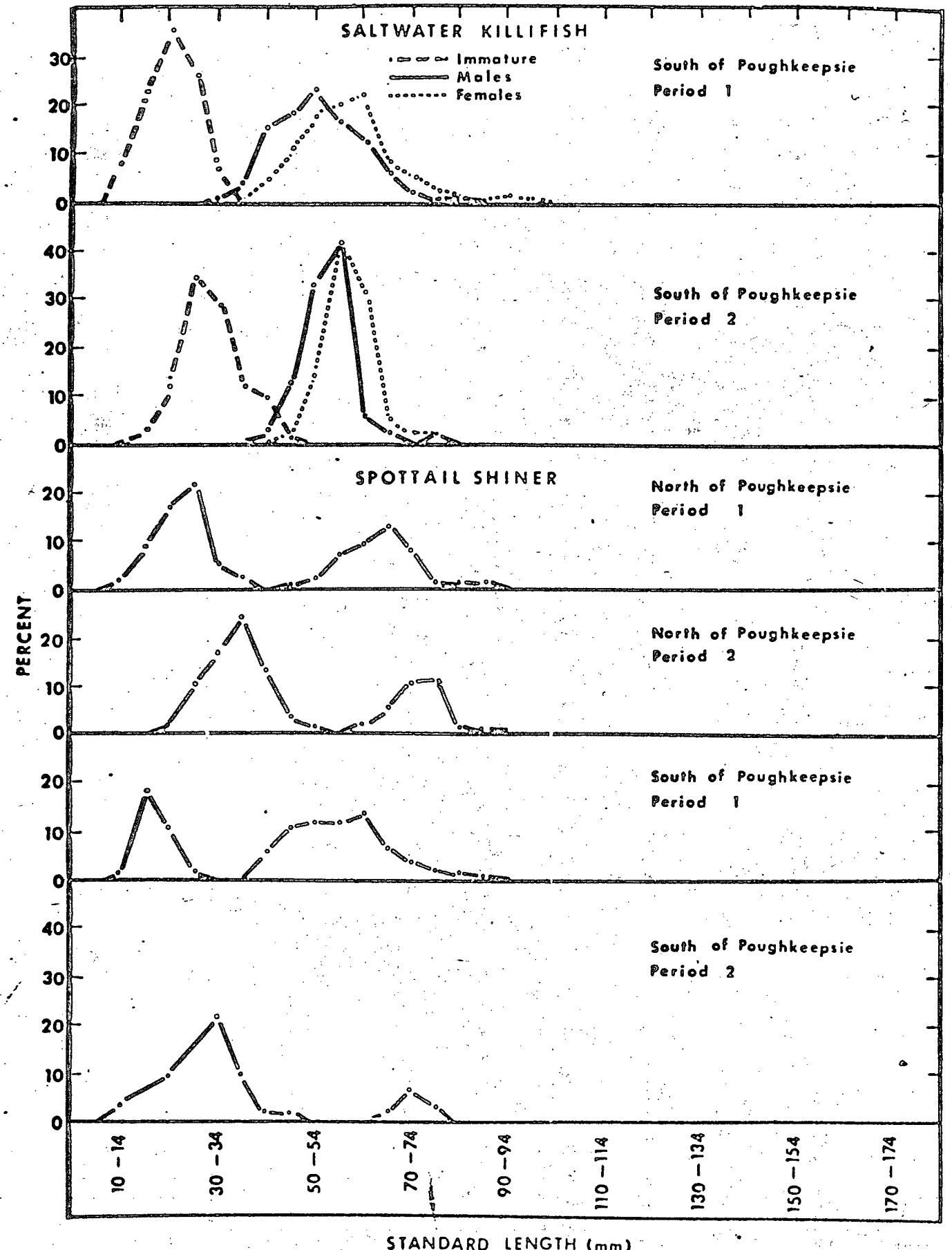


Figure 10 Length frequency distribution of the Goldfish and Common Sunfish.

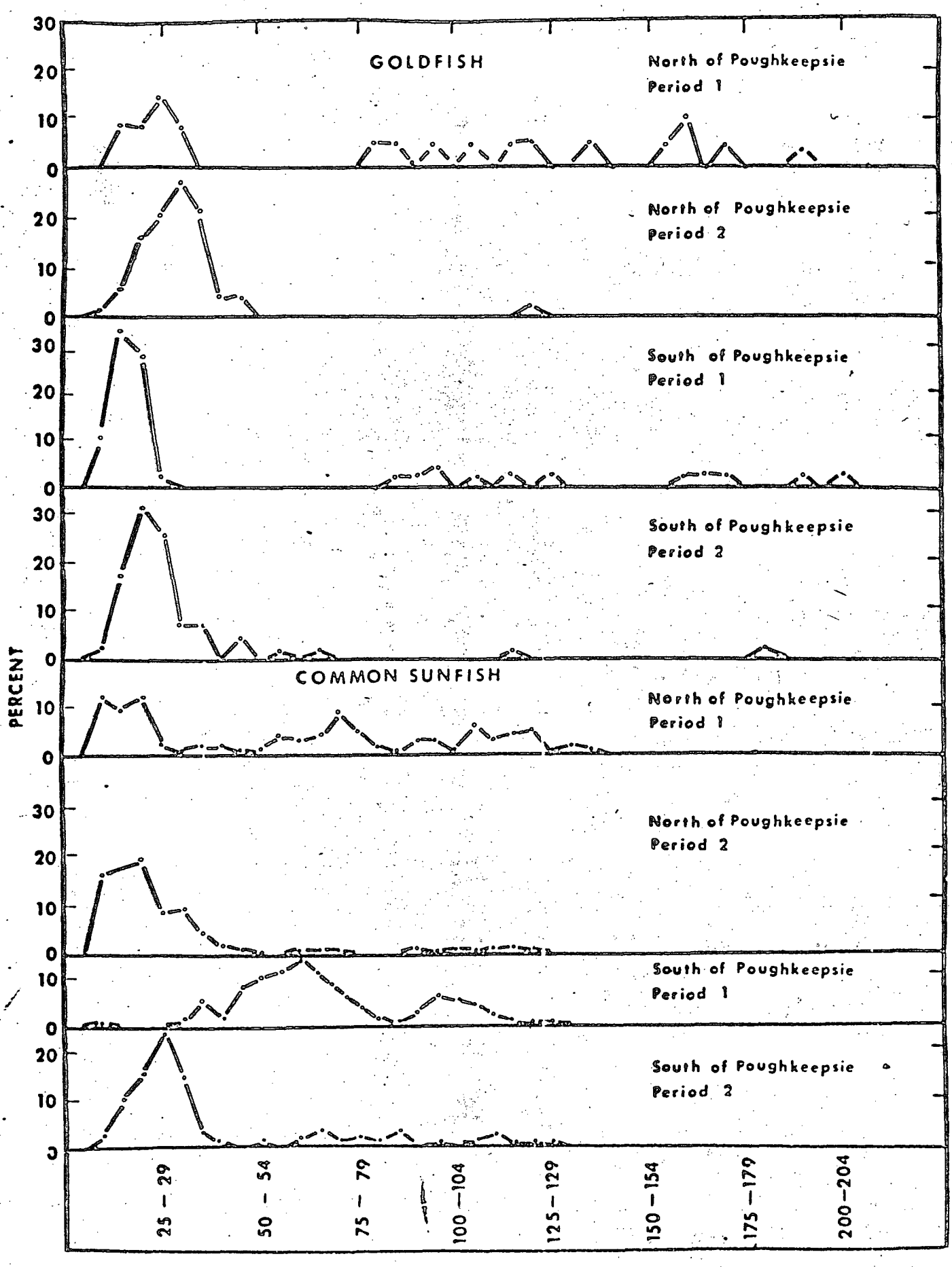


Figure 11 Length frequency distribution of the Golden Shiner.

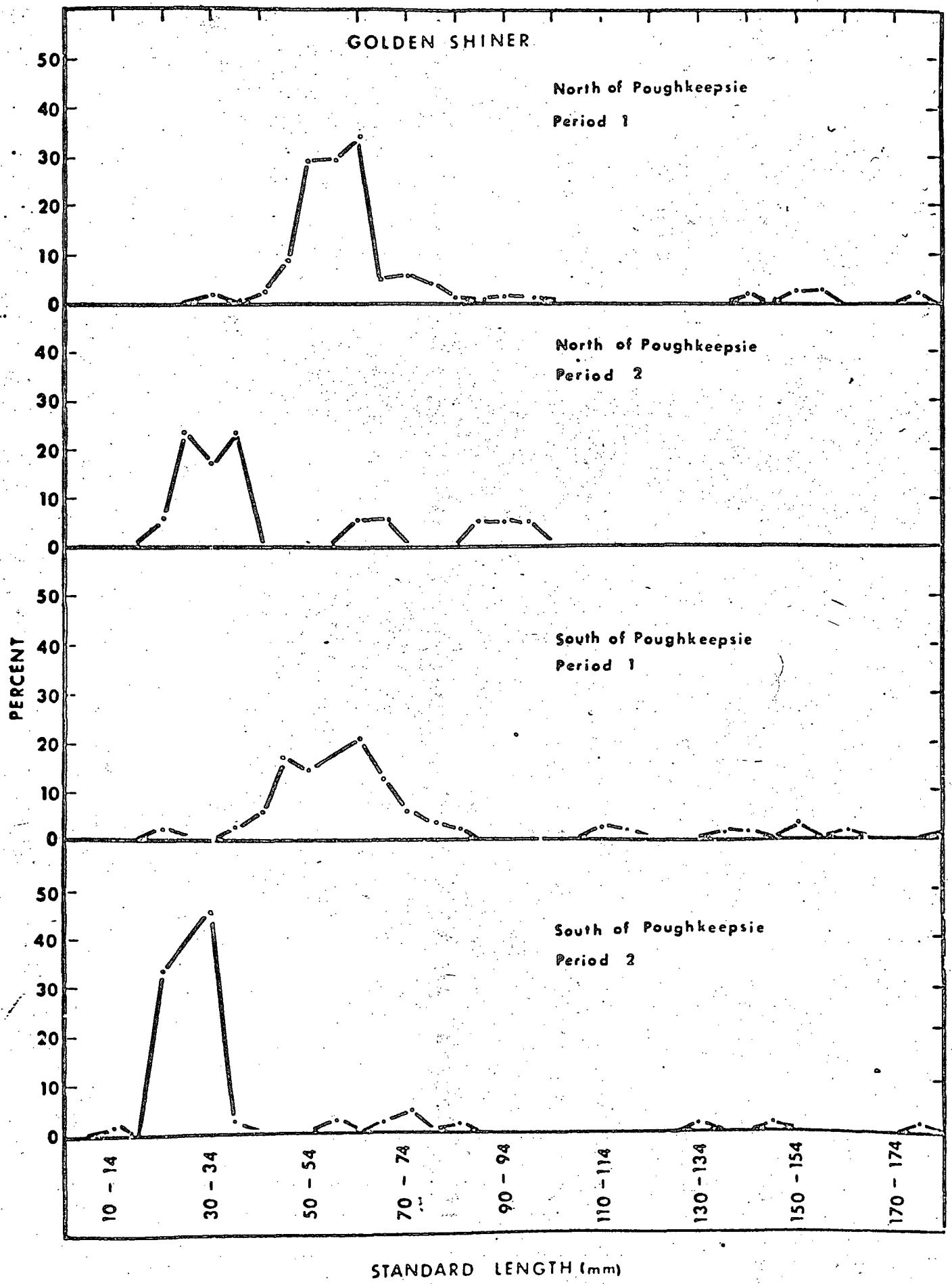
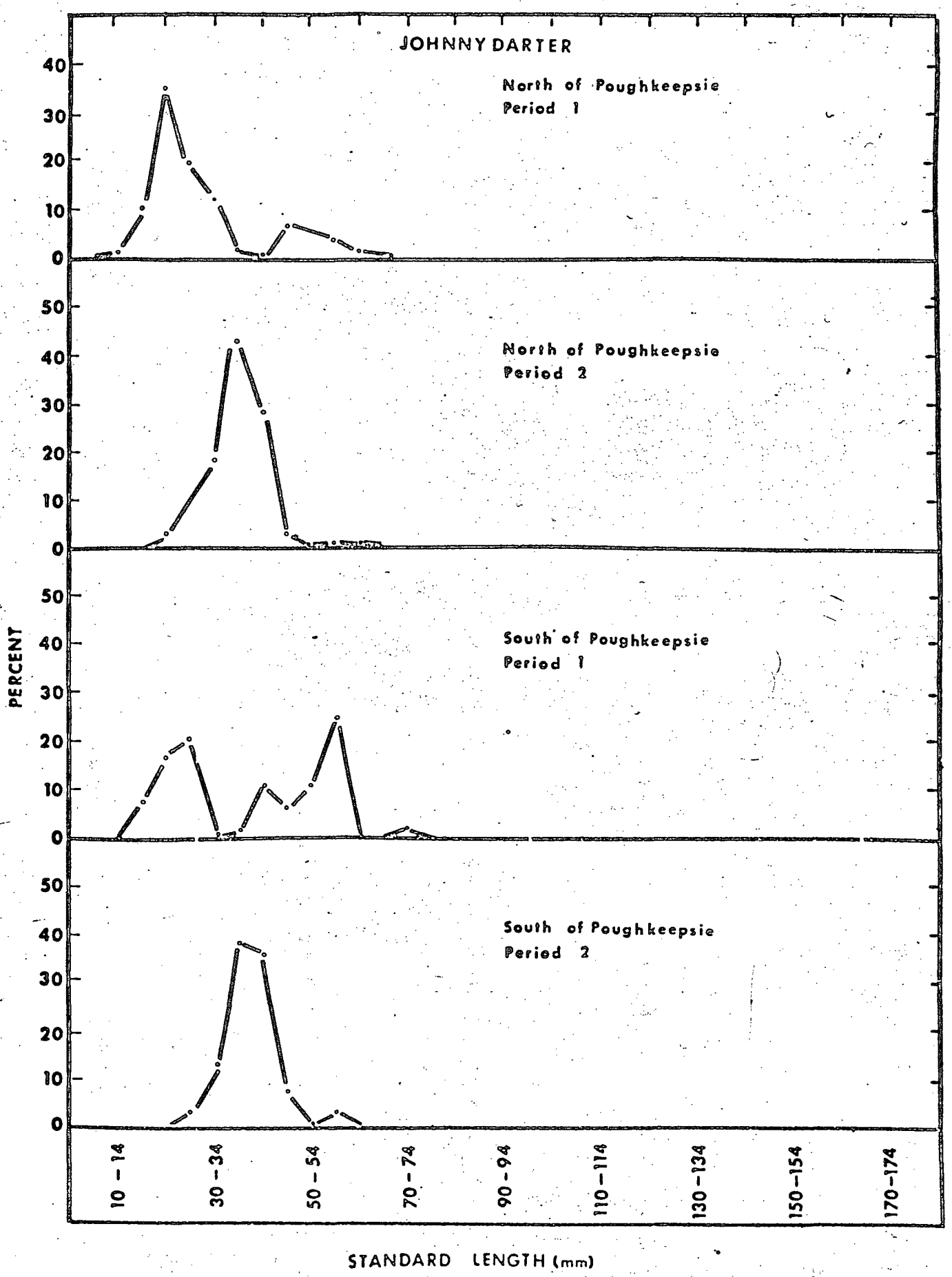


Figure 12 Length frequency distribution of the Johnny Darter.



APPENDIX A

Hudson River Sampling Sites 1967

STATION	SITE IDENT. NO.	MILES FROM BATTERY PARK
Tappan Zee Bridge (West End)	I-W-3	26.6
Fleet	II-W-1	41.4
Iona Isle	II-W-2	45.2
Cornwall (Mouth of Moodna)	II-W-2a	56.5
Marlboro	III-W-2	67.3
Esopus Meadows Light	IV-W-1	86.1
Ulster Landing	IV-W-2	95.1
Glunt's Point	IV-W-3	100.5
Cementon	IV-W-4	104.7

ZOOPLANKTON AND OTHER INVERTEBRATES IN THE HUDSON RIVER

By: H. I. Hirshfield and Elayne Musnick

Introduction and Specific Aims

A program of sampling for zooplankton and larger invertebrates in the Hudson River was conducted during the summer and subsequent months of 1967. Zooplankton studies were considered to be of particular interest.

A primary objective of the study was to obtain an inventory of invertebrate species in the midstream and along the shore and to compare the findings with the inventories made in 1936 and 1964. A comparison was made of the midstream plankton with the inshore plankton and the findings were correlated with a preliminary study of the distribution of coliform bacteria. An attempt was made to differentiate between fecal and other coliforms (Appendix A). Measurements of salinity and temperature were made concurrently and species distribution was related to salinity and temperature gradients throughout the length of the river studied. Attempts were also made to quantify the zooplankton abundance from vertical tows at selected stations.

It was expected that the zooplankton would provide an indication of the degree and kind of pollution in the river. Aquarium studies together with records of collections were used to provide insight into the survival of organisms in the laboratory, thus leading to the development of future ecological and laboratory studies (Appendix B). A brief study of organisms in ponds and lakes in Sterling Forest was also made (Appendix C).

Sampling Program

Collections of plankton were made with a #20 1/2 meter plankton net (173 meshes/inch or 0.075 mm mesh) with a revolving flowmeter. The 1/2-meter net was fished vertically in the midstream (using a one lb. weight to submerge the net), or towed horizontally across the river, just below the surface. Inshore samples were collected with a long-handled plankton net pulled along the shore, in about three feet of water. During this manoeuvre some sediment was collected with the plankton sample. In addition, interfacial layers of bottom sediments, detritus, twigs and leaves were scooped up in 700 ml Mason jars.

For sampling the mainstream of the river, three sectors, each with three transects, were selected and several stations sampled along each transect. The stations, and their distance from Battery Park, Manhattan, are listed in Table I. Each

TABLE I

Hudson River Sampling Site Mileage Designations

"O" miles at "Battery" along E-W Meridan 40° -
North to South Points measured along mid-channel of river.

Area Description	Site Ident. Number	Station #'s	General Information	Miles	Channel/ Shore
Inwood (I)	I-I	1-2-3		12.8	C
	I-II	1-2-3-4	(Stat. #1 Harlem River)	13.4	C
	I-III	1-2-3		14.1	C
Inwood-Shore		750 yds. into South Bank on Harlem River		13.4	S
Indian Point (II)	II-II	1-2-3		41.7	C
Indian Point Shore			West Bank	42.0	S
Indian Point (II)	II-III	1-2-3		43.6	C
Cornwall Yacht Club			West Bank	56.5	S
Cornwall (III)	III-I	1-2-3		56.5	C
Kingston (III)	III-II	1-2-3-4	Stat. 1-2 Channel Stat. 3-4 Rondout Creek	89.7	C
Kingston Shore (Rondout)		Same as Station 4, 2.2 miles up creek		89.7	S
Saugerties (III)	III-III	1-2-3-4	Stat. 1-3 Channel Stat. 4 Esopus	100.5	C
Saugerties Shore (Esopus)		Same as Station 4, 0.9 miles up creek		100.5	S

TABLE I (Cont'd.)

Area Description	Site Ident. Number	Station #'s	General Information	Miles	Channel/ Shore
Coeymans-Ravena (Finkes Marina)	IV-I		Shore West Bank	127.0	S
Coeymans-Ravena	Southern light		Finkes Marina	127.0	C

transect had 3 to 5 stations numbered east to west: a mid-river station and a station to the east and west of it as close to shore as possible. A tributary of the Hudson was selected wherever available for mid-transect of each sector, and additional transects were made above and below the mid-transect. The object of this sampling plan was to compare the distribution of organisms above and below the tributary with those of the main-stream of the river. At first, no collections were made on the west side at sector II, transect II; however, permission was later generously granted to make collections in the vicinity of the "Reserve Fleet" *.

At each station, in addition to plankton, sediments were sampled using an Ekman foot-release dredge. The sedimental organisms were often difficult to separate due to the thick mucky texture of the sediment. Salinity, visibility (using a Secchi disc), conductivity, and temperature were also recorded at each station. The samples were placed in labelled jars containing approximately 40 ml of formaldehyde and filled to capacity (approximately 700 ml) with river water. Water samples were collected in Kemmerer bottles for coliform examination, and in thermos bottles for incubation and examination in the laboratory. A millipore field sampling technique ** was also used for coliform collections.

---

* Captain Thomas King. Atlantic Coast Director, Maritime Admin.

** Millipore Filter Catalogue MHWG 037

Living material was examined in the laboratory as soon as possible, and discarded, or placed in an incubator at 18° C for further detailed examination. Some Protozoa and other invertebrates grew well when placed in large bowls with wheat grains and Cerophyl as food, both in the incubator at 18° C and in variable room temperature (25-35° C), and could be studied for some time after collection.

Data Collected

Initially qualitative inventories of organisms from each sector were made (Table 2a, 2b, 2c, 2d). The inventories prepared for the four sectors of the Hudson River indicate a general change from species characteristic of marine or euhaline waters in Sector I, to true brackish water inhabitants in Sector II, and to characteristically freshwater species in Sector III.

The fixed plankton samples were studied semi-quantitatively. Zooplankton counts were made by first stirring up the contents of a Mason jar filled to capacity (approx. 700 ml) to insure a uniform distribution of the contents. Total organisms were counted in Sedgwick-Rafter slides from a minimum of three 1 ml aliquots taken from each jar. Where possible, the organisms were identified as to species. The data obtained are summarized in Tables 3-5. The abundance of species and their distribution

Table 2 Inventory of invertebrate species in the Hudson River

2a: Sector I, Inwood, approx. 13 miles north of Battery

N = numerous, C = common, O = occasional, R = rare, - = not observed.

Organisms	I-I	I-II	I-III	Spuyten Duyvil Creek	Inwood Park Creek
PROTOZOA					
Flagellata:					
Dinoflagellata	N	N	N	-	-
Oikomonas sp.	-	-	-	-	N
Chilomonas sp.	-	-	-	-	N
Sarcodina:					
Foraminiferans (Difflugia?)	O	O	O	-	-
Ciliata:					
Tintinnidia	O	O	O	-	-
Amphileptus sp.	-	-	-	-	O
Colpoda sp.	-	-	-	-	C
Condylostomum spp.	-	-	-	-	C
Cyclidium sp.	-	-	-	-	O
Euplotes sp.	-	-	-	-	C
Frontonia sp.	-	-	-	-	-
Holosticha sp.	-	-	-	-	O
Lionotus sp.	-	-	-	-	O
Loxophyllum setigerum	-	-	-	-	C
Metopus sp.	-	-	-	-	O
Pleuronema sp.	-	-	-	-	C
Paramecium sp.	-	-	-	-	O
Spathidium sp.	-	-	-	-	O
Stylonychia sp.	-	-	-	-	O
Stentor sp.	-	-	-	-	O
Uronema sp.	-	-	-	-	O
Vorticella sp.	-	-	-	-	O
Suctoria:					
Tokophrya sp.	-	-	-	-	C
COELENTERATA					
Medusae:					
Nemopsis bachei	-	C	C	C	-
Anemones:					
Sagartia leucolena	-	O	-	-	-
CTENOPHORA					
Mnemiopsis leidyi	-	O	-	O	-
PLATYHELMINTHES					
Rhabdocoel	-	O	-	-	-
NEMERTEA	-	-	-	O	-
NEMATODA	O	O	O	O	C

Table 2a (cont'd.)

Organisms	I-I	I-II	I-III	Spuyten Duyvil Creek	Inwood Park Creek
ROTIFERA					
Trichocerca sp.	O	O	-	O	N
Keratella cochlearis	-	O	-	-	-
Asplanchna	-	-	-	C	-
ANNELIDA					
Polychaete larvae	N	N	N	O	-
Polychaete adults	O	O	O	O	-
Tubificids ?	-	-	-	-	C
CRUSTACEA					
Larvae:					
Nauplii	N	N	N	N	N
Zooea	O	O	O	O	-
Megalops	O	O	O	O	-
Barnacles:					
Nauplii & Cypris	N	N	N	N	-
CLADOCERA					
Bosmina longirostris	N	N	O	O	-
Leptodora kindti	-	-	O	-	-
OSTRACODA					
Cypris sp.	C	O	O	O	C
COPEPODS					
Calanoida:					
Acartia discaudata	N	N	N	N	-
Eurytemora hirundoides	-	-	-	O	-
Harpacticoida:					
Microarthridion littorale	N	N	N	O	-
Harpacticoid sp. (brown)	C	C	C	C	C
Cyclopoida:					
Cyclops bicuspidatus	O	N	O	O	O
CIRRIPEDIA					
Balanus sp.	C	C	-	C	-
ISOPODA					
Cyathura carinata	-	R	-	-	-
Livoneca ovalis (on fish)	-	-	O	-	-
AMPHIPODA					
Gammarus fasciatus	C	C	-	C	-
DECAPODA					
Crago septemspinosus	-	-	C	-	-
Palaemonetes paludosus	-	-	C	-	-
Rhithropanopeus harrisii	C	C	C	-	-
PYCNOGONIDA	-	-	R	-	-
GASTROPODA					
Snail larvae	C	C	C	C	C
Physa heterostropha	-	-	-	-	C
PELECYPODA					
Mya arenaria	C	C	C	C	-
Macoma balthica	O	O	O	-	-
Sphaerium sp.	-	O	-	-	-
Crassostrea virginica	C	C	C	-	-

Table 2b: Sector II, Indian Point, approx. 42 miles north of Battery

Organisms	II-I	II-II	II-III	Shore
PROTOZOA				
Flagellata:				
Ochromonas sp.	-	-	-	C
Polytomella sp.	-	-	-	C
Mastigamoeba ?	-	-	-	C
Chilomonas sp.	-	-	-	O
Astasia sp.	-	-	-	O
Volvocids	-	-	-	O
Sarcodina:				
Foraminiferans	O	O	O	-
Difflugia sp.	O	O	O	O
Arcella sp.	-	O	O	-
Ciliata:				
Aspidisca ?	-	-	-	O
Coleps sp.	-	-	-	O
Colpidium sp.	-	-	-	O
Cyclidium sp.	-	-	-	O
Euplotes sp.	-	-	-	O
Stylonychia sp.	-	-	-	O
Tetrahymena sp.	-	-	-	O
NEMATODA	O	O	O	O
GASTROTRICHA	-	-	-	O
ROTIFERA				
Brachionus sp.	C	O	-	-
Keratella cochlearis	C	N	C	O
Kellicottia longispina	C	O	-	O
Trichocerca sp.	C	O	-	O
Platyias sp.	O	-	-	-
ANNELIDA				
Aeolosoma sp.	O	O	-	-
Tubificid	-	O	-	-
CRUSTACEA				
Larvae:				
Nauplii	N	N	N	O
Metanauplii	C	C	C	O
Zooea	O	-	-	-
Megalops	-	-	O	-
Barnacles:				
Nauplii & cypris	C	C	C	-
CLADOCERA				
Bosmina longirostris	N	N	C	-
Daphnia pulex	O	C	O	-
Leptodora kindti	-	-	-	-
OSTRACODA				
Cypris sp.	-	O	O	-

Table 2b (Cont'd.)

Organisms	II-I	II-II	II-III	Shore
COPEPODA				
Calanoida:				
Acartia discaudata	R	-	-	-
Eurytemora hirundoides	N	N	N	N
Harpacticoida:				
Microarthridion littorale	N	N	N	-
Harpacticoida sp. (brown)	C	C	C	C
Harpacticoida sp. (white)	C	C	C	C
Cyclopoida:				
Cyclops bicuspidatus	C	N	C	C
Cyclops vernalis	O	O	O	O
ISOPODA				
Livoneca ovalis	-	O	-	-
AMPHIPODA				
Gammarus fasciatus	N	N	N	-
DECAPODA				
Palaemonetes paludosus	-	O	-	-
Orconectes limosus	O	O	O	O
INSECTA				
Chaoborus albipes	C	C	C	C
Pentaneura monilis	-	R	-	-
HYDRACARINA				
Halacaridae sp.				
GASTROPODA				
Larvae	C	C	-	-
Amnicola limosa	O	-	-	-
PELECYPODA				
Congeria leucophaeata	-	C	C	C
Crassostrea virginica (shells)	C	-	-	-
BRYOZOA				
Hyalinella	R	-	-	-

Table 2c: Sector III, Cornwall, approx. 56 miles north of Battery, to Saugerties, approx. 100 miles north of Battery.

Organisms	Cornwall Yacht Club Shore III-I		Rondout Shore III-II		Esopus III-III		Esopus Shore
PROTOZOA							
Flagellata:							
Astasiidae	-	-	-	O	-	-	O
Euglena sp.	-	-	-	-	-	-	C
Chlamydomonas sp.	-	-	-	-	-	-	C
Gonium sp.	-	-	-	-	-	-	C
Eudorina sp.	-	-	-	-	C	C	C
Ceratium sp.	O	-	-	-	-	-	-
Oikomonas sp.	-	O	-	O	-	-	O
Polytomella sp.	-	O	-	-	-	-	O
Synura sp.	-	N	-	N	-	-	N
Phacus sp.	-	-	-	-	-	-	R
Volvox sp.	-	-	N	-	C	C	C
Ochromonas sp.	-	C	-	-	C	C	-
Dinoflagellata spp.	-	-	-	-	C	C	-
Sarcodina:							
Foraminiferans	O	-	-	-	-	-	-
Difflugia sp.	O	-	O	O	C	C	C
Arcella sp.	O	C	O	O	C	C	C
Actinophrys sp.	-	C	-	O	-	-	C
Amoeba proteus	-	-	-	-	-	-	C
Small amoebae	-	C	-	O	-	-	-
Ciliata:							
Blepharisma sp.	-	-	-	-	-	-	O
Amphileptus sp.	-	O	-	-	-	-	R
Bursaria sp.	-	-	-	-	-	-	N
Coleps sp.	-	O	-	N	-	-	C
Colpidium sp.	-	-	-	N	-	-	-
Cyclidium sp.	-	O	-	-	-	-	-
Euplotes sp.	-	C	-	N	-	-	C
Epistylis sp.	-	-	-	-	-	-	C
Frontonia sp.	-	-	-	-	-	-	C
Halteria sp.	-	O	-	-	-	-	N
Glaucoma sp. ?	-	-	-	-	-	-	N
Homalozoon sp.?	-	-	-	C	-	-	N
Lacrymaria sp.?	-	-	-	-	-	-	O
Nassula sp.	-	-	-	-	-	-	O
Paramecium sp.	-	N	-	N	-	-	N
Oxytricha sp.	-	O	-	-	-	-	-
Spirostomum sp.	-	-	-	-	-	-	C
Stentor coerulus	-	-	-	-	-	-	C
Stentor spp.	-	O	-	N	-	-	C
Tetrahymena sp.	-	N	-	-	-	-	-
Urocentrum sp.	-	O	O	C	-	-	C

Table 2c (con't)

Organisms	III-I	Cornwall Yacht Club Shore	III-II	Rondout Shore	III-III	Esopus Shore	Esopu
Vorticella spp.	-	C	-	-	-	-	C
Stylonychia sp.	-	-	-	-	-	-	C
SUCTORIA	-	O	-	-	-	-	-
COELENTERATA	-	-	-	-	-	-	-
Hydra oligactis	-	R	-	-	-	-	-
PLATYHELMINTHES							
Planaria sp.	-	-	-	-	-	-	C
Stenostomum	-	-	-	-	-	-	C
NEMATODA	C	C	C	O	O	O	O
ROTIFERA							
Keratella cochlearis	C	-	N	O	C	N	O
Trichocerca sp.	-	-	O	-	O	-	-
Filinia sp.	-	-	O	-	C	C	-
Brachionus sp.	-	-	O	-	O	C	-
Platyias sp.	-	-	-	O	-	O	-
Asplanchna sp.	-	-	O	-	O	C	O
Collotheca sp.	-	-	-	-	-	R	-
Ploesoma sp.	O	-	O	-	O	-	-
GASTROTRICHA	-	O	-	-	O	-	O
ANNELIDA							
Aeolosoma sp.	-	-	-	O	-	-	O
Tubificid sp.	-	-	-	O	-	-	O
CRUSTACEA							
Larvae:							
Nauplii	N	-	N	N	N	N	C
CLADOCERA							
Bosmina longirostris	N	O	C	C	C	C	C
Daphnia pulex	C	-	N	N	-	-	C
Leptodora kindti	-	-	-	-	C	-	-
OSTRACODA							
Cypris sp.	O	-	O	O	O	O	O
COPEPODA							
Calanoidea:							
Diaptomus pallidus	-	-	C	C	C	C	C
Eurytemora hirundoides	C	-	-	-	-	-	-
Harpacticoidea:	-	O	N	-	-	-	-
Microarthridion littorale	C	-	N	N	O	C	-
Harpacticoida sp. (white)	C	C	C	C	C	C	C
Harpacticoida sp. (brown)	C	C	C	C	C	C	C
Cyclopoidea:							
Cyclops bicuspidatus	C	-	O	O	C	C	O
Cyclops vernalis	O	O	O	O	O	O	O
AMPHIPODA							
Gammarus fasciatus	C	-	C	-	C	-	O
DECAPODA							
Orconectes limosus	-	C	-	-	C	-	C
Palaemonetes paludosus	-	R	-	-	-	-	-

Table 2c (con't)

Organisms	Cornwall Yacht Club Shore III-I		Rondout Shore III-II		Esopus Shore III-III		Esop Sho
INSECTA							
Chaoborus albipes pupae	C	-	O	O	O	O	C
Tendipes sp. larvae	O	O	-	O	O	-	C
Chironomus pupa	-	-	O	O	-	-	-
Pentaneura monalis larvae	-	-	-	-	-	-	F
Alluaudomyia sp. larvae	-	-	R	-	-	-	-
HYDRACARINA	-	-	O	O	O	O	C
MOLLUSCA							
Elliptio complanatus	-	-	-	-	C	-	C
Sphaerium sp.	-	-	-	-	-	-	C
GASTROPODA							
Bulimus tentaculus	-	-	-	-	O	-	C
Helisoma anceps	-	-	-	-	-	-	C
Physa heterostropha	-	-	-	-	-	-	C
BRYOZOA							
Statoblasts	-	-	-	-	-	-	C
TARDIGRADA	-	-	-	-	R	-	R

Table 2d: Coeymans-Watervliet section, 127 miles north of Battery

Organisms	Mid-Channel	Shore
PROTOZOA		
Flagellata:		
Volvox sp.	C	-
Eudorina sp.	C	-
Synura sp.	C	-
Oikomonas sp.	-	C
Chilomonas sp.	C	-
Sarcodina:		
Arcella sp.	C	-
Amoeba proteus	C	-
Heliozoa sp.	C	-
Small amoebae	-	C
Difflugia sp.	-	C
Ciliata:		
Frontonia sp.	C	-
Paramecium sp.	C	C
Tetrahymena sp.	C	-
Glaucoma sp.	C	-
Colpidium sp.	C	-
Uronema sp.	C	-
Blepharisma sp. (C strain)	-	O
Homalozoon sp.	-	C
Vorticella sp.	-	C
Coleps sp.	-	C
ROTIFERA		
Brachionus	O	-
Philodina sp.	C	C
Keratella quadrata	-	R
GASTROTRICHA	O	-
COELENTERATA		
Hydra oligactis	O	-
ANNELIDA		
Tubifex sp.	N	-
Aeolosoma sp.	-	C
NEMATODA	-	C
PLATYHELMINTHES		
Stenostomum sp.	-	O
CRUSTACEA		
Larvae:Nauplii	N	-
CLADOCERA		
Bosmina longirostris	N	
COPEPODA		
Calanoidea:	O	-

Table 2d (cont'd.)

Organisms	Mid-Channel	Shore
INSECTA		
Chironomus spp.pupa	-	O
MOLLUSCA		
Bulimus tentaculatus	-	R
Lymnea palustrus	-	R
Helisoma anceps	-	R

in relation to main channel and inlets, to collection date, and to different stations on a transect are indicated.

Some studies of different types of preservatives were made, since it was found that formalin fixation preserved virtually none of the soft bodied forms, such as Protozoa, worms, athecate rotifers, etc. Thus, the quantitative inventories do not include these organisms and the data can only be considered semi-quantitatively.

Results

Table 3 compares the abundance of principal zooplankters at some stations on the Hudson River with adjacent tributary creeks, and with the Spuyten Duyvil Creek, running via the Harlem River to the East River and Long Island Sound. The salinity in Spuyten Duyvil Creek was less than that of the related station in the Hudson River, but was still within the euhaline range (9-16‰). True marine organisms were found here both in the creek and in the main river.

During the summer months the turbidity of the Hudson River water, approximately 2 1/2 feet, is partly due to the abundance of plankton which varies from less than 200 to 1200 organisms/

Table 3 A comparison of zooplankton in the Hudson River and adjacent inlets.

(Sector II omitted from this table)

Key * ≥ 50 organisms/ml aliquot of sample
** ≥ 100/ml, *** ≥ 300/ml, B ≥ 500/ml.

Organisms	Spuyten Duyvil I	Spuyten Duyvil III	Rondout Creek	Esopus	Esopus Creek
COELENTERATES					
Hydra	-	*	*	-	-
Medusae	*	-	-	-	-
Ctenophores	*	-	-	-	-
NEMERTEA	-	-	-	-	-
ROTIFERA					
Trichocerca	*	*	-	B	*
Keratella	-	**	*	*	*
Filinia	-	-	-	*	-
ANNELIDA					
larvae	*	*	-	-	-
CRUSTACEA					
nauplius larv.	*/B	*/B	*	*	*
zooea larvae	*	-	-	-	-
megalops larv.	*	-	-	-	-
Cladocera					
Bosmina	*	*	*	*	*
Daphnia	-	*	B	-	-
Leptodora	-	-	-	*	-
Ostracoda					
Cypris	*	*	*	-	*
Copepoda					
Calanoid	*/***	*	*	*	-
Cyclopoid	*	-	-	*	-
Harpacticoid	*	*/B	*/B	*	*
Amphipoda					
Gammarus	*	*	*	*	*
Decapoda					
Rhithropanopeus	*	*	-	-	-
INSECTA					
Chaoborus larv.	-	*	-	-	-
Dipteran pupae	-	*	*	*	-
HYDRACARINA	-	*	-	*	*
PELECYPODA	*	*	-	*	
GASTROPODA	*	-	-	*	*

liter * of river water. The latter concentrations can be concentrations can be considered as "blooms", that is, the samples consisted principally of only one or two species (1). The blooms usually consisted of copepods, nauplii or Bosmina and appeared to be localized concentrations, rather than uniformly dense and extensive populations. The distribution of common organisms shown in Table 3 does not indicate any significant differences between the main river samples and those from the adjacent tributaries.

The main stream zooplankters were found to be primarily microcrustaceans: calanoid and harpacticoid copepods and Cladocera, particularly Bosima longirostris and their larval nauplii as well as occasional blooms of rotifers, such as Keratella cochlearis. The samples also had a high population of diatoms.

Vertical tows and horizontal plankton tows made at all three sectors at Indian Point in July and August showed some variation between sectors and stations. However, the overwhelming bulk of the population of zooplankters was composed of copepods and their nauplii, 72-98%. On one occasion in late August, 15% of

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* Calculated from counts of 450-2000 organisms/ml (Sedgwick-Rafter cell), for 700 ml concentrated sample representing a plankton net vertical tow through an average depth of 10 meters. The actual sampling depths ranged from 5 to 65 feet, with a mean depth for all samples of 24 feet = 7.25 meters.

the total zooplankters present were Cladocera (Bosmina and Daphnia); Gammarus usually appeared from 1% to 6%. Rotifers, especially Keratella, were commonly 1-2%. Other inhabitants of the plankton, notable but not present in great numbers, were zooea larvae and Chaoborus. The horizontal tows seemed characteristically to contain more Cladocera and fewer copepods than vertical tows in the same sector.

Table 4 compares samples collected from the different stations on different collecting dates during the period June to September, 1967. A comparison may also be made between different sectors, different transects of a sector, or different stations on a transect (Table 5). Blooms of nauplii were observed in all sectors at different times, and of calanoid copepods in sector I and II and of harpacticoid copepods in sector III. A bloom of Trichocerca (rotifer) was seen at Saugerties (sector III) and of Daphnia in Rondout Creek. In all the samples, harpacticoid and calanoid copepods and their nauplii appeared to be the dominant zooplankters. The difficulty of sampling repetitively either from the same station on successive dates, or from adjacent stations on the same dates, is reflected in the variability of the data. Consequently, deductions about the distribution and abundance of most organisms would be unjustified.

Table 4 Quantitative Comparison of Plankton Samples from Hudson River Stations on Different Collecting Dates

Quantitative Symbols as in Table 3

I - I Station 1, Hudson River

	June 27	July 25	August 8
Nauplii	***	***	*
Annelid larvae	-	*	-
Trichocerca	-	-	*
Bosmina	-	-	*
Harpacticoid copepods	*	*	*
Cyclopoid	*	-	*
Calanoid	*	*	*
Pelecypods	*	*	*
Gastropods	-	*	*

I - II Station 1, Spuyten Duyvil Creek

	July 6	July 25	August 22
Nauplii	**	B	-
Nemerteans	-	-	*
Medusae	-	-	*
Annelid larvae	*	-	-
Ostracods	*	-	-
Harpacticoids	**	-	*
Cyclopoids	**	-	-
Calanoids	*	**	*
Pelecypods	*	-	-
Gastropods	-	-	*
Rhithropanopeus	-	-	*

I - II Station 2, Hudson River at Spuyten Duyvil Creek

	July 6	July 25	August 15	August 22
Nauplii	**	***	**	-
Megalops	-	*	*	-
Zooea	-	-	-	*
Annelid larvae	-	*	-	*
Medusae	*	*	*	*
Harpacticoids	-	*	-	-
Calanoids	*	**	*	*
Ostracods	-	*	-	-
Pelecypods	-	-	-	*
Gastropods	-	-	-	*

I - III Station 2,
Hudson River, Midchannel

	July 25	August 15
Nauplii	**	B
Megalops	-	*
Annelid larvae	*	-
Harpacticoids	*	-
Cyclopoids	*	-
Calanoids	**	*
Gastropods	*	-
Pelecypods	*	-

II - I Station 2,
Hudson River, Midchannel, Traprock Area

	June 28	July 24	August 8
Nauplii	***	***	*
Keratella	*	-	-
Trichocerca	-	-	*
Kellicottia	*	-	-
Ostracods	-	-	*
Bosmina	-	**	*
Daphnia	-	*	*
Harpacticoids	*	***	*
Calanoids	*	B	***
Gammarus	-	*	*
Gastropods	-	-	*
Chaoborus larvae	-	*	*

II - II Station 2,
Hudson River, Midchannel, Indian Point

	July 24	July 26	August 8	August 22
Nauplii	-	*	***	**
Keratella	-	*	*	*
Trichocerca	-	-	*	-
Brachionus	-	-	-	*
Harpacticoids	*	*	**	*
Cyclopoids	*	*	-	-
Calanoids	*	*	***	*
Gammarus	*	-	*	-
Bosmina	-	*	*	-
Daphnia	-	-	*	-
Gastropods	-	-	*	-

II - III Station 2,
Hudson River, Midchannel, Roa Hook

	July 24	August 18
Nauplii	B	*
Keratella	*	-
Trichocerca	*	-

	July 24	August 18
Daphnia	-	*
Bosmina	*	-
Harpacticoids	B	*
Cyclopoids	-	*
Calanoids	**	-
Gammarus	-	*

III - I Station 1,
Hudson River at Cornwall, Pollepel Island

	July 11	July 25	July 26
Nauplii	-	*	*
Keratella	*	-	-
Bosmina	-	-	*
Harpacticoids	-	*	-
Cyclopoids	*	-	*
Calanoids	-	*	*
Daphnia	*	-	-

III - II Station 2,
Hudson River at Kingston, Midchannel

	August 1
Nauplii	B
Keratella	**
Trichocerca	*
Annelid larvae	*
Bosmina	*
Daphnia	*
Harpacticoids	*
Calanoids	*
Hydracarina	*

III - II Station 4,
Rondout Creek

	August 1	August 23	August 29
Nauplii	*	-	-
Keratella	-	*	*
Bosmina	*	-	-
Daphnia	B	-	-
Ostracods	*	-	-
Harpacticoids	B	-	*
Calanoids	*	-	*
Dipteran pupae	*	-	-

III - III Station 2,
Hudson River at Saugerties, Midchannel

	August 1	Sept. 19
Nauplii	*	*
Trichocerca	B	-
Brachionus	-	*
Keratella	*	*
Bosmina	*	*

	August 1	Sept. 19
Leptodora	-	*
Harpacticoids	*	-
Cyclopoids	*	*
Calanoids	**	*

III - III Station 4, Esopus Creek

	August 1	August 23	August 29	Sept. 19
Nauplii	*	-	-	*
Trichocerca	-	*	-	*
Keratella	-	*	-	-
Bosmina	-	-	*	-
Ostracoids	-	-	*	-
Harpacticoids	-	-	*	*
Hydracarina	*	-	-	-

Table 5 Quantitative Comparison of Plankton Samples in Sector II (Indian Point) From Different Stations on Each Transect

Organisms	June		July		August		
	27	28	24	26	8	18	22
Sector II, Transect I, Station 1							
Nauplii		**	**		-		
Keratella		*	-		-		
Kellicottia		*	-		-		
Bosmina		B	**		-		
Daphnia		-	*		-		
Harpacticoid		*	**		-		
Calanoid		*	*		-		
Polychaete		-	*		-		
Sector II, Transect I, Station 2							
Nauplii		**	***		*		
Keratella		*	-		-		
Trichocerca		-	-		*		
Kellicottia		*	-		-		
Ostracod		-	-		*		
Bosmina		-	**		*		
Daphnia		-	*		*		
Harpacticoid		*	***		*		
Calanoid		*	B		***		
Gammarus		-	*		*		
Chaoborus larvae		-	*		*		
Gastropods		-	-		*		
Sector II, Transect I, Station 3							
Nauplii		*	-		***		
Keratella		*	-		*		
Trichocerca		-	-		*		
Bosmina		-	-		*		
Daphnia		-	-		*		
zooealarvae		-	*		-		
Cyclopoid		*	*		-		
Harpacticoid		*	**		*		
Calanoid		-	***		*		
Gammarus		-	*		-		
Gastropods		-	-		*		
Pelecypods		-	-		*		

Organisms	June		July		August		
	27	28	24	26	8	18	22
Sector II, Transect II, Station 1							
Nauplii	B	B	**		*		*
Keratella	*	*	*		-		-
Kellicottia	-	*	-		-		-
Trichocerca	-	-	-		*		-
Daphnia	-	-	-		*		-
Bosmina	B	**	-		*		*
Harpacticoid	*	*	**		**		*
Cyclopoid	*	*	-		-		-
Calanoid	*	*	*		**		**
Gammarus	-	-	*		*		-
Pelecypods	-	-	-		*		-
Sector II, Transect II, Station 2							
Nauplii			-	*	***		**
Keratella			-	*	*		*
Trichocerca			-	-	*		-
Brachionus			-	-	-		*
Harpacticoid			*	*	**		*
Cyclopoid			*	*	-		-
Calanoid			*	*	***		*
Gammarus			*	-	*		-
Bosmina			-	*	*		-
Daphnia			-	-	*		-
Gastropods			-	-	*		-
Sector II, Transect II, Station 3							
Nauplii	B	B					*
Keratella	**	***					-
Brachionus	-	-					*
Bosmina	B	B					*
Harpacticoid	B	***					-
Cyclopoid	***	*					-
Calanoid	***	**					-
Pelecypods	-	*					-

Organisms	June		July		August		
	27	28	24	26	8	18	22
Sector II, Transect III, Station 1							
Nauplii			-		**	***	
Keratella			-		-	*	
Trichocerca			-		*	*	
Bosmina			-		-	*	
Daphnia			-		*	-	
Harpacticoid			-		*	*	
Cyclopoid			-		-	*	
Calanoid			-		*	*	
Hydracarina			-		-	*	
Pelecypods			-		-	-	
Sector II, Transect III, Station 2							
Nauplii			B			*	
Keratella			*			-	
Trichocerca			*			-	
Daphnia			-			*	
Bosmina			*			-	
Harpacticoid			B			*	
Cyclopoid			-			*	
Calanoid			**			-	
Gammarus			-			*	
Sector II, Transect III, Station 3							
Nauplii			B		*		
Keratella			*		-		
Trichocerca			*		*		
Bosmina			*		-		
Harpacticoid			B		-		
Calanoid			**		-		

Some species seem to be ubiquitous throughout the 100 mile stretch of the Hudson studied. The planktonic crustaceans are especially well distributed.

These ubiquitous species are: -

Diffugia sp. (Sarcodina)
Euplotes sp. (Ciliata)
Stylonychia sp. (Ciliata)
Keratella cochlearis (Rotifera)
Trichocerca sp. (Rotifera)
Tubificid worms
Bosmina longirostris (Cladocera)
Leptodora kindti (Cladocera)
Cypris sp. (Ostracoda)
Eurytemora hirundoides (Copepoda, Calanoida)
Microarthridion littorale (Copepoda, Harpacticoida)
Cyclops bicuspidatus (Copepoda, Cyclopoida)
Gammarus fasciatus (Amphipoda)
Palaemonetes paludosus (Decapoda)

The ubiquity of some of the zooplankton species may indicate relatively uniform conditions in the Hudson River between Inwood and Saugerties during the summer months. On the other hand, the ubiquitous species may be those able to tolerate the range of salinity recorded for this part of the river (2). The tolerance of microcrustacea and rotifers to salinity is of interest since it is well-known that some of the larger Crustacea, such as the Harris crab and the crayfish have a much more limited tolerance to salinity changes.

Stations on the west shore of the river were sampled (as described on p. 3-2) by hand, net and scoop. The shore samples were consistently high in nematodes and Protozoa, and usually contained some microcrustacea and their larvae, ostracods, and annelid worms. Abundant green algae and bacterial masses were observed in the shore samples. In one sample taken at Coeymans (Schodack's Landing), a bloom of Spirillum was present. In addition to samples collected as above, samples of the larger invertebrates were collected (along with young fish) with a shore seine. Sector I (Station I-W-2 at the Tappan Zee Bridge) was inhabited by Rhithropanopeus, Palaemonetes and Crago, with one record of an isopod. Sector II (at II-W-1, Sneden Landing and II-W-2, Iona Island) also had Palaemonetes, Livoneca and Gammarus. Sector II at Cornwall (II-W-2A and II-W-2) showed the first appearance of Orconectes, the freshwater crayfish, although Palaemonetes was also rarely present. At stations further north, Orconectes was common, together with Sphaerium and Elliptio. The distribution of the macroinvertebrates was studied briefly and the data support the results and conclusions of the survey of 1936 (5) (Table 6).

The distribution of organisms was studied at 13 adjacent

Table 6 A Comparison of the Common Invertebrate Fauna of the Hudson River in 1936, 1964-65 and 1967

(* = present, - = not found)

Organisms, 1936	1964-65	1967
Barnacles	*	*
Asellus	*	-
Chiridotea	-	-
Edotea	*	-
Cassidinidea	-	-
Cyathura	*	*
Hyalella	-	-
Gammarus	*	*
Leptocheirus	-	-
Monoculoides	*	-
Corophium	*	-
Palaemonetes	*	*
Crago	*	*
Cambarus (Orconectes)	*	*
Callinectes	*	-
Rhithropanopeus	*	*
Elliptio	*	*
Crassostrea	-	Shells
Lymnaea	*	*
Sphaerium	*	*
Lymacum	-	-
Helisoma	-	*
Physa	*	*
Limnodrilus	-	-
Chironomids	*	*
Enallagma	-	-
Sthenelais	*	*

sites (about 1000 yds.) along the shore of the Esopus Creek (Table 7). It was found that the distribution of the smaller invertebrates was uniform excepting for the Protozoa. This group, particularly the ciliates, showed remarkable little uniformity of distribution. No prediction could be made as to which species of Protozoa might be present in a given sample. Repeated sampling of the same column of water did not always yield identical species. An attempt was made to maintain these collections as cultures in the laboratory, to facilitate their study. However, some were more successfully maintained than others. Much of our ignorance of protozoan distribution is undoubtedly due to poor fixation, and also to inadequate collection procedures, but these do not completely explain the variations found.

In Table 7, species distributed throughout the collecting sites were Amphileptus, Coleps, Euplotes, Frontonia, Halteria, Paramecium, Synura, Spirostomum, Stylonychia among the Protozoa; annelids, copepods and rotifers among the Metazoa. Species showing restricted distributions were Blepharisma-C, Bursaria, Cyclidium, Phacus, Stentor coerulus, Trachelius.

Discussion:

The diversity of species follows Dahl's axiom that numbers of species are greater in the marine and freshwater environment

Table 7 Distribution of Protozoa and Metazoa at Thirteen Sites Along the Shore of the Esopus Creek

* = present - = not observed

Organisms	Stations												
	1	2	3	4	5	6	7	8	9	10	11	12	13
PROTOZOA													
Arcella	*	*	*	*	*	*	*	*	*	*	*	-	-
Ampnileptus	*	*	*	*	*	*	*	*	*	*	*	*	*
Blepharisma - E	*	-	*	*	-	-	-	*	-	-	-	-	-
Blepharisma - C	-	-	-	-	-	*	-	-	-	-	-	-	-
Bursaria	-	-	-	-	-	-	*	-	-	-	-	-	-
Coleps	*	*	*	*	*	*	*	*	*	*	*	*	*
Colpoda	*	*	*	-	-	*	*	-	-	-	-	-	-
Cyclidium	-	*	-	-	-	-	-	-	-	-	-	-	-
Difflugia	-	-	*	*	-	*	-	*	*	-	-	-	-
Euglenoids	*	*	*	-	-	*	*	*	*	*	-	-	*
Frontonia	*	*	*	*	*	*	*	*	*	*	-	*	*
Homalozoon	*	*	*	-	-	*	*	*	-	-	-	-	-
Epistylus	-	*	*	-	-	-	*	-	-	-	-	-	*
Halteria	*	*	*	-	*	*	*	*	*	*	*	*	-
Lacrymaria	*	*	-	-	*	-	-	*	*	*	-	-	*
Nassula	-	*	*	-	-	-	-	-	-	*	-	*	*
Phacus	-	-	-	-	-	-	-	-	-	-	-	-	*
Paramecium	*	*	*	*	*	*	*	*	*	*	*	*	*
Synura	-	*	*	*	*	*	*	-	*	-	*	*	*
Stentor spp.	*	*	*	*	-	-	-	-	-	*	*	-	*
Stentor coerulus	-	-	*	-	-	-	-	-	-	-	*	-	*
Spirostomum	*	-	*	*	-	*	*	*	*	*	-	*	*
Trachelius	-	-	-	-	-	-	-	*	-	-	-	-	-
Urocentrum	*	*	*	-	*	*	-	*	-	-	*	*	*
Vorticellids	-	-	-	*	-	-	-	*	-	*	-	-	-
Amoeba proteus	-	-	-	-	*	-	*	*	*	-	-	-	-
Stylonychia	*	*	*	*	*	*	-	*	-	*	*	*	*
Euplotes	*	*	*	*	*	*	*	-	-	*	*	*	*
Volvox - Series	*	*	-	*	*	-	*	*	-	-	-	-	-
Ochromonas	*	*	*	-	*	-	*	-	-	-	-	-	-

Table 7 . Continued

Organsims	Stations 1	2	3	4	5	6	7	8	9	10	11	12	13
METAZOA													
Planaria	*	*	*	*	*	-	*	-	*	-	*	-	*
Nematodes	*	-	*	-	*	*	*	*	*	*	*	-	-
Rotifers	*	*	*	*	*	*	*	*	*	*	*	*	*
Rhabdocoele (Steno)	*	*	*	-	*	*	-	*	-	-	*	-	-
Annelids	*	*	*	-	*	*	*	*	*	*	*	*	*
Gastrotrichs	*	*	*	*	-	-	*	-	*	*	-	*	-
Crustacea:-Nauplii	*	*	*	*	*	*	*	*	*	-	-	*	*
Cladocera	*	*	*	*	*	-	-	*	-	*	-	*	*
Copepoda	*	*	-	*	*	*	*	*	*	*	*	*	*
Gammarus	-	-	-	-	-	-	-	-	-	*	-	*	-
Ostracods	*	*	*	-	*	*	*	*	*	*	-	*	-
Diptera: larvae	*	*	*	-	-	*	-	*	-	-	-	*	-
Corixid larvae	-	-	-	-	-	-	-	*	-	-	-	-	-
Tardigrades	-	-	-	-	*	*	*	*	*	-	-	-	*
Bryozoan statoblasts	-	-	-	-	-	-	-	-	*	-	-	-	-

NOTE: COLLECTION SITES ON ESOPUS CREEK

1 SPBA MIDDLE OF WEST BOAT RAMP
2 SPBA WEST SIDE OF WEST BOAT RAMP
3 SPBA EAST SIDE OF WEST BOAT RAMP
4 SPBA EAST BOAT RAMP, ROCKY AREA
5 SPBA EAST BOAT RAMP, MUCK
6 ESOPUS BACKWATER, EAST OF SPBA, ESOPUS SIDE
7 ESOPUS BACKWATER, EAST OF SPBA, ESOPUS SIDE
8 BACKWATER FROM HUDSON, EAST OF SPBA
9 HUDSON AND/OR ESOPUS BACKWATER, EAST OF SPBA
#10 GLUNTS POINT, NORTH SIDE OF ESOPUS
#11 GLUNTS POINT, SOUTH SIDE OF ESOPUS
#12 BEHIND DAM, NORTH SIDE OF ESOPUS (CLOSE TO DAM)
#13 BEHIND DAM, NORTH SIDE OF ESOPUS, WEST OF DAM

SPBA - SAUGERTIES POWER BOAT ASSOCIATION

and fewer in intermediate salinities (3, 4). As expected, some marine species such as sea anemones, medusae, ctenophores and nemertines were found only in Sector I, about 13 miles from Battery Park in salinities ranging from 9-22‰. On the other hand, in Sector III, and at stations further north, typically freshwater representatives such as insect larvae, the crayfish Orconectes, and freshwater mussels Elliptio appear. Some marine forms, e.g. barnacle larvae and oysters, extend upstream as far as Indian Point (salinity range 0.4 - 9.8‰). In contrast, Chaoborus extends downstream to Indian Point, but was not collected at Sector I.

The inventories compiled for different collection sites indicate that there is little difference in the composition of the zooplankton found in the tributaries of the Hudson and throughout the stretch of the Hudson River studied. The water is high in phytoplankton (not inventoried) and in zooplankton, with regional patches of blooms. During the early summer, the blooms consisted primarily of Bosmina and rotifers, and throughout the entire collecting periods there were patches of copepods and their nauplii. Collections at Inwood were remarkably high in barnacle larvae which dwindled northwards with decreasing salinity. The heavy rainfall in 1967 and subsequent low salinity in the river

limited their distribution to Indian Point and resulted in their absence from stations north. The ubiquity of the copepods Cyclops bicuspidatus, Eurytemora hirundoides, and Microarthridion littorale, and of the rotifers Keratella cochlearis and Trichocerca in the Hudson and its tributaries is an indication of the mixing of water throughout the length of the river studied, and the tolerance of these species to the range of salinities recorded. The relatively small differences observed between stations for temperature and salinity and the isothermic and isohaline depth sample readings also indicate the extent of water mixing. The relatively few ubiquitous species in shore samples (with the possible exception of Trichocerca) indicates that they may be sensitive to polluting materials, or to organisms characteristic of highly polluted conditions. The shore sites provided great numbers of ciliates and nematodes associated with bacterial masses. Aquarium studies (Appendix B) showed that the copepod and rotifer species could not survive well whereas nematodes, ostracods (Cypris), snails (Physa) and some annelids (Aeolosoma) were tolerant of aquarium conditions.

During 1967, a low yield of larger Crustacea was obtained from shore collections. Notable was the complete absence of

blue crabs (Callinectes sapidus). It is possible that the increasing freshness of the water has limited its northward migration; however, earlier reports (5) give its distribution as far north as Beacon which is well into the freshwater zone. It seems likely that the discontinuous distribution and apparently erratic occurrence of the larger invertebrates are due to inadequate sampling of benthic organisms (either on shore or in the main river) as well as to their natural fluctuations.

The relatively low numbers of aquatic insect larvae observed similarly indicate poor sampling procedure rather than absence, although Chaoborus larvae were abundant in plankton samples taken in the early summer at Indian Point and at stations further north. Other insect larvae were found only in the freshwater sector.

The distribution of Gammarus fasciatus confirms findings of previous studies that it is ubiquitous in the region studied. It appears most abundant in deeper water and in the interfacial layer of sediment in the brackish water sector at Indian Point.

The pelecypods seem to be stenohaline in their distribution, with the marine Mya in Sector I being replaced by Congeria in Sector II, and Congeria by Elliptio in the freshwater Sector III.

Congeria is considered to be resistant to sewage pollution and is a good sewage indicator; this appears to be true in the Coeymans area, where Protozoa, blue green algae, nematodes, bacterial masses and motile bacteria, were abundant.

There is, as yet, little to say about the protozoan populations of the stations sampled. Quantification must be made with fresh samples; on the other hand, specific identification is almost impossible in fast-moving living forms. Thecate and loricate forms are recognizable in samples fixed in 4% formalin, and comprise the bulk of the Protozoa in samples collected and fixed in the field.

The most abundant Protozoa, almost absent in fixed samples, are undoubtedly the soft-bodied dinoflagellates, present in high numbers in the lower regions of the Hudson. The shelled amoebae, Arcella and Difflugia, as well as foraminiferan species, were found widely distributed in the river. However, no Foraminifera were found in the tributaries or north of Cornwall.

The backwater shore samples appear to differ markedly from the main stream zooplankton samples in their population of sewage tolerant organisms. In some sediments, coliform bacteria were abundant and could be differentiated by appropriate culture techniques from the fecal coliforms which were found

only in the shore samples (Appendix A). The coincidence of bacteria, ciliates, nematodes and blue-green algae provide an index of sewage contamination. Sewage contamination appears to be relatively limited to the shores of the river, perhaps because the sewage effluents spread more rapidly along the shore from the outfalls, than in the mid-channel.

Conclusions

From this preliminary survey it is difficult to draw valid comparisons between the present and past condition of the Hudson River, or between the Hudson and other rivers. However, in order to answer the questions; has the river changed in recent years, or is it seriously polluted, an attempt is made to relate our findings for 1967 with other data.

A fairly comprehensive account of the Hudson River made in 1936 (5) and a brief survey conducted by this laboratory in 1964-65 (2) can be compared with the present study. In none of these surveys was a quantitative or complete study of the benthic organisms attempted. Table 6 lists the commonest invertebrate species found in each study. In general, the collections of 1967 and 1964-65 include the species listed in 1936, but in 1967 a number of animals appear to be missing from the collections. Whether this is truly a reflection of changing river

conditions during 1967, or simply the result of inadequate collection methods, it is not possible to say without further study.

While the Hudson River is considered to be polluted by domestic sewage wastes and by some industrial wastes, the fauna is not altogether that to be expected of a polluted river. For instance, a list of common sewage organisms (6, 7) shows many species not listed for the Hudson (Table 8). However, there is a clear predominance of sewage organisms in the shore samples compared with midchannel samples.

The major gaps in our study of invertebrates in the Hudson appear to be in identification of the benthic organisms of the shore and midchannel, in obtaining reliable quantitative estimates of these organisms, and in improving our quantitative account of the zooplankton. In addition, a technique for estimating productivity of the river for both plankton and benthos would go far to achieving our purpose of defining the present state of the river's biology. It is our intention to improve the quantitative evaluation of the river, and also to study the inter-relationships of the microfauna and flora with environmental changes.

Table 8. Comparison of Hudson River Organisms with Common Sewage Organisms

Common Sewage Organisms		Present/Absent in Hudson River
PLANTS		
Sphaerotilus		Not found
Phormidium		Included with filamentous blue green algae
Oscillatoria		Common all shore samples
Oedogonium		Not identified
Stigeoclonium		Not identified
Spirogyra		Common in Sector III
Diatoms		Common in all Sectors
Zooglea		Not identified
PROTOZOA		
Chilomonas		Found in Sector II
Euglena		Found in Sector III, Shore
Tetrahymena		Found in Sectors III and II, Shore
Glaucoma		Found in Sector III, Shore
Vorticellids		Found in all Sectors
METAZOA		
Flatworms:	Sorocelis	Not found
	Microstomum	Stenostomum found in Sector III
Nematoda		Common in all Shore Samples
Annelida:	Chaetogaster	Not found
	Naias	Probably included as Tubificids
	Limnodrilus	Not found
	Glossiphonia	Not found
	Tubifex	Common in all Shore Samples
Crustacea:	Copepods (Paracyclops)	Cyclops common in all Sectors
Mollusca:	Burnupia	Not found, but Crepidula present
	Limnaea	Found, Sectors II and III
Insecta:	Mosquito larvae	Found in Sectors II and III
	Eristalis	Not found
	Psychoda	Not found
	Baetis	Not found
	Simulium	Not found
	Hydropsyche	Not found
	Chironomus	Chaoborus found in Shore Samples and Midstream II and III
	Tanytarsus	Found in Shore Samples, Sectors II and III
	Ephemera	Not found
	Caenis	Not found

Acknowledgements

For field collections, D. Bath, R. Broseus, K. Degnan, A. Hernandez, J. Miller, D. Minn; for identifications, A. Erdman, H. Hiller, E. Schmidt, L. Zubarick; for program support, M. Eisenbud; for editing, G. P. Howells, and A. Goldhamer.

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Appendix A: COLIFORM ANALYSIS, JULY-AUGUST 1967

By: Roger W. Broseus

Introduction

Coliform analysis of samples from the Hudson River were carried out in accordance with standard methods (1). The membrane filter technique (1) was chosen because of its apparent simplicity. Since members of the coliform group of organisms are found associated with vegetation and some industrial wastes, and are not always of fecal origin, a distinguishing "fecal coliform test" was made to determine the presence or absence of coliform from sewage (1).

Methods

Samples of water were collected in washed and sterilizied 200 ml brown glass bottles. Mid-channel samples of Hudson River water were taken by (a) immersing the bottle with the mouth of the bottle toward the current, and (b) with a Kemmerer sampler. Shore samples of water were taken by method (a) in shallow water. Samples were kept iced during transport to the laboratory in a polystyrene cooler; they were inoculated within 24 hours of sampling.

A membrane filter test of samples was made using the Millipore Field Monitoring Kit*. Some samples were inoculated in the field and some in the laboratory. "Standard Methods" was used as a reference for the procedure. Plates were read by counting the number of colonies under low-power magnification with a dissecting microscope. Inocula of approximately 10 ml were of sufficient quantity to provide measureable response.

The fecal coliform test was used on colonies from the millipore filter cultures, and carried out following "Standard Methods".

Sediments were sampled with a grab sampler. A few grams of mud were selected from the center of the mass brought up by the grab, to minimize contamination. The sample was then placed in a tube with 9 ml of "dilution water" and the supernatant from this was analyzed as above.

Results

The results of this investigation are reported in Table I. The values for the mid-channel water samples are the means of 2-4 samples taken from varying depths at each site. The

*Catalogue No. MHWG 037

coliform count is the number of coliform colonies produced per sample, converted to an equivalent 100 ml sample size. A positive fecal coliform test implies that fecal coliforms were present, not that all coliforms present were of fecal origin. The absence of a X for a particular date indicates that a sample was not taken.

Significance of the Data

The significant levels of coliform counts appear to be: -

0/100 ml of sample,

1-2/100 ml of sample,

and 10/100 ml (and greater powers of ten).

The values obtained and listed in Table I indicate a relatively stable situation, with a range of values from 100 to 18000/100 ml. The values compare reasonably well with those reported for similar sampling sites (2, 3, 4), but the relatively low counts reported for Inwood (in Spuyten Duyvil Creek and the Hudson River) near the northern tip of Manhattan are surprising, and require confirmation. The millipore technique employed for this analysis is inadequate in the sense that plate counts are considered significant if there are 20 coliform colonies/plate, and 200 colonies of all types/plate. However, the coliform/non-coliform ratio of Hudson River samples is such that it is impossible

to dilute samples in order to produce plates falling within this range.

The test for fecal coliforms indicate that these were present as a component of total coliforms whenever tested. Sediments had variable coliform content, and were very high at some stations (e.g. at Esopus). In two instances, at Rondout and Esopus, the tributary streams appeared to have higher coliform counts than mid-channel samples.

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TABLE I

Coliform analysis of water and sediment in the Hudson River

July - August 1967

Samples Site	Coliform Count/100 ml water Mid Channel	Shore	Presence of fecal coliforms	Presence of coliforms in sediment	Values reported (HEW, 1965)
Inwood 7/25/67	100				
8/15/67	700				5000
8/24/67		8200	X		
8/22/67				X	
Indian Point					
7/24/67	3000				
8/8/67	18000				4500
8/24/67		7600	X		
Moodna					
7/13/67	1800				
7/19/67	600				1200-5000
8/24/67		85	X		
8/31/67	7700				
Rondout Creek					
8/1/67	8400			XX	
8/24/67		5000	X		
Hudson R. at Rondout					
8/1/67	1500				5500
Esopus Creek					
8/1/67	8100			X	
8/24/67		17200	X		
Hudson R. at Esopus					
8/1/67	1600			XXX	220

Note: X indicates a positive result; multiple X's indicate a more strongly positive one.

Appendix B

Aquarium Studies

Collections of invertebrates from different sectors of the Hudson were placed in 15 gallon aquaria and some sediment collected from midchannel of the Hudson River at the same sectors. These were:

Inwood
Indian Point
Moodna (at Cornwall)
Rondout Creek
Esopus Creek (at Saugerties)

Similar collections from various ponds in Sterling Forest were pooled in a single aquarium. GroLux* lamps and forced air were used for each aquarium. The aquaria were occasionally monitored for oxygen, salinity and pH to ensure uniformity of conditions.

Survival and Succession

In the Inwood collection (Sector I), the longest-lived organisms proved to be nematodes (alive after 12 mo.), sea anemones, Sagartia leucolena (8 months), the Harris crab, Rithropanopeus harrissii harpacticoid copepods. Annelids and Gammarus, as well as the steamer clam Mya, survived for a short time (one week). A bloom

* Metaframe, Maywood, New Jersey

of diatoms occurred shortly after the establishment of the aquarium, possibly of the genus Nitzschia. During the bloom, the harpacticoids also reached their peak abundance. In all of the other aquaria no obligate carnivores were present, so that copepods, ostracods, Gammarus, water mites, and flat worms, survived for many months. The Gammarus in the Indian Point collection (Sector II) did well until removed, while those from the Esopus collection (Sector III) are also alive at this writing. All collections have ostracods and nematodes still present. Twelve mussles from Sterling Lake survived from 2 to 10 months. They were exposed to algal blooms occurring in the Indian Point aquarium and they did not visibly affect the abundance of algae. Two blooms of Anabaena occurred, one in November-December, 1967 and the second in January-February, 1968; the conditions leading to the development of the blooms are not known. Snails (Physa) have survived extremely well in the freshwater aquaria.

Shore organisms added to midchannel Hudson River water did not do well initially, except for Anabaena in the Indian Point collections, and rotifers and nematodes from other locations. The Protozoa and bacteria vanished almost immediately on transfer to the aquaria. Later the ostracods and nematodes became, and

remain, the dominant invertebrates in all of the aquaria (except Inwood) with snails and Gammarus growing vigorously in the Indian Point and Esopus aquaria. Organisms placed in large bowls, without aeration or direct lighting, also lived for a surprisingly long time, i.e. months. This is particularly true of the annelid, Aeolosoma, nematodes, insect larvae (Chaoborus and Tendipes) as well as ostracods. The copepods survived at best for several months. The nematodes again survived longest for approximately an 8 month period. On the other hand, Gammarus and snails did not survive these unaerated conditions well. The Protozoa at first flourished, but if copepods or annelids were present, they disappeared within a short time. In finger bowls with wheat grains added, Protozoa did not show a classical succession of species; instead, the carnivores survived longer than expected and were succeeded by Spirostomum which is bacterial feeder and after 9 months is the dominant form. In one bowl, most of the hypotrichs have vanished or were eaten, instead of becoming the dominant forms as expected.

An interesting example of possible mutualism was found. A mixed collection from Esopus (Sector III) was placed in a finger bowl; Cerophyl and an occasional wheat grain were added from

time to time. After a month, the population consisted primarily of a species of the protozoan genus Blepharisma and the ostracod, Cypris. The ostracods were growing and reproducing vigorously, (as evidenced by size of living forms and shell remnants present) and the Blepharisma, while paler than those usually found in laboratory culture (pale pink rather than bright red) had not either conjugated, formed cysts or cannibal giants, which occurred in all of the other bowls or isolations containing the ciliate. Isolations of the ostracod were unsuccessful. It is possible that the waste products from the ostracods were stimulating bacterial growth which in turn provided food for the ciliate. The role of the ciliates may have been to reduce the number of unfavorable bacteria and to allow growth of algae, yeasts or molds which can be eaten by the ostracods. Subsequently after 8 months, the Blepharisma were replaced by rotifers (Trichocerca).

Studies of the distribution of the distinctively different Esopus strain and the Coeymans strain of Blepharisma were attempted, but no continuity of organisms along the shore of the Esopus could be found. The ciliates appeared to be local to small regions near the shore (see p. 29, Table 7) containing detritus, especially fallen leaves. However, the presence of

Blepharisma in detritus in an area close to another site containing Blepharisma could not be assumed.

The development of the aquarium or the bowl culture technique offers an interesting possibility for study of those organisms in plankton or shore collections which are lost in the customary bulk fixation procedures. In addition, the study of the succession of species in simply controlled environmental conditions offers a technique for understanding some of the natural changes observed in the field.

Appendix C

A brief survey of the plankton of a number of small lakes in Sterling Forest, as well as the larger Greenwood Lake has been made. The common organisms are listed below. The collections were made in July/August 1967.

Greenwood Lake	Filamentous algae
	Philodina
	Dinoflagellates
	Keratella
	Bosmina
	Daphnia
	Copepods
Sterling Lake	Small flagellates
	Shelled amoebae
	Phacus
	Keratella
	Copepods (calanoids) and nauplii
	Bosmina
	Daphnia
Ashman Pond	Spirogyra
	Diatoms
	Desmids
	Orchromonas
	Frontonia
	Hydatina
	Tetrahymena
Indian Kill	Filamentous algae
	Volvox
	Ceratium
	Filinia
	Arcella
	Heliozoa

	Colpidium
	Difflugia
	Brachionus
	Keratella
	Testudinella
	Asplanchna
	Ostracods
	Copepods (calanoids) and nauplii
	Hydracarina
	Stonefly larvae
Red Pond	Desmids
	Copepods (cyclopoids)
	Bosmina
	Daphnia
Little Sterling Lake	Filamentous algae
	Arcella
	Euglypha
	Hydatina
	Ostracods
	Hydracarina
	Dipteran larvae

Pesticide Residues in the Hudson River and Biota

By: Theo. J. Kneip

(with technical assistance by J. Hernandez,
J. Miller and D. Wohlgemuth)

Introduction

A program of sampling water, sediments, plankton, larger invertebrates and fish from the Hudson River for pesticide residues was initiated in 1966 and continued through 1967, in relation to a study of the use of freshwater and marine lamellibranchs as monitors of pesticides in the environment.

At present this study is aimed at the identification and measurement of selected chlorinated hydrocarbons being used as pesticides in the Hudson River Watershed Area. Chlorinated insecticides were selected for initial investigation because of their chemical stability and long-term retention in the environment. Consequently the relative ease with which concentrations of these insecticides could be determined was considered important in establishing collection and analytical techniques. The method of analysis is Gas Chromatography

utilizing an electron capture detection system. The electron capture detection is a selective, highly sensitive method for quantitative determinations of chlorinated pesticides.

To understand the effects of pesticides, it is necessary to determine the concentrations in the various life forms in the food chain in relation to the time of year. This overall information provides knowledge of the input and ultimate fate of these potentially harmful toxins.

Procedure

The procedures used are based on those recommended in the "Pesticide analytical Manual-Volume I of the U. S. Department of Health, Education and Welfare, Food and Drug Administration, Revised January 1965. Yield studies have been performed for each pesticide through all steps of the procedures.

Extraction

A 20 to 25 liter river water sample is taken in a glass container and sealed until extracted. Extraction of pesticides is made as soon as possible after receipt of sample, usually within 1-2 days. The water

is continuously extracted with recirculating hexane in an apparatus specifically designed for this purpose. The extraction unit consists of a metering pump withdrawing the river water sample at a constant rate into a glass chamber under constant agitation while introducing fresh hexane into the chamber continuously from a distillation apparatus. The contacted hexane is returned to the distilling pot via an overflow tube. The hexane extract is then passed through a drying column of sodium sulfate and concentrated to a final volume of approximately 20 ml.

Recovery of spiked insecticides from 20 to 25 liters of Hudson River water was found to be a minimum of 50% under these conditions. The current procedure includes acidification of the sample when taken and addition of 1 liter of hexane at that time. Current yields consistently exceed 90%.

Mud samples of approximately 200-300 grams wet weight are collected in a clean Mason jar. The wet mud is then dried at room temperature in a Buchner funnel under vacuum. The dry powder is then ground using a mortar and pestle and 50 g samples are extracted with n-hexane using a Soxhlet extraction apparatus. The hexane is then concentrated to a

volume of approximately 20 ml in a Kuderna-Danish evaporator with a 3-ball Snyder column.

Plankton samples were collected and weighed after excess water was filtered off in a Buchner funnel. The sample was then introduced into a Waring Blendor with 50 ml hexane. Fish and bivalve samples are drained of excess water, weighed, and placed in the blendor. After two minutes blending at low speed the mixture was allowed to settle and the supernatant decanted. A further 50 ml hexane was added to the solid, and the blendor run for four minutes. Again the mixture is settled, and the supernatant decanted and added to the first. Again, 50 ml hexane was added to the solid, the blendor run for five minutes and a final supernatant decanted and the combined supernatant filtered (Whatman No. 1). The volume was then reduced to about 20 ml.

Partition and Cleanup

The hexane extract is washed twice with 40 ml acetonitrile. Subsequently the acetonitrile extract is reduced to 20 ml, backwashed with 20 ml hexane after addition of 20 ml of de-ionised water saturated with sodium chloride. Then the hexane is introduced on to

a prepared fluorosil column (Mills procedure). After elution with 15% by volume of ethyl ether-hexane mixture (200 ml), the extract is reduced to 20 ml and is ready for gas chromatographic analysis.

All analyses were made with a Beckman GC-5 gas chromatograph. Two independent analyses were run with different columns. Both columns are made of coiled glass, 10 feet in length, 2mm I. D. One column is packed with 10% DC-200 on Gas Chrom Q 80/100 mesh, the other is a QF-1/OV-17 on Anakrom ABS 100/120 mesh. The chromatograph tracings were compared to standard curves for identification and quantitation of nine pesticide residues: lindane, heptachlor, aldrin, heptachlor epoxide, dieldrin, DDE, TDE, orthopara DDT, para-para DDT.

Detection Limits and Recovery

The values in Table 1 represent the lowest quantitative levels measurable by the Gas Liquid Chromatographic procedures in use. The first column shows the absolute amounts measured by the detector in a 1 µl injection of a hexane solution of pesticides. Columns 2 and 3 represent normal lower detection limits for the standard sample handling procedures in use. Column 4

TABLE 5

Quantitative Detection Limits for Selected Pesticide Residues

Pesticide	Injected pg	Solids-100 g ng/g	Aqueous-25 l ng/l	Recommended Detection Limits* ng/l
Lindane	3.0	0.6	2.4	5.0
Heptachlor	12.5	2.5	10.0	10.0
Aldrin	6.6	1.3	5.3	10.0
Heptachlor-Epoxide	6.0	1.2	4.8	10.0
DDE	10.0	2.0	8.0	
Dieldrin	10.0	2.0	8.0	10.0
TDE	12.5	2.5	10.0	20.0
o, p DDT	20.0	4.0	16.0	20.0
p, p DDT	75.0	15.0	60.0	20.0

indicates one set of limits currently recommended in the literature.

Samples showing activity below the limits given have been reported as "Trace" if a peak is noted for both GLC columns, and T (for tentative) if only on one GLC column. Values reported as T or those left unreported may be assumed to be less than two-fifths the levels given for quantitative measurements.

The extraction, concentration, partition, and chromatography methods used in sample preparation are based on standard FDA-PHS methods. Recoveries have been checked by the standard addition method with both samples and blanks.

The overall recoveries for concentration, partition and chromatographic steps are shown in Table 2. Individual steps in the procedure normally show 95% recovery.

The recovery in the first preparation step is checked by adding standards before use of solvents in the extraction. It is of course impossible to add standards to samples in the identical form in which the pesticides exist in the environment. However, the extraction procedure can be checked by comparison of differing methods along with the standard addition

TABLE 2

Pesticide Recoveries

Pesticide	Overall Recovery, %
Lindane	87.9
Heptachlor	80.7
Aldrin	80.0
Heptachlor Epoxide	85.8
DDE	82.7
Dieldrin	83.9
TDE	86.9
o, p' DDT	81.5
p, p' DDT	89.9

techniques. Recoveries for extraction of solids normally exceed 95%. Table 3 shows typical results for recoveries from bivalves using the Waring Blendor extraction method. Intercomparison of Soxhlet extractor and Waring Blendor techniques have shown essentially identical overall results for the unknown materials originally present in the samples. This indicates essentially complete recoveries by both methods. Recoveries from 25 l water samples show more variation. The values for water must therefore be regarded as minimal results, averaging about 50% recovery.

Sampling Schedule

Hudson River water was sampled at seven sites (see Table 4), at Inwood 12.8 miles north of Battery Park, Manhattan to Saugerties, about 101 miles north. Collections were made in 1967 from March until November. Mud samples near the shore were collected from four sites, from Iona Island 45 miles from Battery Park to the Esopus River, about 101 miles from Battery Park. Seven plankton samples were collected in sufficient quantity for analysis, all in July, at stations between Inwood and Saugerties.

TABLE 3

Extraction of Bivalves: "Waring Blendor" Technique

Compound	GLC Response: Standard	Sample	% Recovery
Lindane	48	47.0	97.9
Heptachlor	23.5	23.0	97.8
Aldrin	30.0	28.0	93.3
DDE	24.5	24.5	100.0
Endrin	28.0	28.0	100.0
p, p' DDT	20.0	21.0	105.0

Results and Discussion

The data are given in Tables 1-4 of appendix A. Water - Lindane was detected in 42% of the shore site water samples. The frequency was higher in the Rondout Creek (78%) than at any other site. No seasonal variation is noted in the results for this material.

Dieldrin was detected in 26% of the samples again showing no definite seasonal variation. There appears to be a somewhat uniform distribution, with Esopus Creek possibly showing less evidence of this material.

Heptachlor is essentially absent from the water samples. DDT, DDE, TDE, Aldrin and Heptachlor Epoxide all showed a remarkably similar pattern of association with spring fresh water runoff. All high values were found in the April samples.

Aldrin and Heptachlor Epoxide ranged from 2 to 12 ng/l with the Rondout Creek values highest. The ranges for DDT and metabolites are: DDE-10 to 52 ng/l, TDE-36 to 182 ng/l, o, p-DDT-14 to 75 ng/l, p, p-DDT-44 to 244 ng/l. Further examination of the data indicates that the sites divide into two types with values at the highest end of the ranges found at the Esopus Creek

and Iona Island sites and at the low end at the Rondout Creek and Marlboro sites.

To properly establish the real input of pesticides into the aquatic system on a mass balance basis would require far more frequent sampling at a greater number of sites over the period of spring fresh water runoff. This monthly study completed at four sites in 1967 may not have detected the highest levels and certainly does not indicate the period of introduction with sufficient precision. Channel water samples corresponding to all shore samples showed only occasional Lindane and Dieldrin, but the rest of the residues were never detected.

Sediments

Sediments in the Hudson River shore areas vary from gravel to muck in consistency. The condition at a given site also varies from time to time, apparently depending on the tide, flow and river traffic.

The sites which most consistently provide black muck were Iona Island and Marlboro (miles 45.2 and 67.3 respectively.) Both sites are marshy and separated from the main flow of the river by railroad trestles. The Marlboro site is some 10 yards from the opening to

the main channel and was less consistent in bottom conditions. The Esopus and Rondout sites were on the streams in areas of relatively good flow which produced generally grainier sandy types of samples.

The overall pattern of the results clearly shows a spring input to the sediments. The general level is 0 to 100 µg/g or about 1000 times more concentrated than the water at its highest levels.

The muck samples show the highest levels and most consistent findings of residues throughout the year. A general range of 10 to 50 µg/g occur in these samples from Iona Island and Marlboro. There are indications of low (0-10 µg/g) levels of several pesticide residues throughout the year at all sites. The Iona Island site and to some extent the Marlboro site show evidence of degradation or loss of certain residues followed by fresh inputs. This is particularly evident for DDT, DDE, and TDE, but also shown for Dieldrin at Iona Island.

Mid-Channel Plankton and Sediments

Plankton samples and bottom sediments were obtained from the channel at various sites in July. Water samples at this time are at levels below the detection limits

and shore site sediments are at or near the low point for the year.

The channel sediments are moderately elevated in several residues including Aldrin, Dieldrin and DDE. The plankton, however, are extremely high in all pesticides examined with many values as high as 600 to 800 µg/g. These exceed the highest sediment values by at least a factor of five (20 to 600 for concurrent samples) and represent concentration factors of 3000 to 4000 over the highest levels observed in water. The concentration is probably 100,000 to 600,000 fold over the levels in the water from which the plankton were collected.

These levels are very high in comparison to the plankton found by Woodwell (1) in a Long Island marsh. Associated Crustacea, fish and birds showed much higher levels, even nearing lethal values in birds. The plankton observed in the Hudson in 1967 include oil containing species which may account for the concentrating of the residues in these members of the food chain. No information has been obtained to date on fish or bird species. However, if the usual concentrating processes occur, the hazard to some species on the Hudson may be greater than that noted in the Long Island marsh.

The chromatograms obtained from water, sediment, plankton and bivalves show a qualitative similarity in retention times and numbers of peaks despite the considerable variation in concentration levels. Typical results for bivalves and plankton have been evaluated to provide tentative identification for the various peaks. No attempt has been made to estimate the probability of extraction and separation of the proposed materials by the procedure in use, nor has any evaluation been made of potential interfering substances. Comparisons have been made with published data from the Food and Drug Administration.

Appendix A

Table 1

Pesticide Residues in Water

Concentration, ng/l (a).

Location (b)	Date	Lindane	Heptachlor	Aldrin	Heptachlor Epoxide	DDE	Dieldrin	TDE	O'P, DDT	P, P'DDT
Inwood	7/25	-	-	-	-	-	-	-	-	-
(12.8 mi)	8/22	-	-	-	-	-	-	-	-	-
Iona Island	3/2	1.5	T	-	-	2.2	Trace	T	-	-
(45.2 mi)	4/13	-	-	-	5.0	52.0	-	182.0	75.0	244
	5/12	Trace	-	-	-	-	-	-	-	-
	6/20	-	-	-	-	-	Trace	-	-	-
	7/25	T	Trace	-	-	-	-	-	-	-
	8/24	-	-	-	-	-	Trace	-	-	-
	10/11	-	-	-	-	-	-	-	-	-
	11/15	Trace	-	-	-	-	T	-	-	-
Moodna Creek	7/26	-	-	-	-	-	-	-	-	-
(56.5 mi)										
Marlboro	3/2	3	-	-	-	1.2	2.2	T	-	-
(67.3 mi)	4/13	-	-	2.2	2.5	15.0	-	75.0	26.0	90.0
	5/12	6	-	-	-	-	-	-	-	-
	6/20	Trace	-	-	-	-	-	-	-	-
	7/25	T	-	-	-	-	-	-	-	-
	8/24	-	-	-	-	-	Trace	-	-	-
	10/11	-	-	-	-	-	Trace	-	-	-
	11/15	T	-	-	-	-	T	-	-	-

Table I (con't)

Location (b)	Date	Lindane	Heptachlor	Aldrin	Heptachlor Epoxide	DDE	Dieldrin	TDE	O'P, DDT	P, P'DDT
Rondout Creek	3/2	T	-	-	-	Trace	Trace	Trace	-	-
(89.7 mi)	4/13	4	-	5.0	12.5	10.0	-	36.0	14.0	44.0
	5/12	Trace	-	-	-	-	-	-	-	-
—	6/20	Trace	-	-	-	-	-	-	-	-
	7/25	Trace	-	-	-	-	Trace	-	-	-
	8/1	-	-	-	-	-	-	-	-	-
	8/11	-	-	-	-	-	-	-	-	-
	8/24	Trace	-	-	-	-	Trace	-	-	-
	10/11	Trace	-	-	-	-	-	-	-	-
Esopus Creek	3/2	T	-	-	-	-	-	1.5	-	-
(100.5 mi)	4/13	3	-	-	-	47	-	162	62	222
	5/12	-	-	-	-	-	-	-	-	-
	6/20	Trace	-	-	-	-	-	-	-	-
	7/25	T	-	-	-	-	-	-	-	-
	8/1	-	6	-	-	-	-	-	-	-
	8/24	Trace	-	-	-	-	Trace	-	-	-
	10/11	Trace	-	-	-	Trace	-	-	-	-
	11/15	-	-	-	-	-	-	-	-	-
Saugerties	8/1	-	-	-	-	-	-	-	-	-
(100.5 mi)										

(a) T = tentative identification (one GLC column only)
- = not detected on either column

(b) Mileage figure is the distance from Battery Park, Manhattan

Appendix A (con't)

Table 2

Sediment Sample Shore Sites
Concentration, ng/g

Mile	1967 Date	Lindane	Heptachlor	Aldrin	Heptachlor Epoxide	DDE	Dieldrin	o, p' DDT	TDE	p, p' DDT
45.2	3/2	3.0	-	T	2.2	1.1	1.1	T	3.2	-
45.2	4/13	T	-	T	10.0	1.2	T	T	8.4	T
45.2	5/12	T	T	-	-	3.5	8.0	-	3.2	-
45.2	6/20	-	-	16.0	38.0	28.0	28.0	-	20.0	28.0
45.2	7/25	-	-	-	36.0	28.0	-	-	-	-
45.2	8/23	10.0	-	-	-	12.0	14.0	-	60.0	-
45.2	10/11	2.6	-	-	-	-	-	-	32.0	133.0
45.2	11/15	-	-	-	T	0.3	T	T	T	-
67.3	3/2	0.24	-	2.8	1.7	2.4	T	T	5.0	-
67.3	5/12	4.0	-	-	76.0	14.0	15.0	-	110.0	-
67.3	6/20	-	-	-	-	0.4	Trace	-	-	-
67.3	7/25	-	-	-	-	15.0	-	-	-	-
67.3	8/23	-	-	-	-	0.4	0.4	-	-	-
67.3	10/11	-	-	-	-	0.8	1.0	-	4.0	-
67.3	11/15	-	-	-	T	0.2	T	T	T	-
89.7	5/12	1.6	-	-	13.0	1.4	1.0	-	0.4	10.0
89.7	7/25	-	-	-	-	-	-	-	-	-
89.7	8/23	-	-	-	-	-	-	-	-	-
89.7	10/11	-	-	-	0.8	0.6	-	-	2.4	-
89.7	11/15	-	-	-	-	T	T	T	T	-
100.5	4/13	T	-	T	3.8	2.4	T	T	20.0	5.8
100.5	5/12	-	-	-	1.4	0.8	-	-	-	-
100.5	7/25	-	-	-	1.0	0.8	1.0	-	-	-
100.5	8/23	-	-	-	-	0.8	-	-	-	-
100.5	10/11	-	-	-	-	0.2	-	-	0.2	-
100.5	11/15	-	-	-	T	0.1	T	T	T	-

Table 3

Pesticide Residues in Mid-Channel Plankton and Bottom Sediments

Concentration, ng/g

Plankton

Mile	Date	Lindane	Heptachlor	Aldrin	Heptachlor Epoxide	DDE	Dieldrin	TDE	o,p'DDT	p,p'DDT
13.4	7/25	-	510	-	360	370	300	780	253	670
"	"	-	-	-	40	60	60	160	110	430
"	"	-	320	150	160	200	150	380	190	450
41.7	7/25	-	-	-	140	40	80	100	20	110
41.7	7/26	-	420	250	390	170	210	280	150	500
56.6	7/5	-	-	120	130	60	140	-*	-*	-*
56.5	7/26	-	250	130	110	30	50	40	40	90
89.7	7/5	-	-	150	125	50	65	-*	-*	-*
100.5	7/5	-	610	190	240	50	110	40	60	60

Sediment

13.4	7/5	-	-	-	9.0	15.0	16.0	T	-	T
41.7	7/5	-	-	-	7.0	3.0	8.0	T	-	T
41.7	7/24	-	-	16.0	-	10.0	15.0	T	-	T

* Normal detection limits not applicable as the detector sensitivity was lower than normal for these samples.

Appendix A (con't)

Table 4

Qualitative Identification

Bivalves		Plankton	
Relative Retention Time	Pesticide	Relative Retention Time	Pesticide
0.18	Diuron, Neburon, Ethide	0.18	Diuron, Neburon, Ethide
0.25			
0.32	(DDT-Tech.)	0.33	DDT Tech.
0.40			
0.45	BHC (alpha)	0.45	BHC (alpha)
0.52	Lindane	0.52	Lindane
0.58	Pentachlorophenol	0.58	Pentachlorophenol
0.68	N-Butyl Ester, 2,4-D	0.68	N-Butyl Ester 2,4-D
0.74	Ronnel	0.74	Ronnel
0.85		0.89	Strobane
0.94	Chlordane Tech.		
1.00	Aldrin	1.00	Aldrin
1.20	Hept. Epoxide	1.19	Hept. Epoxide
1.33	o,p - DDE, Chlordane- (Tech)	1.33	o,p - DDE Chlordane- (Tech)
1.38		1.38	
		1.50	BEP Ester, 2,4-D (Tech)
1.61		1.62	
1.71	Dieldrin	1.70	Dieldrin
2.00		2.00	Butoxy
2.30	Butoxy Ethanol Ester 2,4,5-T	2.34	Butoxy Ester 2,4,5-T
2.50	pp', Methoxychlor Olefin	2.52	p'p, Methoxychlor Olefin
2.68	p;p', DDT	2.72	BEP Ester, 2,4,5-T (Tech)

BIOLOGICAL MONITORING EXPERIMENTS: PESTICIDES

By: T. J. Kneip, G. P. Howells and A. Perlmutter

with assistance from D. W. Bath, H. Hernandez and J. Miller

Introduction

The ability of lamellibranch molluscs to concentrate trace quantities of pollutants in the aquatic environment suggests their use as biological monitors in the field. Several investigators have demonstrated the concentrating powers of different species of molluscs (Rice, 1963; Chipman, et al. 1958; Polikarpov, 1966; Butler, 1966) and it has been shown that if exposed to continuing low concentrations, shellfish accumulate insecticides and other pollutants until the source is removed. In some environments, appropriate species to demonstrate accumulation are not available, or not easily collected, or they may be already too heavily contaminated with the pollutant to be studied. In such instances, it is more convenient to collect animals from an uncontaminated environment and to transfer them to the contaminated environment.

This laboratory has sought to identify suitable species for the Hudson River and to use them in field conditions to test their ability as monitors.

Appropriate species for this purpose must be chosen with a number of criteria in mind: 1) The species should be able to live successfully in the polluted aquatic environment in question, and ideally should be endemic to that environment. 2) It should be available in large numbers if necessary, and easily maintained and handled for the purposes of experiment. 3) It should concentrate the pollutant effectively and in a manner bearing a simple mathematical relationship to the severity of the dose 4) It should respond to changes in pollutant concentration neither too rapidly for effective sampling, nor too slowly to achieve an adequate response in a reasonable time period.

Hudson River Test Sites

Two sampling sites were selected, one at Piermont Pier, Piermont, New York and the other at Saugerties, New York (Fig. 1). The site at Piermont is mesohaline (3.9 °/oo - 69 °/oo) and was chosen to test four species of marine shellfish as monitors: the eastern oyster, Crassostrea virginica, the soft-shell clam, Mya arenaria, the hard shelled clam, Mercenaria mercenaria and the ribbed mussel, Modiolus demissus. These shellfish were un-

Figure I
Shellfish Sampling Sites
HUDSON RIVER

available, or not readily available, in the river even though the oyster has been cultured and exploited commercially in the river as far north as Haverstraw Bay. Hence these species were obtained from the New York State Conservation Department's Division of Shellfisheries Laboratory at Oakdale, Long Island. The animals were transferred from an average salinity of 22 °/oo (range 18-28 °/oo at different Long Island collecting sites) and were found to be already contaminated with a low level of pesticide residues.

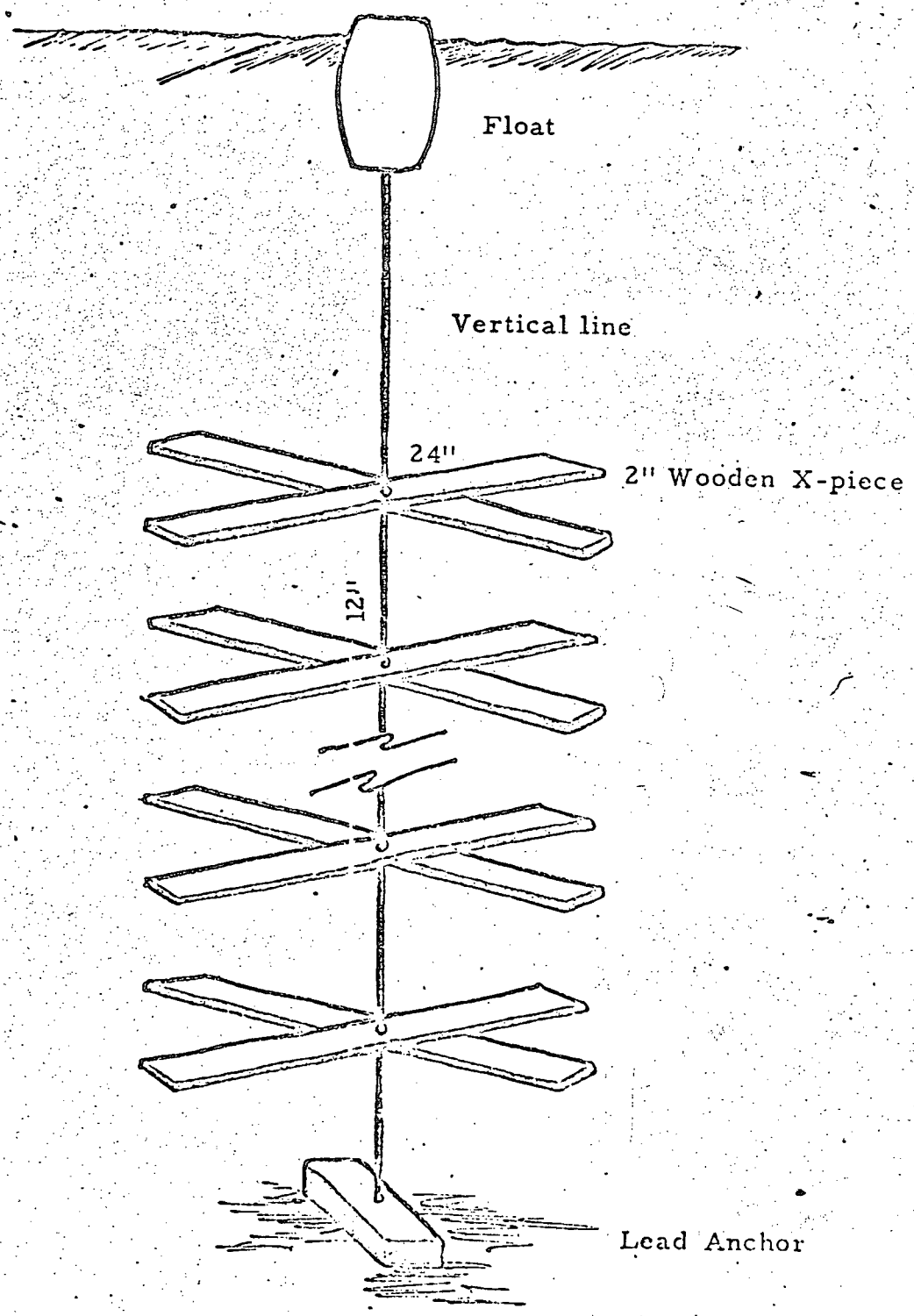
The second site at Saugerties, just north of Esopus Creek, is a freshwater environment, although a tidal rise and fall is observed. For this site the freshwater mussel, Elliptio complanatus, was used. This mussel is found commonly in the Hudson River in the freshwater zone, but it is already heavily contaminated by pesticide residues in the river. However, the same species is found uncontaminated, easily accessible and present in sufficient numbers, in a lake (Sterling Lake) adjacent to the laboratory, and mussels were transferred for the experiment from the lake to the Hudson River site.

Initially, various types of cages were constructed for restricting the animals at the two sites. These have been used and

reported satisfactory in other environments (Godsil et al., 1968). However, these proved bulky and cumbersome to handle from small boats; in addition, we found that sediment levels and water movements in the Hudson River led to the shellfish being overwhelmed by silting and unable to clean themselves. The unique system developed here consists of fastening the animals to a set of simple wooden X pieces suspended on a line held upright in the river. In this way, the animals were able to maintain themselves in a healthy conditions, and the apparatus was easy to reach and handle from the small boat in the river. A similar method of attaching freshwater mussels to a nylon line, and suspension in a river proved unsuccessful (Bedford et al., 1968).

The cross-shaped wooden slats measured 2" x 24" and a total of seven were assembled at foot intervals along a vertical line (Fig. 2). This could be anchored on the river bottom with a lead weight and was held upright by a plastic float. The shellfish were held at 16° C in the laboratory after their collection from Sterling Lake or receipt from the New York State Conservation Department's laboratory, and then assembled on the cross pieces in the laboratory before being transferred to the appropriate

Figure 2: Diagram of implantation frame.



sampling site. Some difficulty was experienced in fastening the shellfish firmly to the wooden slats. The freshwater and marine mussels with their relatively smooth and regular shaped shells were easily fastened with rubber cement*. However, oysters and hard clams with irregular shaped shells had to be fastened by both rubber cement and a fast setting cement** in an individual preshaped cast, which was in turn glued to the wooden slats. This whole procedure took about 5 hours for setting up each "line" carrying six individuals of the four marine species, with a total of 42 animals for each "line". The process required 3 days from collection to implantation. During this period they were kept out of water, but in a 16° C constant temperature room and kept covered with damp cloths.

Six lines each carrying 7 cross pieces were set in the river at Piermont over a period of 6 weeks, beginning 20 July 1967; weekly samples of animals were taken from the cross pieces at a predetermined level of each line over a period of 8 weeks (Table 1). At the freshwater site at Saugerties, the same procedure was used, with the single species Elliptio complanatus, and with only a single cross piece on each vertical line since the water is shallow at this

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* Weldwood Contact Cement, By: - U.S. Plywood Corp., Michigan.
** "Por-rok", Fast setting cement, Hallemite Mfg. Co.

Table I Sampling Procedure for Shellfish Monitor Experiment

		Lines						Elevation on Line
		1	2	3	4	5	6	
week	1							
	2	x	-	-	-	-	-	1st level
	3	x	x	-	-	-	-	2nd level
	4	x	x	x	-	-	-	3rd level
	5	x	x	x	x	-	-	4th level
	6	x	x	x	x	x	-	5th level
	7	x	x	x	x	x	x	6th level
	8	x	x	x	x	x	x	7th level

x animals sampled

- animals not sampled, which remained on crosspiece

site. Each cross piece carried 24 animals, and 2 lines were set each week for 6 weeks, and samples were taken over a period of 8 weeks.

Control samples were analyzed for each species used and for each line set. In total, a weekly sample was taken of each of the five species, together with a 5 gallon water sample at each site. Salinity and temperature at the two sites were recorded (Table 2).

Analytical Procedure for Pesticide Residues

Each weekly sample of animals was transferred to the laboratory and the flesh separated from the shells and drained. The flesh was weighed, wrapped in aluminum foil and deep frozen.

Subsequently, the frozen samples were partially thawed, re-weighed, and transferred to a Waring Blendor with 100 ml hexane (for a sample weight of 25-40 g). After 2 minutes blending at low speed the mixture was allowed to settle and the supernate decanted. A further 50 ml hexane was added to the solid, and the Blendor run for 4 minutes. Again the mixture is settled, and the supernate decanted and added to the first. Again, 50 ml hexane was added to the solid, the Blendor run for 5 minutes and a final supernate decanted and the combined supernate filtered (Whatman No. 1).

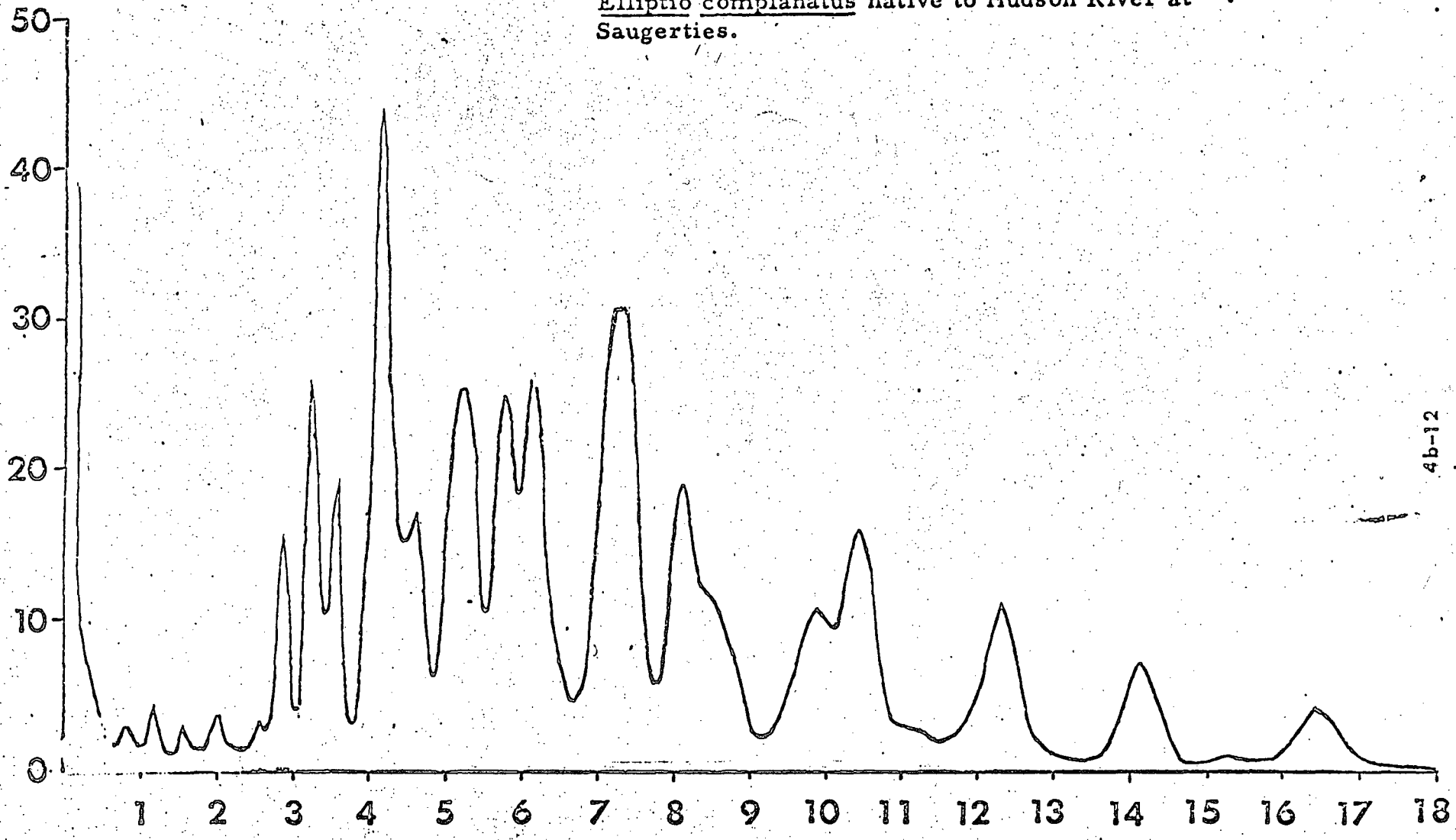
Table 2: Salinity and Temperature of Hudson River at Implantation Sites.

	Piermont			Saugertics	
	Salinity*	Temp.**		Salinity*	Temp.**
July 20			July 21		
Top	5.2	28.9	Top	0.06	26.8
Bottom	5.8	27.8	Bottom	0.06	26.7
July 27			July 28		
Top	5.2	27.3	Top	0.0	28.0
Bottom	5.0	27.3	Bottom	0.0	27.0
Aug. 3			Aug. 4		
Top	3.9	26.2	Top	0.14	26.2
Bottom	4.1	26.2	Bottom	0.04	26.2
Aug. 10			Aug. 11		
Top	6.9	26.0	Top	0.05	24.8
Bottom	6.9	26.0	Bottom	0.04	24.8
Aug. 17			Aug. 18		
Top	6.5	25.5	Top	0.05	25.8
Bottom	6.5	25.3	Bottom	0.06	25.8
Aug. 24			Aug. 25		
Top	5.4	23.2	Top	0.02	22.5
Bottom	5.6	23.1	Bottom	0.02	22.4
Aug. 31			Sept. 1		
Top	4.4	24.3	Top	0.12	21.1
Bottom	4.2	24.3	Bottom	0.12	21.2
Sept. 7			Sept. 8		
Top	6.5	22.5	Top	0.08	23.0
Bottom	6.4	22.4			

* Salinity expressed as ‰.
** Temperature expressed as degrees C.

This extract (approx. 200 ml) was reduced to 20 ml in a Kuderna-Danish evaporator and the reduced extract washed twice with 40 ml of acetonitrile. Subsequently the acetonitrile extract was reduced to 20 ml, back-washed with 20 ml hexane after addition of 20 ml of deionised water saturated with sodium chloride. Then 20 ml of the hexane extract is introduced on to a prepared fluorisil column (Mills procedure). After elution with 15% by volume of ethyl-hexane mixture (about 200 ml), the extract is reduced to 20 ml and is ready for gas chromatographic analysis. All analyses were made with a Beckman GC-5 gas chromatograph. Two independent analyses were run with different columns. Both columns are made of coiled glass, 10 feet in length, 2 mm I. D. One column is packed with 10% DC-200 on Gas Chrom Q 80/100 mesh, the other is a QF - 1/OV - 17 on Anakrom ABS 100/120 mesh. The chromatograph tracing was quantitated by reference to standards of nine pesticide residues: lindane, heptachlor, aldrin, heptachlor epoxide, dieldrin, DDE, TDE, o,p' - DDT, p,p' - DDT. In addition to these substances, there were a number of unidentified peaks in the chromatogram (Fig. 3).

Figure 3 Chromatogram of hexane extract of speciment of Elliptio complanatus native to Hudson River at Saugerties.



Biological Results

Freshwater mussels, Elliptio complanatus, collected from Sterling Lake for the experiment, were of uniform size, 55-79 mm, and showed a unimodal size distribution (Fig. 4 (a)). Elliptio complanatus adapted well to its transfer to the river at Saugerties; mortality was 4.5% of 286 animals used. The mean weight of individuals at the start of the experiment was 5.1 g, and during the period of the 5-week implantation, 5.1 to 7.2 g. In general, the mean weight of individuals appeared to increase during sojourn in the river at the implantation site, indicating that the animals were healthy and continued to feed (Fig. 5).

The ribbed mussel, Modiolus demissus, ranged in size from 60-89 mm, with a unimodal size distribution (Fig. 4 (b)) and their initial average flesh weight was 6.6 g. During the 7 week period of exposure in the Hudson River, the individual weights ranged from 4.7 - 7.1 g, but little indication of any consistent increase in weight (Fig. 6).

The oysters, Crassostrea virginica, ranged from 80-144 mm (Fig. 4 (c)) and the initial average flesh weight was 8.2 g. The range of weight over the 7 week period was 4.8 - 10.8 g, with no apparent consistent weight increase (Fig. 7). The soft shelled clam Mya arenaria and the hard shelled clam, Mercenaria mercenaria

Figure 4 Size frequency distribution of lamellibranch species used in the experiment.

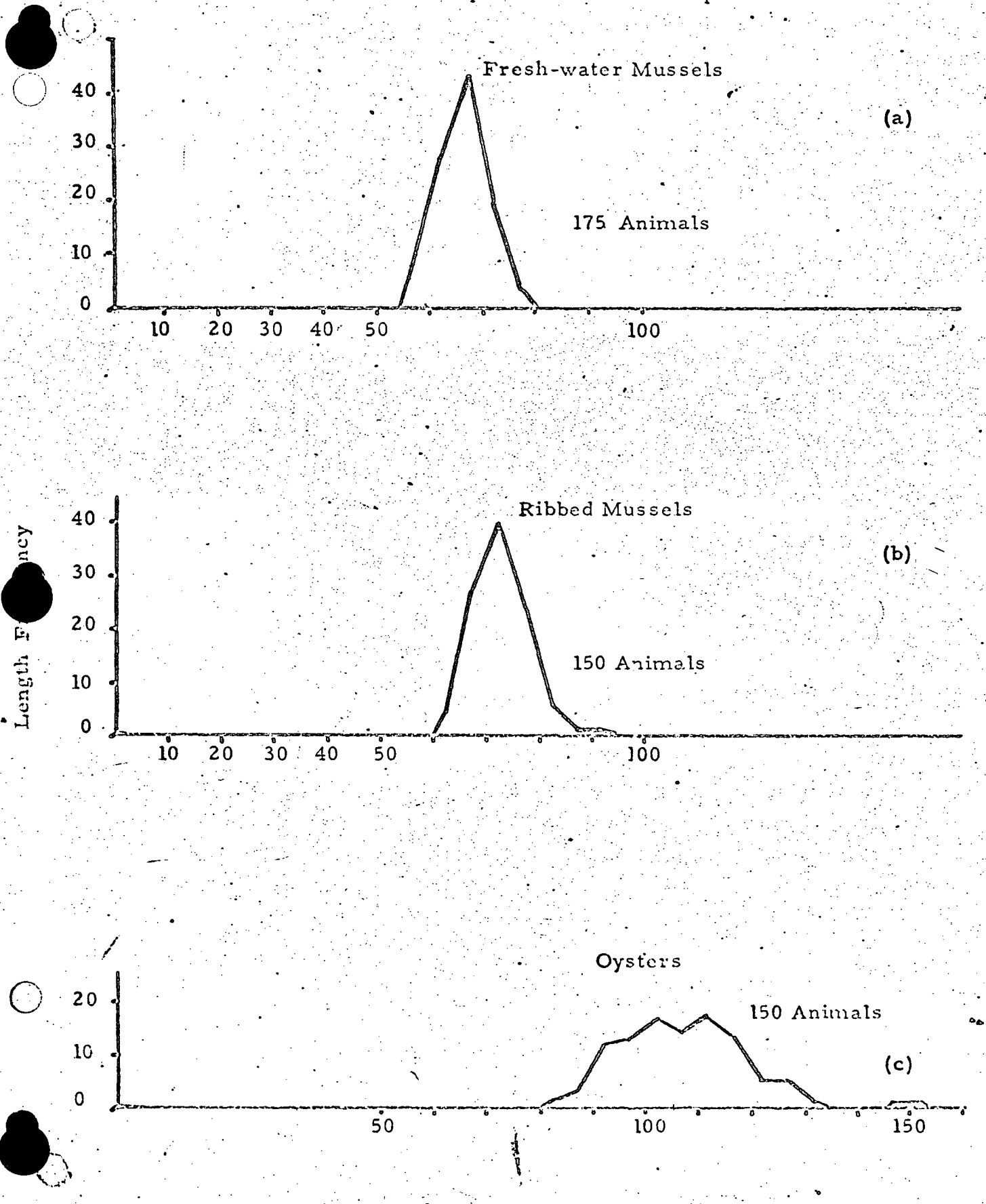


Figure 4 (con't)

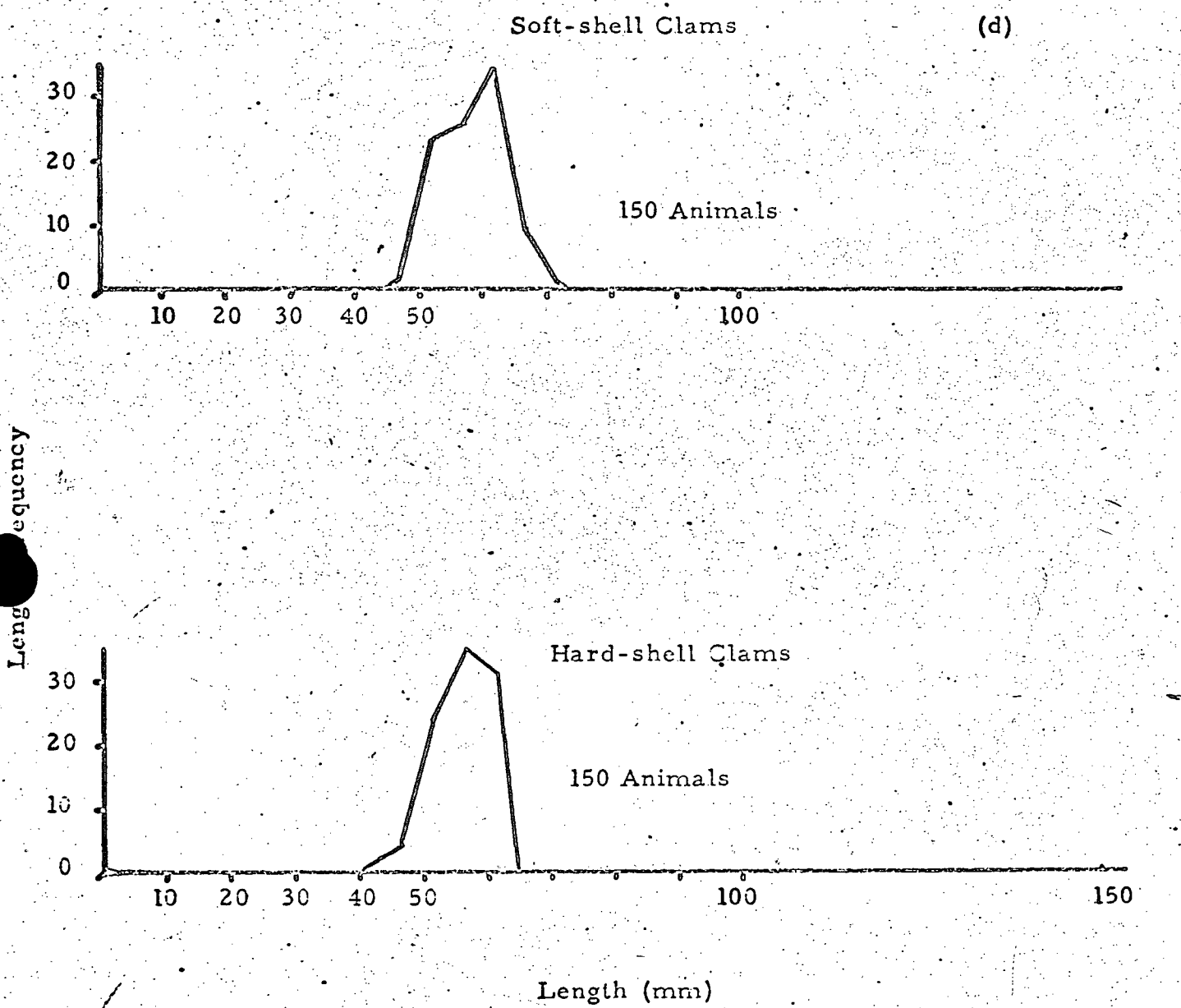


Figure 5 Mean weight of individual Elliptio complanatus at Saugerties, during course of experiment.

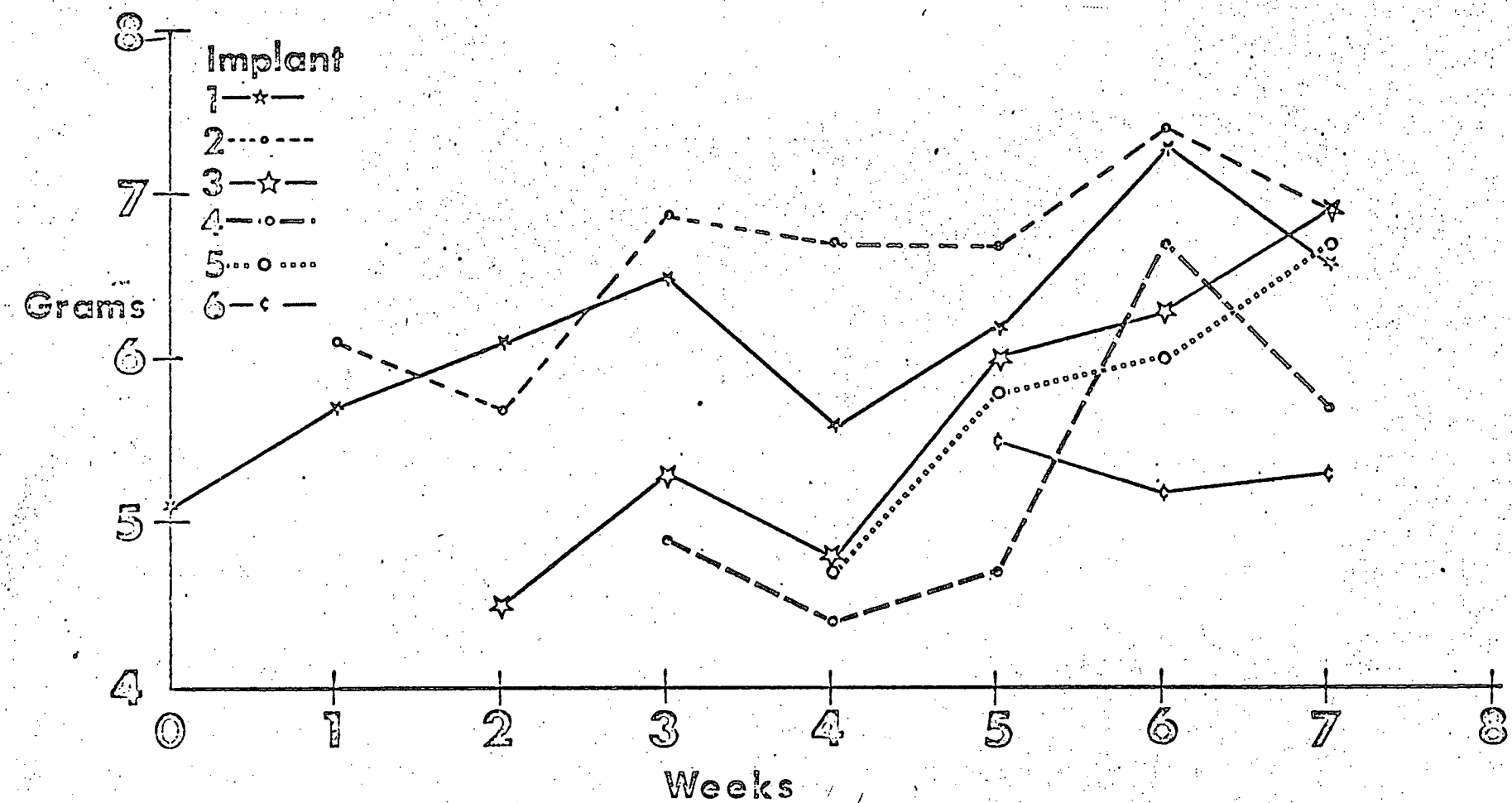


Figure 6 Mean weight of individual Modiolus demissus at Piermont Pier, during course of the experiment.

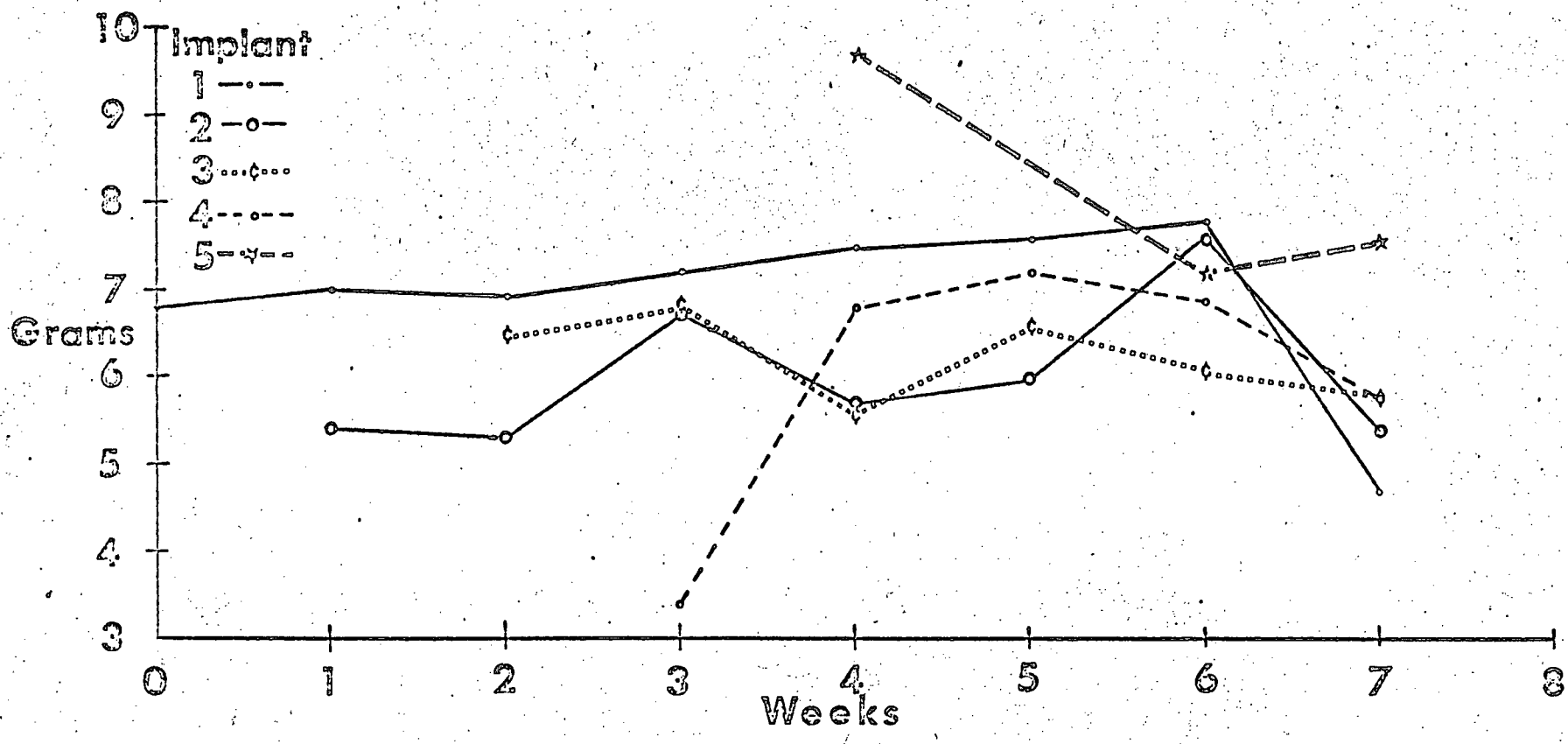
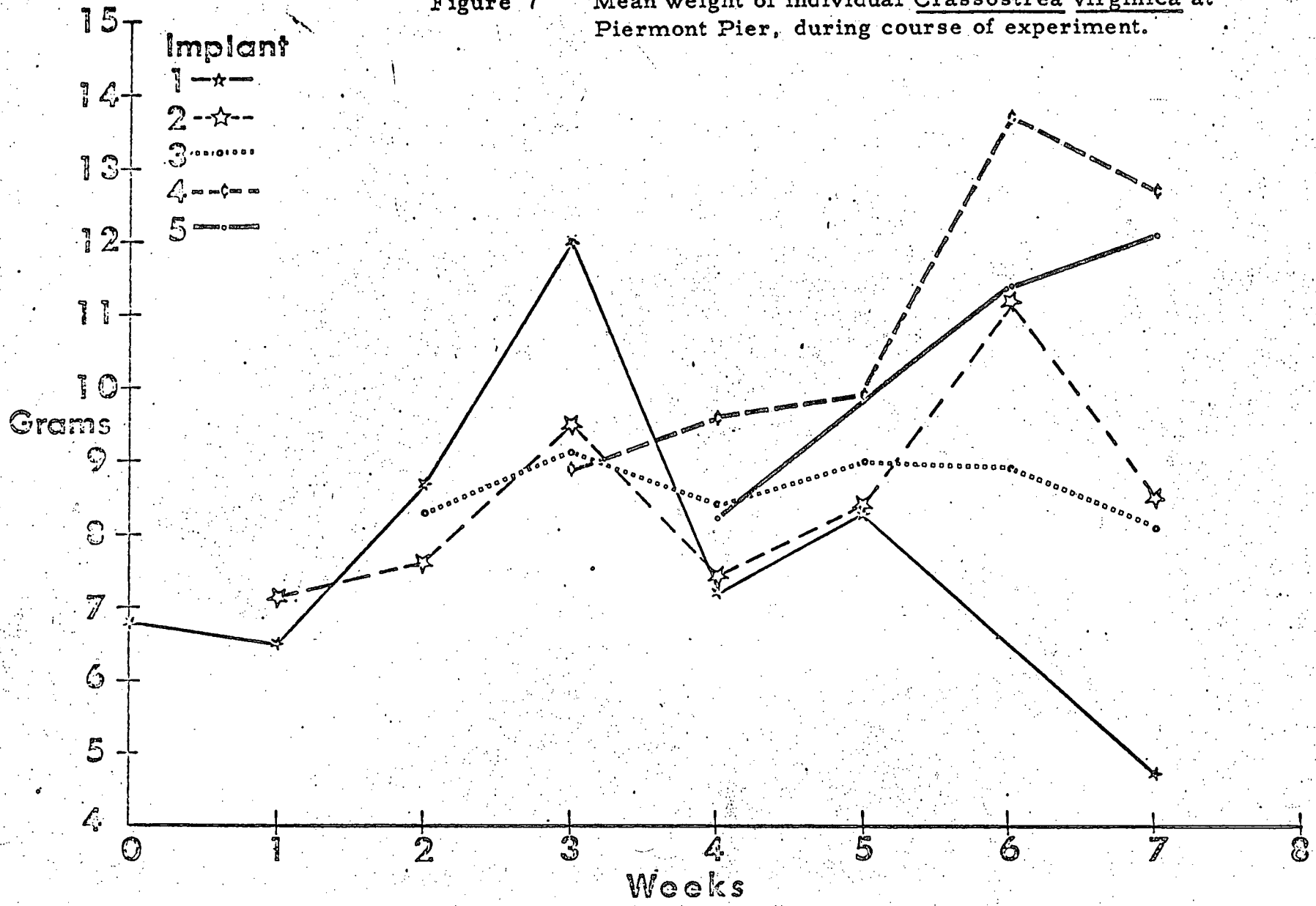


Figure 7 Mean weight of individual Crassostrea virginica at Piermont Pier, during course of experiment.



were similar in size from about 40-75 mm (Fig. 4 (d) and (e)). The initial average weight of the former was 6.8 g and of the latter 14.8 g, but few animals survived the course of the experiment.

Mortality of the marine species at the Piermont sites was*.

Ribbed mussel, Modiolus demissus	18%
Oyster, Crassostraea virginica	25%
Hard shell clam, Mercenaria mercenaria	78%
Soft shell clam Mya arenaria	100%*

Undoubtedly this heavy mortality was caused in part, by delay in handling and setting up the apparatus, especially of the species which were unable to keep the valves tightly closed and, in part by the change in salinity of the medium to the 5.5 °/oo characteristic of the Piermont site during the course of the experiment.

Analytical Results

Estimates of selected pesticide residues in the flesh of the lamellibranchs used in the experiments are shown in Fig. 8-11. Numerical data appear in Appendix A. The level of pesticides in Hudson River water at the two sites was also followed during

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* At the end of 1 week of transfer to the river.

Figure 8 DDE and TDE in Elliptio complanatus implant at Saugerties.

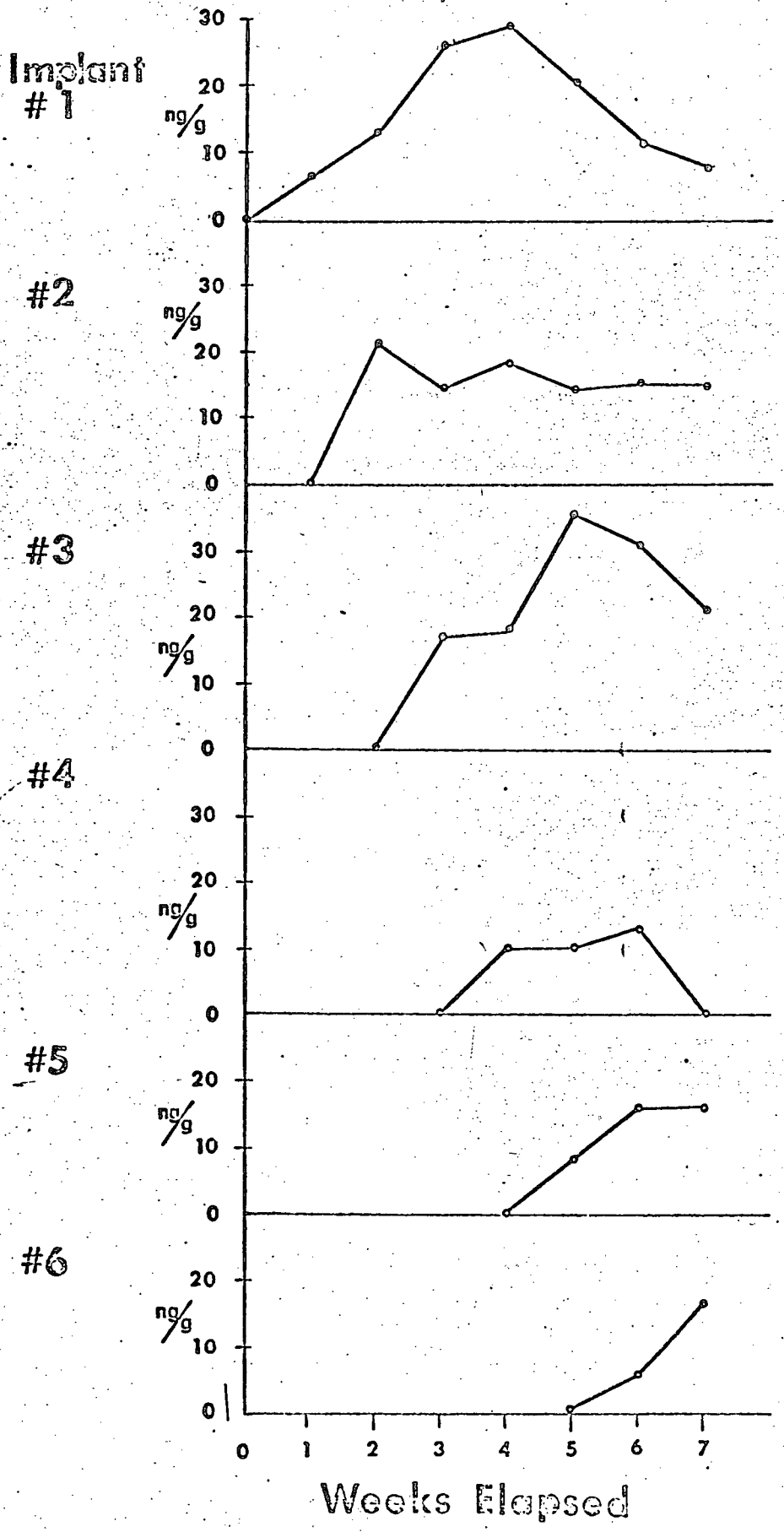


Figure 9 DDE and TDE in Modiolus demissus implant at Piermont Pier.

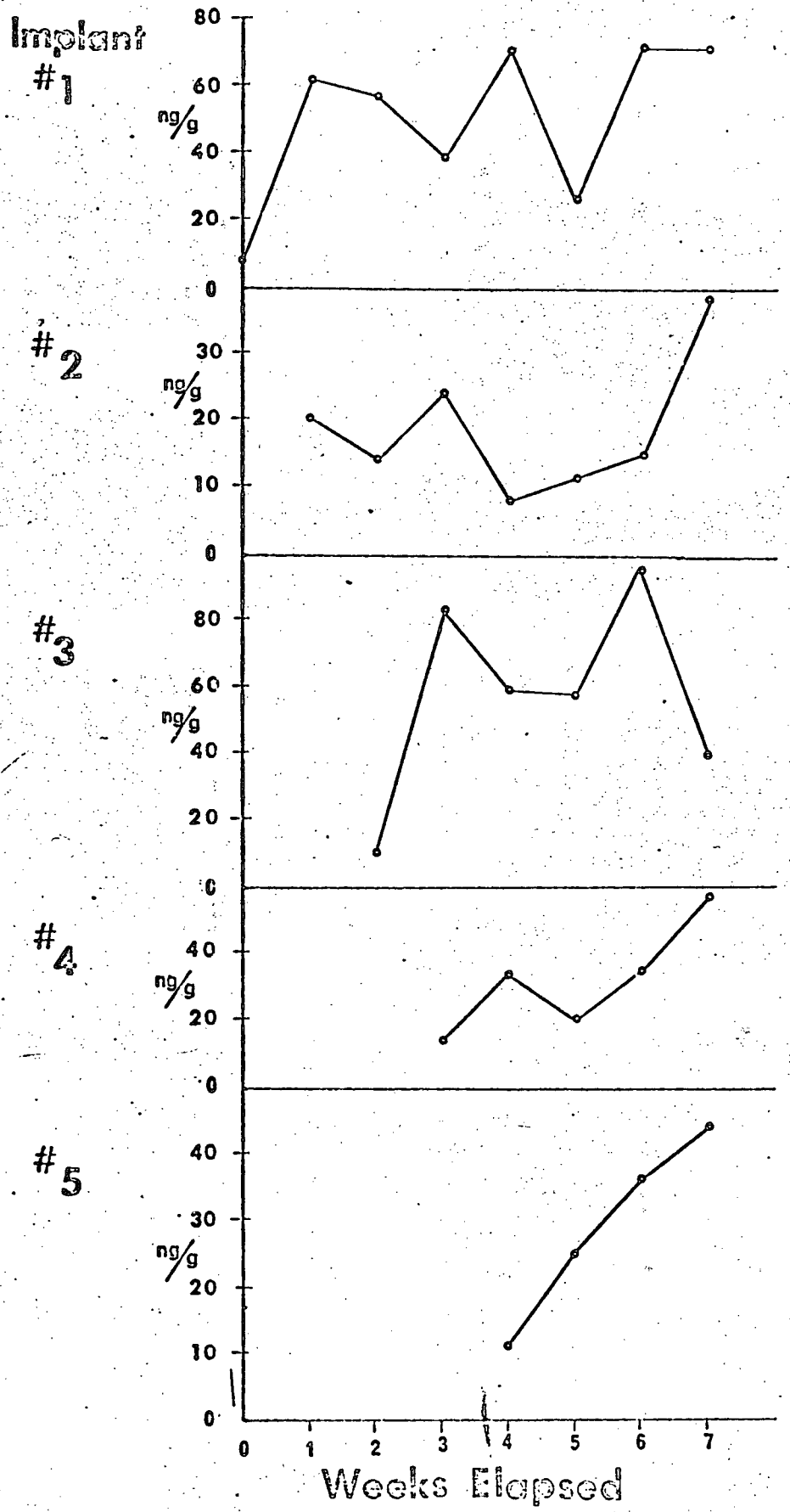


Figure 10 Dieldrin in Miodiolus demissus implant at Piermont Pier.

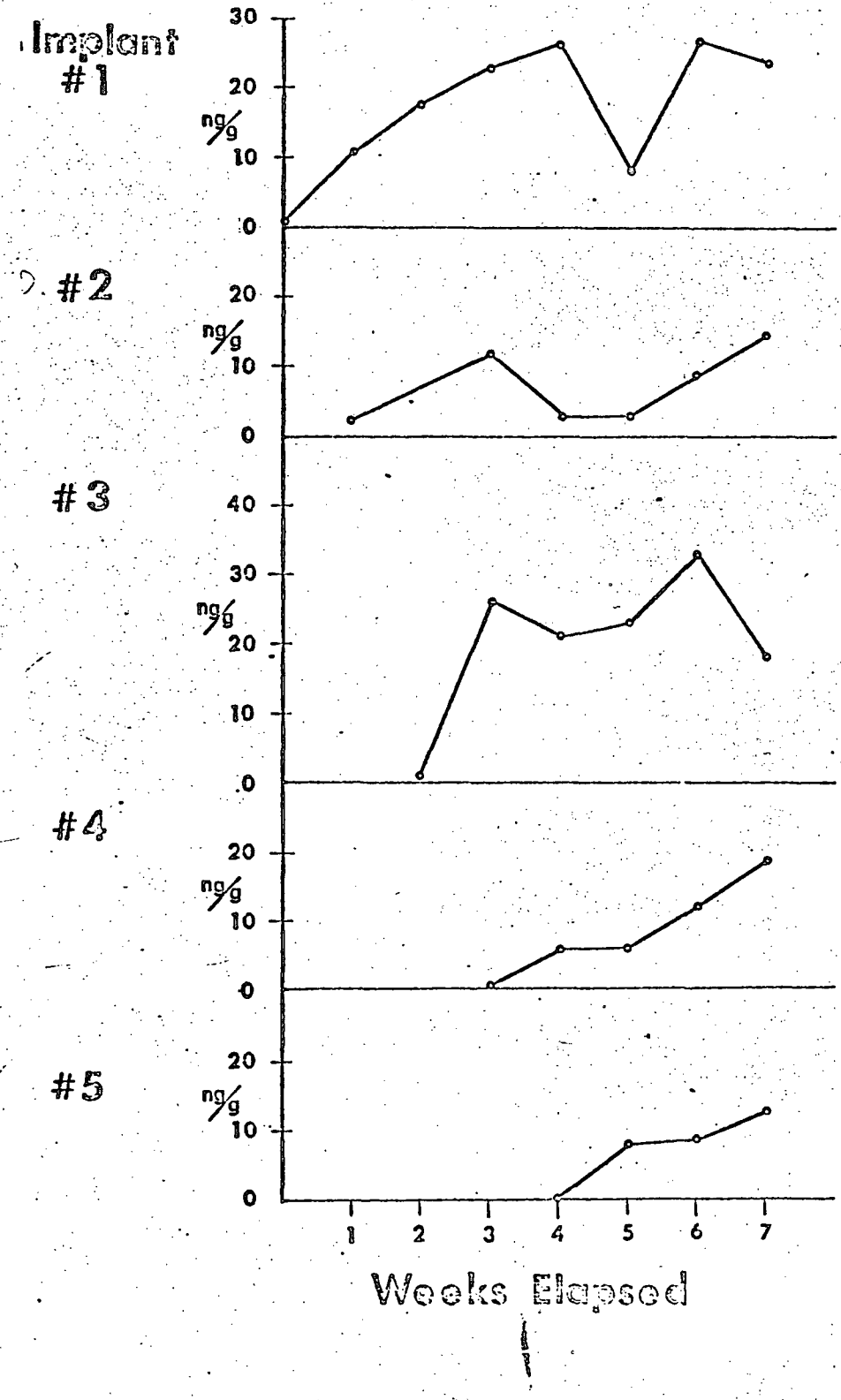
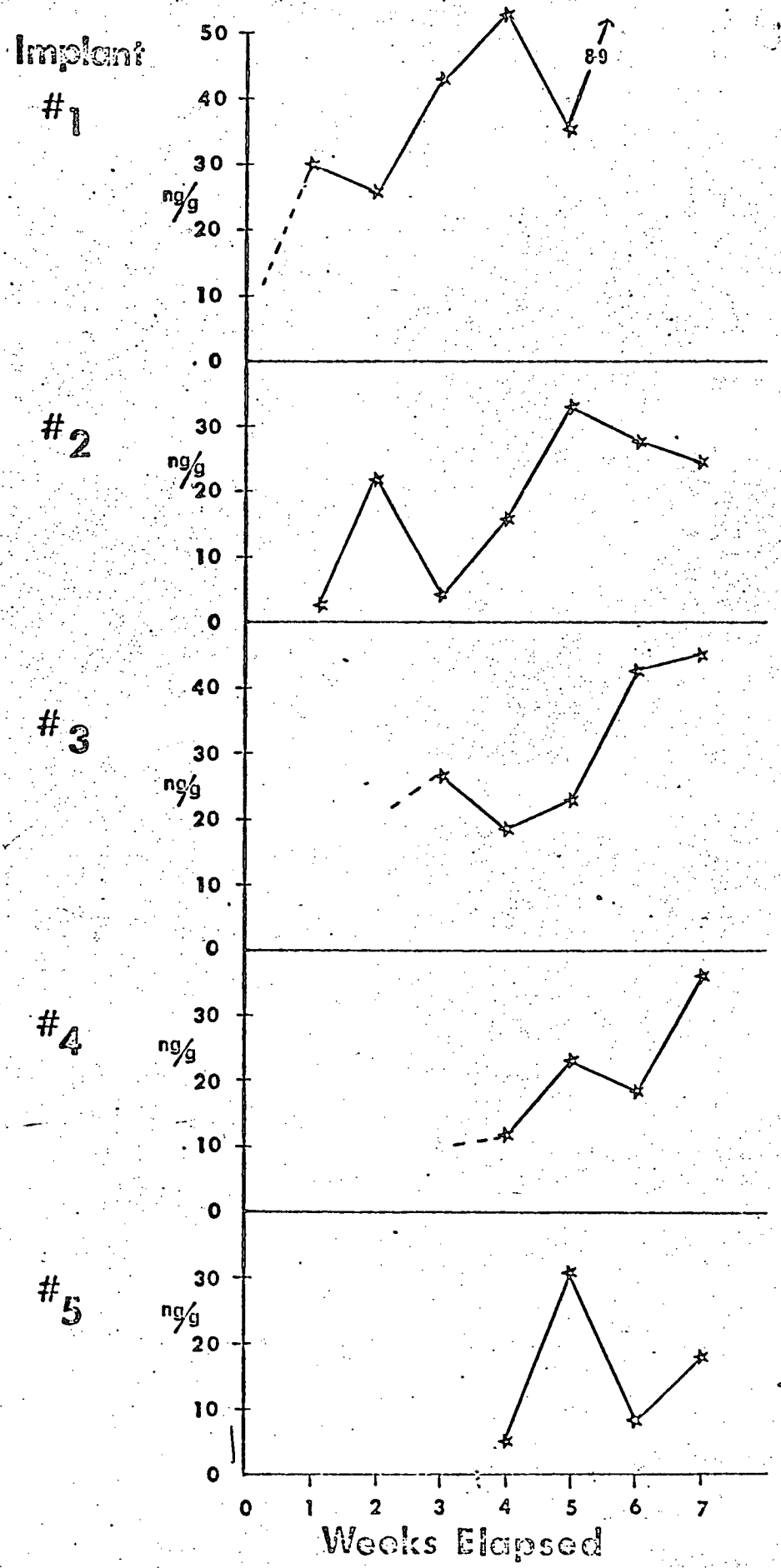


Figure 11 DDE and TDE in Crassostrea virginica implant at Piermont Pier.



the course of the experiment. Only lindane and dieldrin were found consistently, with tentative identifications of DDT metabolites on two occasions only at Saugerties (7/21, 3 mg/l; 8/11, 8 mg/l), but more consistently at Piermont (from 8/10 to 8/31, up to 4 mg/l).

Elliptio complanatus taken from Sterling Lake initially contained about 10 ng/g wet weight of DDT metabolites, but during the course of inplantation (when the shellfish were held in the laboratory) DDT residues diminished to a negligible amount. On the other hand the related Anodonta cataracta and Elliptio complanatus from the Hudson River contained from 50 to 70 µg/g wet weight, reflecting the more contaminated environment of the river. On implantation, all groups during the 5-week starting period showed an initial rapid increase in DDT metabolite concentration followed by some indication of a "levelling-off" or equilibrium (Fig. 8). Subsequently, some groups show a decline, but it is not clear whether this is related to a decline in ambient water concentrations (recorded as "trace" throughout) or to a physiological change. Dieldrin was also followed through these samples, but no consistent data were obtained.

At the mesohaline site at Piermont Pier, the ribbed mussel, Modiolus demissus, similarly showed an increase in DDT metabolite concentrations after implantation, even though this species carried some residual concentration at the start of the experiment. Again, there is some indication that an equilibrium level is reached after two or three weeks sojourn in the new environment (Fig. 9). Dieldrin concentrations in M. demissus were followed and gave a fairly consistent picutre of increase, but little indication of equilibrium during the course of the seven week experiment (Fig. 10). The quantitative identification of dieldrin in water from the Piermont Pier site is significant in this respect.

Data for Crassostrea virginica are illustrated in Figure 11. A similar increase in DDT metabolites is observed in the first few weeks after implantation.

The two other species tested as monitors, the hard clam Mercenaria mercenaria and the soft clam Mya arenaria did not survive any appreciable time in the river, and their tissues were not subsequently analysed.

Discussion

Our observations on three lamellibranch species living in

fresh and brackish water confirm the findings of previous investigators that this group of molluscs is able to concentrate pollutants from the ambient aquatic environment (Butler, 1966; Godsil et al., 1968; Bedford et al. 1968). Our data are not sufficiently precise to be able to conclude that the different species demonstrate different uptake rates, especially in view of our lack of quantitative information about pesticide concentrations in the aquatic medium. However the fresh-water mussels Elliptio complanatus seemed not to build up concentrations in excess of 30 ng/g, even though a preliminary sampling of this species, and the related Anodonta cataracta, indicated concentrations as high as 70 ng/g. The brackish water lamellibranchs used successfully, the oyster and the ribbed mussel, however, both showed concentrations to 70 or 80 ng/g, in some groups within the seven-week sampling period. These concentrations may be compared with lower mean concentrations of DDT and metabolites in Lampsilis siliquoidea at 4 stations of 0.08 - 0.63 ng/g and in Anodonta grandis of 0.28 ng/g, after some weeks in a polluted stream (Bedford et al., 1968). The freshwater clam, Gonidea sp., has a concentration of about 7 ng/g DDT and metabolites in Tule Lake but much higher (100 ng/g) concentrations of endrin (Godsil et al., 1968). Oysters,

Crassostrea virginica, can accumulate a concentration of 25 ng/g during 1 week exposure, and other marine lamellibranchs respond in a similar fashion (Butler, 1966).

The experiment performed in 1967 gives no information about rates of loss of pesticide residues in an uncontaminated environment, about the balance of uptake and loss, nor does it distinguish between two possible rates of intake viz., from the food or directly from the ambient medium. Further field experiments and supporting laboratory experiments to answer these questions are under way in 1968.

Comparison of our data with those published in the literature, indicates that pesticide residues in the Hudson River water or its biota are considerably higher than in other bodies of fresh water in North America, and that the native or experimental lamellibranchs reflect this higher environmental concentration in their higher tissue concentrations. Levels of concentration similar to those seen in the Hudson River have been reported for the biota of a Long Island environment (Woodwell et al., 1967).

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Appendix A

Analysis of Pesticide residues in 3 species of lamellibranchs

T = tentative identification (one GLC column only)

- = not detected on either column

blank = sample not run

1: Fresh-Water Mussel Implants at Saugerties

DDT Metabolites, ng/g
Implant - Date

Exposure Weeks	1	2	3	4	5	6
0	T	T	T	T	T	T
1	6	21	17	10	8	6
2	13	14	18	10	16	17
3	26	18	36	13	16	
4	29	14	31	T		
5	21	15	21			
6	11	15				
7	8					

2: Freshwater mussel implants at Saugerties

Dieldrin ng/g

Implant - Date

Exposure Weeks	1	2	3	4	5	6
0	T	T	T	T	T	T
1	10	31	26	12	T	T
2	T	22	38	T	T	T
3	T	T	30	T	T	
4	T	T	31	-		
5	T	T	T			
6	T	T				
7	T					

3: Oyster Implants at Piermont Pier

DDT Metabolites, ng/g

Implants - Date

Exposure Weeks	1	2	3	4	5	6
1		3			5	22
2	30	22	27	12		
3	26	4	19	23	31	
4	43	16	23	19	18	
5	53	33	43	45		
6	35	28	45			
7		25				
8	89					

4: Oyster Implants at Piermont Pier

Dieldrin, ng/g
Implants - Date

Exposure Weeks	1	2	3	4	5	6
1					T	T
2	11	11	9	5	4	
3	17		7	8	T	
4	20		7	7	T	
5	31	9	15	10		
6	T	9	16			
7		16				
8	29					

5: Ribbed Mussel Implants at Piermont Pier

DDT Metabolites ng/g

Esposure Weeks	1	2	3	4	5	6
0	8	20	9	14	11	17
1	61	14	83	34	25	
2	57	24	59	20	36	
3	38	8	57	34	44	
4	71	11	96	57		
5	26	15	39			
6	72	39				
7	71					

6: Ribbed Mussel Implants at Piermont Pier

Dieldrin ng/g

Exposure Weeks	1	2	3	4	5	6
0	1	2	1	-	-	-
1	11	-	26	6	8	
2	18	12	21	6	9	
3	23	3	23	12	13	
4	26	3	33	19		
5	8	9	18			
6	27	15				
7	24					

RADIOECOLOGICAL STUDIES, 1966 AND 1967

By: Frank J. Cosolito

Introduction

In a previous progress report an account has been given of this laboratory's technique for the preparation of water, sediment and biological samples for radionuclide estimation, together with an account of the automated counting technique [1]. The nuclides estimated in the samples were Ce-144, Cs-137, Ru-106/Rh-106, Co-60, Zn-65, Mn-54, Ra-228, Ra-226 and K-40. The data reported for 1964 and 1965 have indicated a fairly consistent pattern. This conclusion was based on reproducible values for naturally occurring K-40 (at $\alpha = 0.05$ level of significance).

The radionuclide study during 1966 and 1967 has exposed several problems inherent in multiple radionuclide analyses at levels approaching background. These problems have been classified to two major categories: (1) those inherent in sampling and counting; (2) those due to limitations imposed by the mathematical model for analysis of spectral data. Appendix A is a discussion of these errors.

Radiological Findings 1966-1967

During 1966 and 1967, sampling of water, sediments, fish, and rooted plants was continued at sites identical with those of previous years (see Appendix B). All stations were close to the west shore of the river at distances from 26 to 106 miles from the Battery, Manhattan. The collections were made between June and August in 1966 and between June and October in 1967.

The volume of water sampled was initially 8 liters but was subsequently increased to 20 liters to improve counting statistics (see p. 8). Water samples in 1966 were collected from 6/27 to 8/24, every two weeks. In 1967, the sampling period was much more extensive, from 3/2 to 8/1, when samples were taken once a month. This was to obtain data on a broader time base to be more representative of the Hudson River throughout the year. Sites II-E-1 and II-E-3 were eliminated in 1967, and only west shore stations sampled, in order to simplify the collecting schedule. Previous years' results had shown little significant difference between samples from the east and west shores. A notable result of the increased rainfall in 1967 is demonstrated by the changing ^{40}K concentration of the Hudson River water, which was 89 pCi/liter at station I-W-3 in 1966, but only 16 pCi/

liter in 1967. A similar change is seen at station II-W-2, 78 pCi/liter in 1966 and 9 pCi/liter in 1967.

The fish sampled included 17 species, of which 14 were common to the previous 3 years' samples. Sample size varied with catch, from 300 to 2770 g. The rooted plants included 13 species in 1966, but was restricted to 4 "monitor" species harvested in September and October in 1967. The mean sample size was 800 g with a range from 300 to 1850 g. Sediments were collected at all stations and 15-30 g of sample (including any small contained organisms, but excluding larger obvious detritus) was analyzed.

Summaries of the data obtained appear in Appendix C, Tables I-IX, and a comparative account of summarized data for these years, together with previous years, is to be found in the text following.

Summary of Radiological Findings 1964-1967

Radionuclide data for 1964 to 1967 are summarized in Tables 1-6. With minor exceptions, the data support the conclusions presented in earlier progress reports (Refs. 1, 5). Some deviations from previously reported conditions will be cited in this report.

Quantitative estimates for ^{65}Zn and ^{125}Sb have been excluded from the tabulated results but the values observed are reported

in the text. Ruthenium-106 estimates are tabulated but the validity of these values is doubtful in view of the similarity of the Ru-106 gamma spectrum with that of most positron emitters (see Appendix A).

Water Samples

In 1966 sample volume was increased to 8 liters, and in 1967 to 20 liters; before then a sample volume of 6 liters was used (Ref. 5). Improvement in sampling and counting techniques is reflected in smaller standard errors in the 1966 and 1967 estimates. In 1967, the program of analysis was expanded to include trace metals and pesticides as well as radionuclides. In addition, sampling was extended into October 1967.

Sampling sites on the Hudson River during 1966 and 1967 ranged from Tarrytown to Saugerties, over a distance of about 80 miles. Although there were 8 sampling stations the data indicated that an upper (northern) and lower (southern) region can be defined by the concentration of ^{40}K observed (Tables 1 and 2). The ^{40}K concentration and hence stable potassium can be used to delineate the estuarine and freshwater environments. Just south of the sampling site at Cornwall, values up to 65 pCi ^{40}K/l water have been recorded (about 1/5th sea water).

TABLE 2

Radionuclide Concentrations in Hudson River Water
North of West Point
1965 - 1967 Summary

Radionuclide		Concentration in pCi/liter		
		1965	1966	1967
^{40}K	Mean	1.55 ± 0.49	1.57 ± 0.44	1.23 ± 0.24
	Range	ND - 8.51	ND - 5.40	ND - 3.63
	Ratio*	7/18	12/19	13/15
^{226}Ra	Mean	0.19 ± 0.08	0.14 ± 0.06	0.05 ± 0.02
	Range	ND - 0.73	ND - 0.58	ND - 0.20
	Ratio	6/18	12/19	8/15
^{228}Ra	Mean	0.14 ± 0.06	0.07 ± 0.03	0.03 ± 0.01
	Range	ND - 0.50	ND - 0.44	ND - 0.14
	Ratio	13/18	9/19	6/15
^{54}Mn	Mean	0.12 ± 0.06	0.08 ± 0.03	0.05 ± 0.02
	Range	ND - 0.50	ND - 0.45	ND - 0.18
	Ratio	11/18	6/19	10/15
^{60}Co	Mean	0.08 ± 0.04	0.07 ± 0.03	0.02 ± 0.01
	Range	ND - 0.35	ND - 0.40	ND - 0.08
	Ratio	9/18	7/19	7/15
^{106}Ru	Mean	0.27 ± 0.16	0.47 ± 0.17	0.16 ± 0.05
	Range	ND - 1.69	ND - 2.40	ND - 0.49
	Ratio	7/18	11/19	9/15
^{137}Cs	Mean	0.19 ± 0.05	0.10 ± 0.03	0.03 ± 0.01
	Range	ND - 0.50	ND - 0.27	ND - 0.08
	Ratio	13/18	14/19	9/15
^{144}Ce	Mean	0.56 ± 0.17	0.30 ± 0.11	0.12 ± 0.04
	Range	ND - 1.95	ND - 0.80	ND - 0.43
	Ratio	12/18	13/19	9/15

*Ratio = No. of samples containing measurable activity/total No. of samples analyzed

ND = None detected

North of this site the ^{40}K concentrations are much less. Samples from the Cornwall station exhibit highly variable ^{40}K concentrations and have been excluded from the data summary presented here, but are listed in Appendix A.

In the estuarine portion of the river (see Table I) (Tarrytown to Cornwall) a declining ^{40}K concentration during 1966 and 1967 compared with 1965 reflects a greater freshwater runoff in those years, or other unknown factors changing the pattern of salt water intrusion. The average ^{40}K concentration during the past four years is approximately 22 pCi/l, less than 10% that of sea water. For the northern portion of the river (Cornwall to Saugerties) a more consistent ^{40}K concentration of about 1.5 pCi/l has been recorded (Table 2), equivalent to about 2 mg of stable potassium per liter, characteristic of fresh waters.

Estimates reported for ^{226}Ra and ^{228}Ra in water show wide variations for both sectors of the river through the period 1964 to 1967. However, these estimates are based on a small number of samples of low activity and only the limited conclusion is justified that concentrations of about 0.1 pCi/l for both ^{226}Ra and ^{228}Ra are present.

Estimates for ^{65}Zn in 1966 and 1967 were much lower than

those reported in previous years, 0.6 ± 0.3 pCi/l and "traces" respectively. Only trace amounts of ^{65}Zn are likely to be present in the Hudson River water. The low and variable values observed in 1966 and 1967 samples, even with 20 l volumes of water, do not justify any significant conclusions about the behavior of this nuclide in the Hudson River environment.

Estimates for ^{137}Cs and ^{144}Ce indicated that the concentrations of these 2 fission products in the Hudson River water are decreasing. Antimony-125 was added to the reference spectra in 1966 and 1967 but the values obtained (about 0.4 ± 0.2 pCi/l) are low and variable. Three samples analyzed radiochemically for ^{90}Sr in 1966 indicate a concentration of 1 pCi/l, about one-half the level observed in 1965. The observed ratio of $^{137}Cs/^{90}Sr$, 0.3, is compatible with other published data for surface waters [2], in contrast to values of 1.7 in fallout samples.

In general, the results for 1966 and 1967 water samples confirm the conclusions of previous years that natural ^{40}K contributes the major part of the total radioactivity in the river water. Other naturally occurring nuclides, ^{226}Ra and ^{228}Ra, each contribute about 0.1 pCi/l. In the four year period summarised, the upper river shows a declining radioactivity for both fission and activation products, while the results for the lower river are

more variable, year by year, reflecting variable input of both nuclides and diluting fresh water. The radioactivity due to man-made sources, in both upper and lower sectors of the river, is one to four orders of magnitude less than that due to ^{40}K. *

Sediments

Summary radionuclide data for sediments are tabulated in the same way as for water samples (Tables 3 and 4). Sampling sites below West Point are representative of the estuarine sector of the river while sites above West Point are in the freshwater sector.

Potassium-40 has been detected in sediment samples from both sectors at concentrations ranging from 5 to 23 pCi/g. The mean concentration of ^{40}K, in sediments throughout the river, appears to be relatively uniform at about 13 pCi/g.

Radium-226 is found in sediments throughout within a range of 0.2-2.6 pCi/g. The apparent mean concentration for the entire river bed is slightly greater than 1 pCi/g. Radium-228 occurs within the range of 0.1 - 2 pCi/g and at a mean concentration of about 1 pCi/g.

The two activation products ^{54}Mn and ^{60}Co appear in trace amounts. With the exception of high values reported for

TABLE 3

Radionuclide Concentrations in Hudson River Sediments
South of West Point
1964-1967 Summary

Radionuclide		Concentration in pCi/g Dry Weight			
		1964	1965	1966	1967
^{40}K	Mean	12.45 ± 0.36	13.38 ± 0.32	14.39 ± 0.46	12.69 ± 0.3
	Range	5.48 -16.43	6.24 -21.99	8.11 -18.19	3.50 -20.5
	Ratio*	11/11	19/19	12/12	14/14
^{226}Ra	Mean	0.60 ± 0.04	1.62 ± 0.06	0.94 ± 0.05	0.92 ± 0.0
	Range	0.20 - 0.90	0.64 - 2.63	0.52 - 1.37	0.36 - 1.2
	Ratio	11/11	19/19	12/12	14/14
^{228}Ra	Mean	1.07 ± 0.08	1.04 ± 0.03	0.99 ± 0.04	0.92 ± 0.0
	Range	0.09 - 2.10	0.04 - 1.64	0.63 - 1.37	0.27 - 1.6
	Ratio	11/11	19/19	12/12	14/14
^{54}Mn	Mean	0.95 ± 0.03	0.15 ± 0.03	0.20 ± 0.03	0.43 ± 0.0
	Range	ND - 5.90	ND - 0.42	ND - 0.39	ND - 3.5
	Ratio	8/11	15/19	11/12	13/14
^{60}Co	Mean		0.07 ± 0.02	0.09 ± 0.03	0.21 ± 0.0
	Range	ND	ND - 0.25	ND - 0.22	ND - 0.9
	Ratio	0/11	12/19	7/12	12/14
^{106}Ru	Mean	4.54 ± 0.39	0.81 ± 0.01	0.43 ± 0.15	0.55 ± 0.1
	Range	1.43 -11.20	ND - 2.79	ND - 1.98	ND - 1.8
	Ratio	11/11	16/19	8/12	11/14
^{137}Cs	Mean	0.94 ± 0.03	1.12 ± 0.02	0.88 ± 0.05	0.91 ± 0.0
	Range	0.17 - 2.80	0.09 - 2.63	0.31 ± 2.12	0.19 - 2.4
	Ratio	11/11	19/19	12/12	14/14
^{144}Ce	Mean	2.77 ± 0.14	1.15 ± 0.09	0.47 ± 0.07	0.28 ± 0.0
	Range	0.61 - 9.00	ND - 2.93	ND - 2.10	0.02 - 0.7
	Ratio	11/11	18/19	9/12	14/14

*Ratio = No. of samples containing measurable activity/total No. of samples analyzed
ND = None detected

TABLE 4

Radionuclide Concentrations in Hudson River Sediments
North of West Point
1965-1967 Summary

Radionuclide		Concentration in pCi/g Dry Weight		
		1965	1966	1967
^{40}K	Mean	14.20 ± 0.35	12.39 ± 0.30	9.23 ± 0.26
	Range	7.85 -23.43	8.49 -15.80	5.21 -12.54
	Ratio*	20/20	19/19	11/11
^{226}Ra	Mean	1.61 ± 0.14	0.94 ± 0.04	0.70 ± 0.03
	Range	0.91 - 2.40	0.70 - 1.32	0.32 - 0.98
	Ratio	20/20	19/19	11/11
^{228}Ra	Mean	1.09 ± 0.03	0.84 ± 0.02	0.69 ± 0.02
	Range	0.69 - 1.70	0.47 - 1.15	0.27 - 1.09
	Ratio	20/20	19/19	11/11
^{54}Mn	Mean	0.09 ± 0.03	0.10 ± 0.02	0.06 ± 0.02
	Range	ND - 0.20	ND - 0.30	ND -0.19
	Ratio	15/20	13/19	9/11
^{60}Co	Mean	0.02 ± 0.01	< 0.005	0.02 ± 0.01
	Range	ND - 0.10	ND - 0.08	ND - 0.08
	Ratio	7/20	4/19	5/11
^{106}Ru	Mean	0.62 ± 0.10	0.31 ± 0.09	0.11 ± 0.06
	Range	ND - 2.66	ND - 1.41	ND - 0.42
	Ratio	13/20	12/19	7/11
^{137}Cs	Mean	0.74 ± 0.03	0.49 ± 0.02	0.33 ± 0.02
	Range	0.01 - 2.31	ND - 1.30	0.07 - 0.93
	Ratio	20/20	15/19	11/11
^{144}Ce	Mean	0.81 ± 0.10	0.44 ± 0.06	0.18 ± 0.04
	Range	ND - 1.99	ND - 1.05	ND - 0.42
	Ratio	19/20	18/19	10/11

* Ratio = No. of samples containing measurable activity/total No. of samples analyzed
ND = None detected

^{54}Mn in 1964 the maximum concentrations do not exceed 0.4 and 0.2 pCi/g respectively.

Estimates for ^{65}Zn (not tabulated) appeared in 50% of the samples for 1965 and 1966 within the range ND* - 3 pCi/g. The overall mean concentration was 0.30 $\pm$ 0.15 pCi/g and almost all of these estimates had 1σ** errors that included zero.

Antimony-125 appeared in 80% of samples in 1966 within a range ND-4 pCi/g, but two-thirds of these estimates had 2 σ errors that included zero. A mean concentration of about 1 $\pm$ 0.2 pCi/g was calculated, but the accuracy of this estimate is considered to be poor.

Despite the inaccuracies of low level activity estimates, the intermediate lived fall-out nuclides are clearly disappearing from the environment. Over the past 4 years ^{106}Ru has decreased from 4 to 0.5 pCi/g; ^{144}Ce from about 3 to 0.3 pCi/g. Cesium-137 has remained relatively constant at a concentration of about 1 pCi/g in the southern sediments. The sediments in the north show a decrease of from 0.7 to 0.3 pCi/g.

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* ND = none detected
** σ = standard deviation

A closer study of the distribution of ^{106}Ru in the sediments (see Appendix C, Tables 3 and 4) indicates that this radionuclide is principally found in sediments 40-70 miles from the Battery, with negligible amounts outside of this zone. ^{106}Ru is a fission product resulting from weapons testing, so that its distribution is expected to be uniform; on the other hand, if the chemistry of the element differs in salt water and in fresh water, we might expect a distribution related to salinity change along the length of the river studied. However, ^{106}Ru in sediments is highest in the center of the estuary and centered about Indian Point. The larger errors associated with ^{106}Ru estimates indicate that this activity may not be ^{106}Ru at all, but may be attributed to a short or intermediate lived activation product which is not included in the reference spectrum, and which has γ-peaks in the same region as ^{106}Ru. This may be a situation where multiple interferences conceal the individual radionuclide concentrations which are below our lower limits of detection.

Fish

The concentration of radionuclides found in fish do not differ appreciably from those reported previously [3] (Table 5).

An apparent increase in the mean ^{40}K concentration in fish in 1966 has been attributed to variable size selection of fish in the samples.

The total activity in fish due to the man-made radionuclides ^{54}Mn, ^{60}Co, ^{106}Ru, ^{137}Cs and ^{144}Ce is about 0.1 pCi/g, only about a fifth of that due to natural ^{40}K. Five samples of fish analyzed for ^{90}Sr had a range of 0.02 - 0.14 pCi/g (mean 0.1 pCi/g). Estimates for ^{65}Zn and ^{125}Sb are about 0.02 and 0.03 pCi/g respectively so that a total estimate for artifically produced radionuclides would be about 0.3 pCi/g, only 60% of the activity due to naturally occurring ^{40}K.

Vegetation

Table 6 summarizes the data for samples of 13 species of aquatic vegetation which were examined for radionuclide content. Vegetation samples generally contained more radioactivity per sample counted than any other samples analyzed, and adequate counting statistics could be obtained with a count of 40 rather than 100 minutes.

The high activity in vegetation samples relative to other ecological samples is interesting from the standpoint of monitoring the aquatic environment. Vegetation samples appear to be

TABLE 5

Radionuclide Concentrations in Hudson River Fish

1964 - 1967

Radionuclide		Concentration in pCi/g Wet Weight			
		1964	1965	1966	1967
^{40}K	Mean	0.58 ± 0.02	0.54 ± 0.04	1.20 ± 0.02	0.66 ± 0.02
	Range	ND - 2.1	ND - 1.4	0.28 - 3.13	0.32 - 1.22
	Ratio*	47/50	41/44	50/50	16/16
^{226}Ra	Mean	0.005 ± 0.002	0.03 ± 0.01	0.02 ± 0.00	0.02 ± 0.00
	Range	ND - 0.04	ND - 0.19	ND - 0.13	0.01 - 0.04
	Ratio	28/50	26/44	35/50	16/16
^{228}Ra	Mean	0.02 ± 0.004	0.01 ± 0.004	0.008 ± 0.001	0.003 ± 0.00
	Range	ND - 0.08	ND - 0.12	ND - 0.05	ND - 0.01
	Ratio	47/50	17/44	29/50	5/16
^{54}Mn	Mean	0.019 ± 0.001	0.027 ± 0.007	0.020 ± 0.002	0.004 ± 0.00
	Range	ND - 0.05	ND - 0.18	ND - 0.08	ND - 0.02
	Ratio	48/50	33/44	38/50	6/16
^{60}Co	Mean	<0.001	0.010 ± 0.005	0.002 ± 0.001	0.003 ± 0.001
	Range	ND - 0.01	ND - 0.16	ND - 0.02	ND - 0.01
	Ratio	11/50	19/44	7/50	5/16
^{106}Ru	Mean	0.077 ± 0.014	0.092 ± 0.024	0.029 ± 0.009	0.04 ± 0.01
	Range	ND - 0.42	ND - 1.50	ND - 0.15	0.01 - 0.07
	Ratio	41/50	30/44	34/50	16/16
^{137}Cs	Mean	0.036 ± 0.001	0.041 ± 0.005	0.029 ± 0.002	0.02 ± 0.00
	Range	ND - 0.09	ND - 0.13	ND - 0.16	0.01 - 0.10
	Ratio	49/50	42/44	49/50	16/16
^{144}Ce	Mean	0.044 ± 0.003	0.049 ± 0.016	0.012 ± 0.004	0.01 ± 0.00
	Range	ND - 0.16	ND - 0.59	ND - 0.59	ND - 0.03
	Ratio	43/50	22/44	27/50	6/16

*Ratio = No. of samples containing activity/total No. of samples.

ND = None detected

TABLE 6

Radionuclide Concentration in Hudson River Vegetation

1965 - 1967

Radionuclide		Concentration in pCi/g Wet Weight		
		1965	1966	1967
^{40}K	Mean	1.350 ± 0.016	1.237 ± 0.020	1.95 ± 0.04
	Range	0.25 - 3.46	0.29 - 2.56	1.28 - 2.82
	Ratio*	75/75	61/61	37/37
^{226}Ra	Mean	0.156 ± 0.003	0.064 ± 0.004	0.07 ± 0.004
	Range	ND - 0.60	ND - 0.37	ND - 0.47
	Ratio	73/75	57/61	32/37
^{228}Ra	Mean	0.059 ± 0.002	0.016 ± 0.002	0.05 ± 0.002
	Range	ND - 0.60	ND - 0.07	0.02 - 0.11
	Ratio	71/75	45/61	37/37
^{54}Mn	Mean	1.142 ± 0.003	0.997 ± 0.013	0.51 ± 0.004
	Range	ND - 17.85	ND - 15.80	0.08 - 1.82
	Ratio	74/75	59/61	37/37
^{60}Co	Mean	0.042 ± 0.002	0.109 ± 0.003	0.07 ± 0.002
	Range	ND - 0.68	ND - 1.61	0.01 - 0.33
	Ratio	35/75	38/61	37/37
^{106}Ru	Mean	0.177 ± 0.007	0.067 ± 0.013	0.08 ± 0.008
	Range	ND - 0.93	ND - 0.65	ND - 0.29
	Ratio	71/75	58/61	36/37
^{137}Cs	Mean	0.080 ± 0.001	0.023 ± 0.001	0.03 ± 0.002
	Range	0.01 - 0.30	ND - 0.23	0.01 - 0.12
	Ratio	75/75	49/61	37/37
^{144}Ce	Mean	0.161 ± 0.015	0.018 ± 0.007	0.01 ± 0.004
	Range	ND - 0.59	ND - 0.15	ND - 0.06
	Ratio	66/75	30/61	22/37

*Ratio = No. of samples containing activity/total No. of samples.

ND = None detected

good biological indicators for radionuclides. Five of thirteen species of vegetation examined during 1966 appeared to be particularly promising as indicator species. These are Elodea, Myriophyllum Potomageton crispus, Potomageton perfoliatus, and Valisneria americanus. As previously reported, P. crispus and Chara have been found to concentrate ^{54}Mn from the river water. Subsequent studies showed that this was due to their characteristically high stable manganese content (approximately 10% of ashed weight) [1]. The concentration of stable manganese by these and other plant species has previously been reported [3].

In general, the tabulated results indicate that the concentrations of most of the artifically produced radionuclides have decreased over the previous year. Radiochemical analysis for ^{90}Sr (4 samples) showed a concentration of 0.05 pCi/g. Fiver samples were analyzed for ^{55}Fe by a recently developed method [4], indicating a rather uniform concentration of about 0.25 pCi ^{55}Fe/mg stable iron, range 0.13 ± 0.04 to 0.31 ± 0.06 pCi/mg [5].

Activation Products in Vegetation

Three fundamental properties are required of biological

indicators in order that they may be useful to man in studying pollution problems: 1) relative abundance, 2) adequate distribution in the region of interest and 3) ability to concentrate a specific pollutant. Potamogeton species exhibit all of these properties with regard to ^{54}Mn as a pollutant, particularly in an estuarine environment. Two species, P. crispus and P. perfoliatus, can be found in the freshwater and estuarine stretches of the Hudson River. Both species accumulate activation products similarly. Data for P. crispus and Valisneria, (Figures 2 and 3) indicate the levels of radioactivity in samples from different sites on the river. The latter species fail to meet the criterion of adequate "distribution" of an indicator species for an estuary since they are restricted to fresh or very slightly brackish water. Essentially the same picture was obtained (in 1965 and 1966) for samples of mixed vegetation (Figure 4). The high value seen for samples of all these 4 species taken from sites between 40 and 50 miles of the Battery, indicate the release of some activation products from the nuclear power reactor at Indian Point.

A further study in 1967 of ^{54}Mn in Potamogeton crispus and Myriophyllum sp. taken from different stations along the Hudson River shore shows a progressive decline of activity

Figure 1: Distribution of Activation Products in Potamogeton spp. (1966)

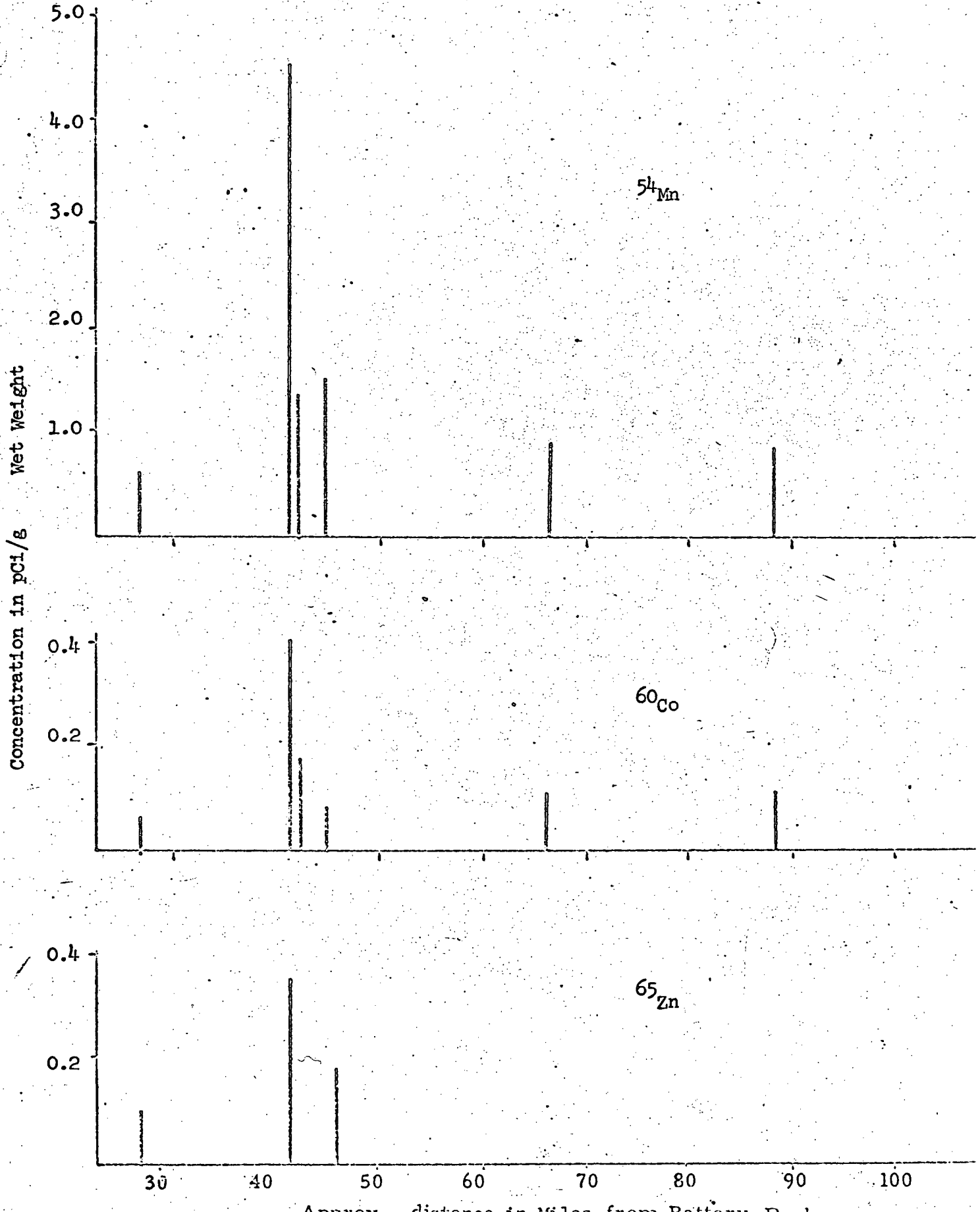


Figure 2: Distribution of Activation Products in Myriophyllum (1966)

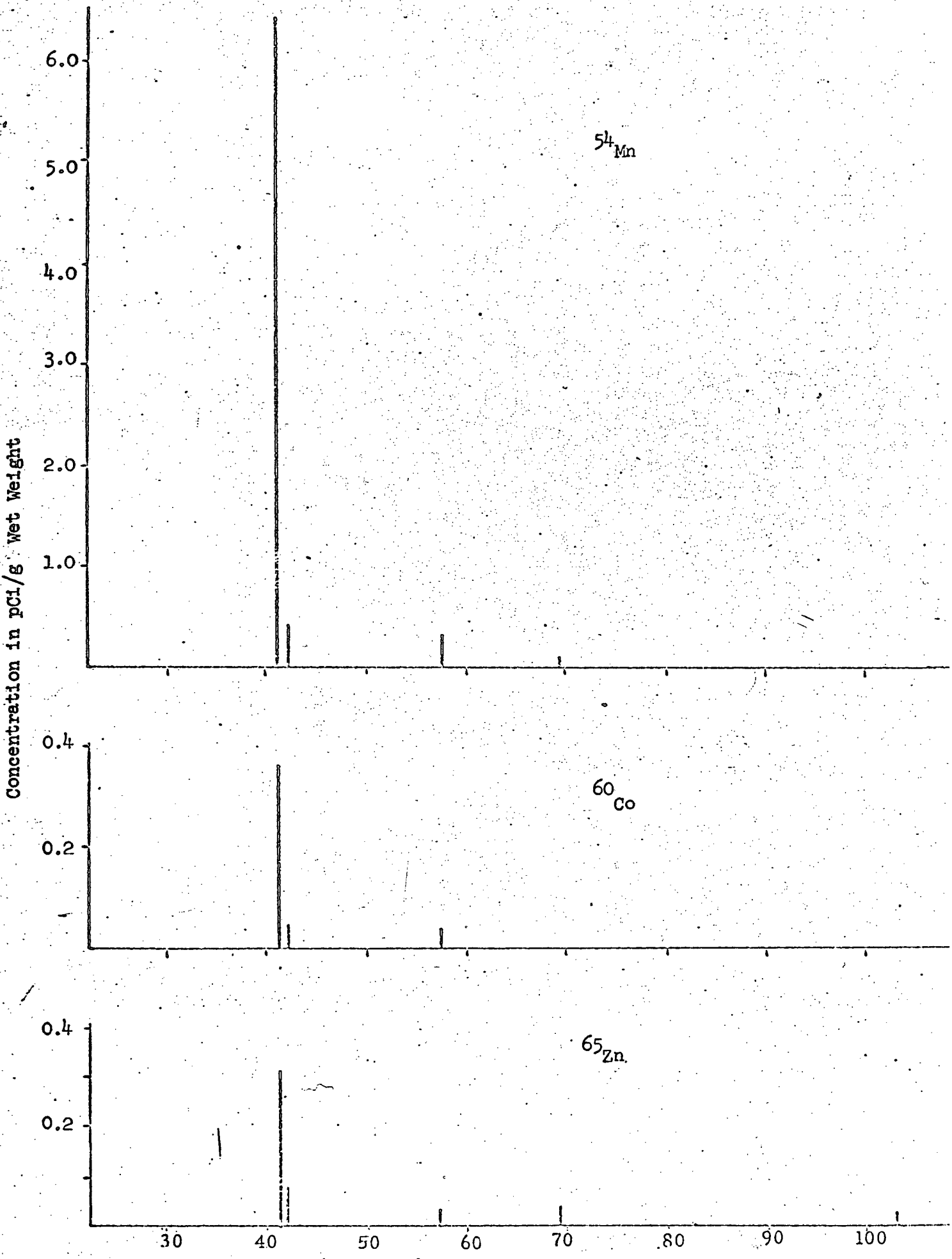


Figure 3: Distribution of Activation Products in Valisneria (1966)

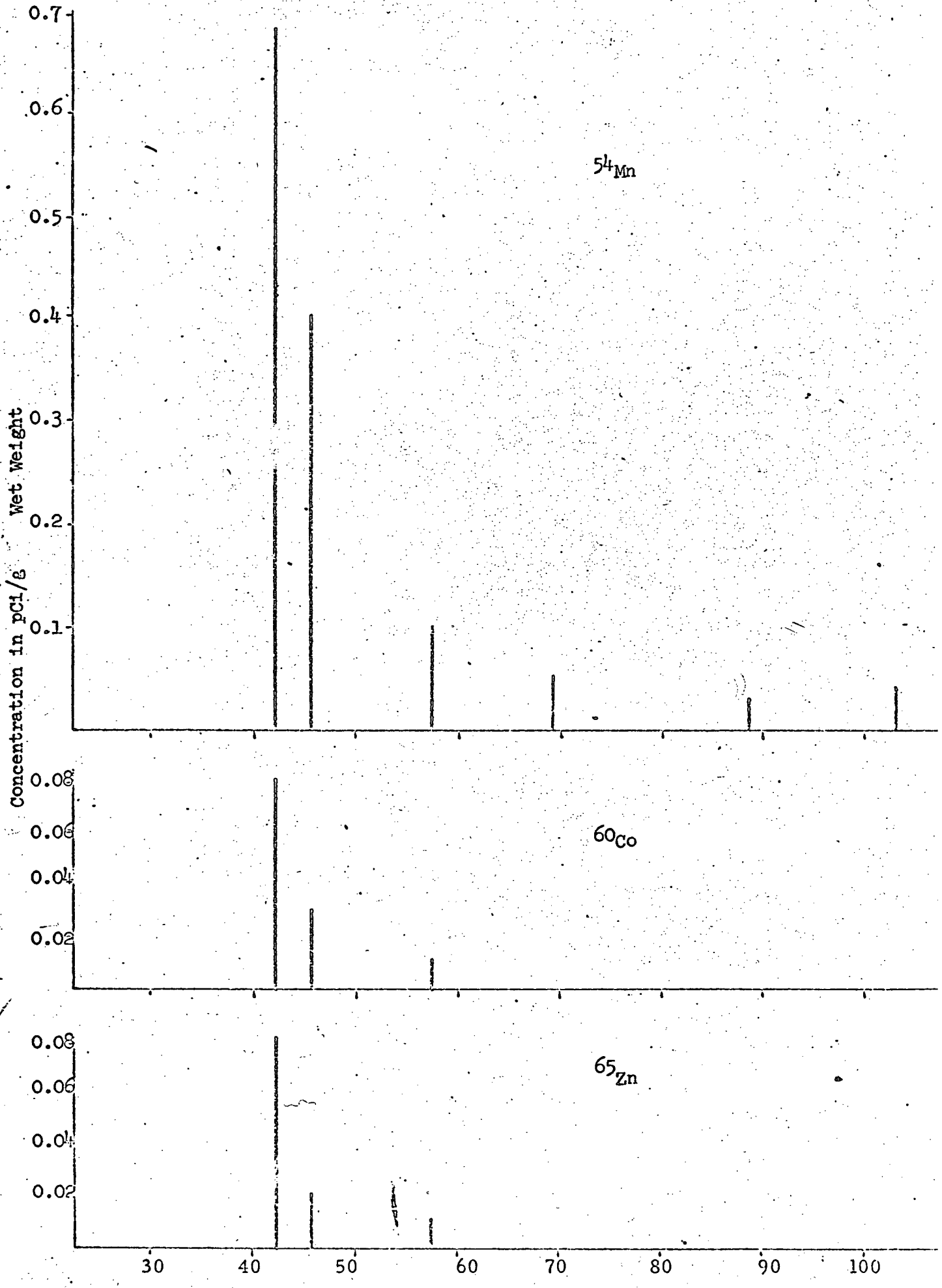


Figure 4: Generalized Distribution of ^{54}Mn and ^{60}Co in Vegetation (1965-1966)

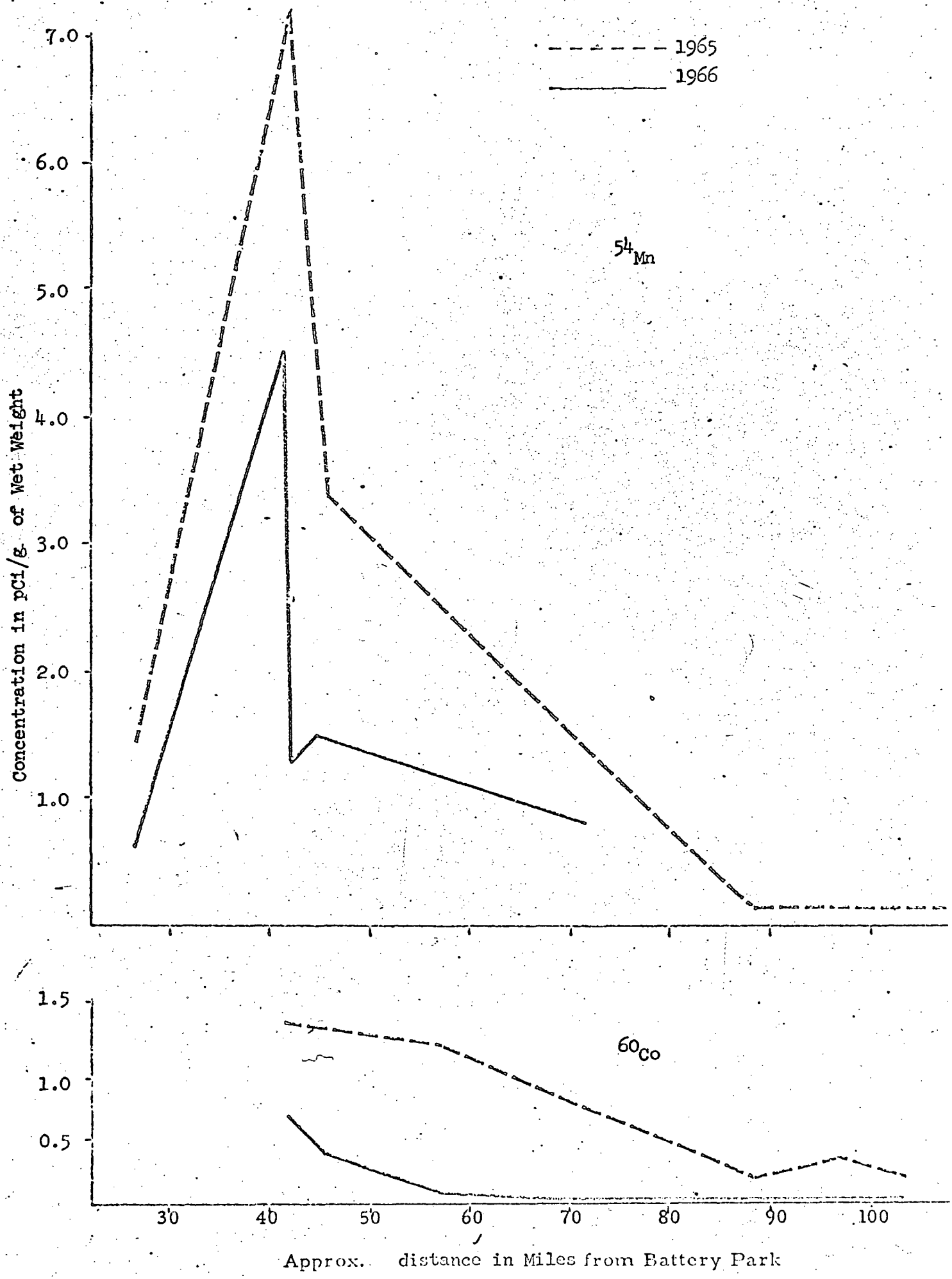
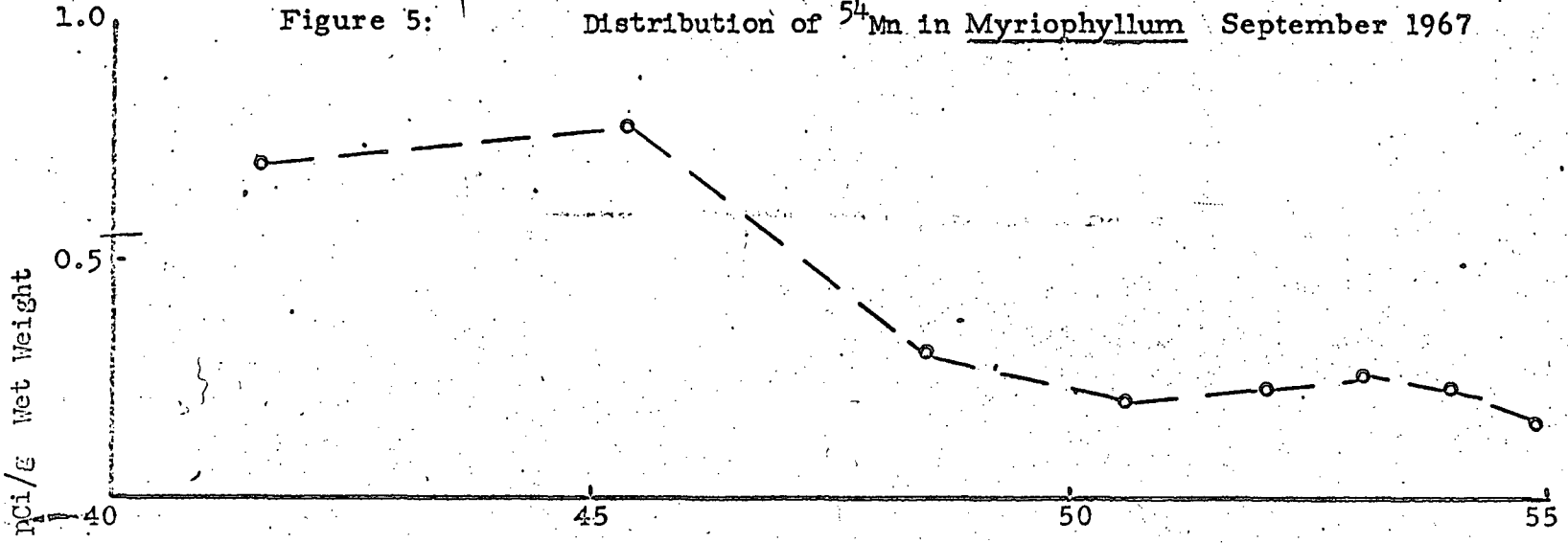
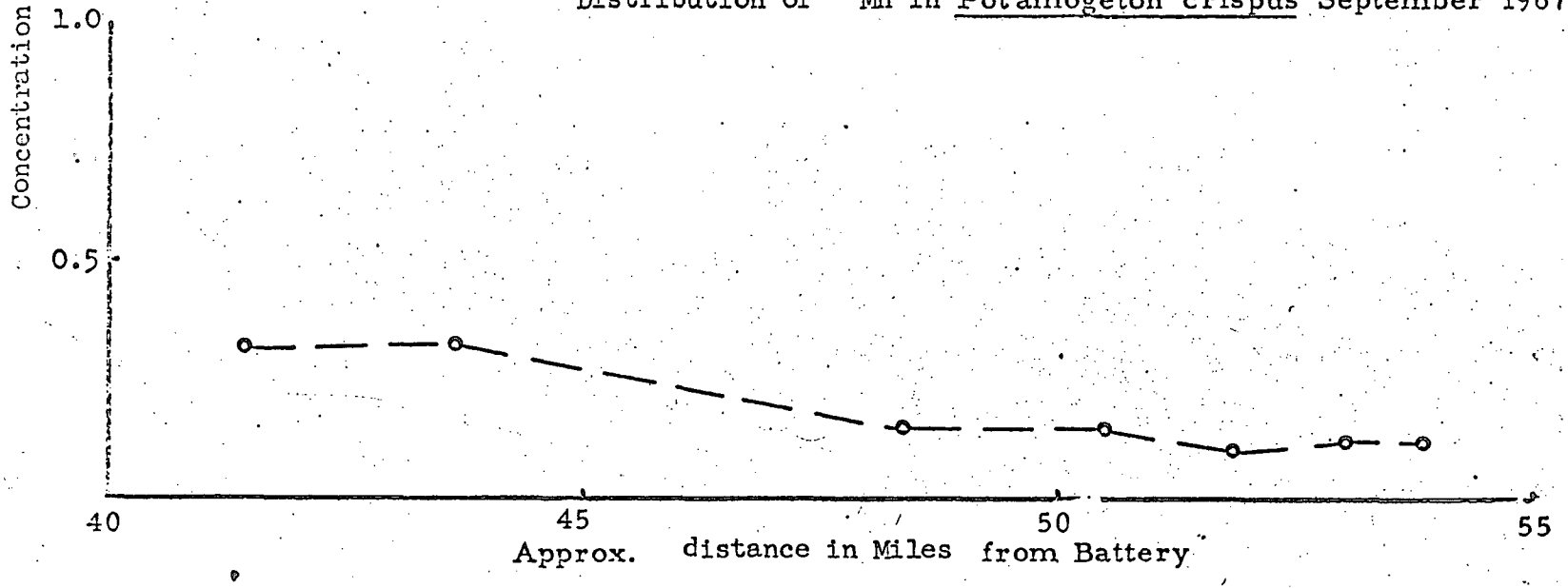


Figure 5: Distribution of ^{54}Mn in Myriophyllum September 1967



Distribution of ^{54}Mn in Potamogeton crispus September 1967



with distance north of the reactor (Figure 5). Similar results were obtained for other species of Potamogeton, and less clearly for a mixed vegetation sample.

The available data for 1965 and 1966 have been combined to produce the generalized distribution of ^{54}Mn and ^{60}Co in vegetation samples (Figure 4) along a 70 mile length of the Hudson River. A decrease in the concentration of both ^{54}Mn and ^{60}Co from 1965 to 1966 was observed. This decrease continues into the 1967 sampling period (Table 6).

These figures illustrate that some plants may be useful as biological indicators (at least during the growing season), for radioactive trace metals. If concentration factors and "response times" of these plants to radionuclides introduced into an estuarine environment can be determined, small samples of vegetation may eliminate the need for more cumbersome water samples.

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Acknowledgements:

To Dr. G.P. Howells for her assiduous effort in editing; to Dr. M. Eisenbud for his advice and guidance; to the staff of the Institute for their innumerable contributions, my sincerest thanks.

Appendix A

Problems of γ-Spectrometry of Environmental Sampling

Limitations in Sample and Background Counting Techniques

A study of the techniques used in counting environmental samples has disclosed several factors which tend to limit the accuracy of the data. These limitations are imposed by the larger number of observations which have to be made in order to sample a representative region of the Hudson River and by the low activity levels encountered. Indeed, in some instances, sample spectra corrected for background resulted in negative counts, a phenomenon occurring most frequently in the energy region from 0 to 0.5 MeV. The present procedure, after calibration of the gamma spectrometer, is to count a sugar background for 100 minutes, followed by 10 samples counted for 100 minutes each. Under these conditions, there are at least three independent factors which may cause this effect.

(1) Gain Shift

The most obvious problem is instability of the gamma spectrometer over one day counting periods. Shifts in calibration of

from 1 to 2 channels (10 keV/channel) are frequently observed. These shifts have not been adequately compensated for in the computer program used for estimating radionuclide concentrations. A new program which includes gain shift compensation has been developed and will be used on the data collected in 1968.

(2) Nature of background sample

Sugar (sucrose) is used for background counting because the high chemical purity with which this compound is produced makes it essentially free of radioactive contaminants that might interfere with gamma spectrometric analysis. Sucrose has an average Z value of 5, while the effective Z of environmental samples varies with the type of sample but is usually greater than this. It follows that photoelectric absorption, proportional to Z^5, is greater in the samples than in a sugar background. Consequently, there is greater absorption of low-energy background-gamma radiation when counting an environmental sample than when counting the sugar background. For samples of very low activity and relatively high Z, a sugar background may give higher counts than appropriate especially in the low energy regions of the spectrum.

The use of alternative uncontaminated background materials is being explored. For example, sodium chloride may be a

appropriate background standard for water residue samples. Reagent grade NaCl contains only 50 ppm potassium so that a 30 gram sample would contain 0.0015 grams or about 1.2 pCi of ^{40}K, a negligible amount.

(3) Variations in gamma background

The background of the 8 x 4 NaI(Tl) crystal used in a shielded room in this laboratory varies non-randomly; the observed variation has been shown to be inversely related to changes in barometric pressure [1]. Accordingly small changes in background are also expected in the shielded automatic counting apparatus used for analysis of the samples described in this report.

Limitations Inherent in Data Processing and Analysis

(1) Gain Shift

Superimposed on the problems of assaying low activity samples are the additional errors introduced by gain shift. Where counts are low it is difficult to estimate the errors due to this.

(2) Similarities in radionuclide gamma energies

Chemical analysis of composite water residue samples indicates that ^{65}Zn and ^{125}Sb may have been overestimated by computer analysis of the spectrum and that at the same

time ^{106}Ru has been underestimated. This error arises due to the similarity of γ-spectra between different nuclides, in particular ^{106}Ru, ^{65}Zn and any other positron emitters which may be present but unidentified. The computer analysis indicates 1 to 2 pCi ^{65}Zn/l Hudson River water, but there is little evidence to support such a concentration of this activation product in the Hudson River. The major gamma peaks of ^{106}Ru occur at energies of 0.51 and 1.12 MeV; ^{125}Sb has several peaks in the energy region from 0.43 to 0.60 MeV, while ^{65}Zn has a major peak at 1.11 MeV as well as an annihilation peaks at 0.51 and 1.02 MeV. In short, the γ-spectra of the nuclides in question are not completely linearly independent as assumed in the mathematical analyses.

Further complications may arise from the presence of trace amounts of ^{60}Co since the 1.1" Cobalt-60 peak may help to emphasize the region of the 1.11 MeV Zinc-65 peak. At the same time, counts in the region of the 1.33 Cobalt-60 peak may be interpreted as belonging to ^{40}K (1.46 MeV).

In the light of the problems of gain shift, variable background and poor counting statistics at low levels of activity, the net sample spectrum may contain artifacts which favor a particular solution by the program. In finding the best possible fit to the data, the program may utilize anomalies present in the net

sample spectrum to identify ^{65}Zn and ^{125}Sb incorrectly.

(3) Ratio-statistic as an indication of goodness-of-fit [2].

The program for evaluating radionuclide concentrations also computes a "ratio statistic" which has an expected value of unity if the fit is correct. However, even with a poor ratio, reasonable estimates may still be obtained. Sample #862 with an exeptionally large residual plot and a ratio statistic of 0.174 was evaluated by the weighted least squares method, as well as by the solution of simultaneous equations as a check of the internal consistency of the computer program.

Radionuclide	^{54}Mn	^{60}Co
	pCi/g wet weight	
Least squares estimate	15.8±0.2	0.64±0.04
Simultaneous equations estimate	16.8	0.63

The results are quite close. At relatively high activities quantitative computer estimates may be accurate and a low ratio-statistic is generally an indicator of gain shift or of activity.

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APPENDIX B

Hudson River Sampling Sites 1966-1967

STATION	SITE IDENT. NO.	MILES FROM BATTERY PARK
Tappan Zee Bridge (West End)	I-W-3	26.6
Verplanck	II-E-1	40.8
Fleet	II-W-1	41.4
Camp Smith	II-E-3	43.7
Iona Isle	II-W-2	45.2
Cornwall (Mouth of Moodna)	II-W-2a	56.5
Marlboro	III-W-2	67.3
Esopus Meadows Light	IV-W-1	86.1
Kingston Shore (Rondout)	K	89.7
Saugerties Shore (Esopus)	S	100.5

Appendix C

TABLE I

Radionuclides in Hudson River Water 1966

Concentration in pCi/liter

Spectrographic Data

Site	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
I-W-3	5	Mean	16.4	0.24	0.18	0.22	0.12	0.06	0.10	0.13
(26.6)		Min.	15.7±2.5	ND	ND	ND	ND	ND	ND	ND
		Max.	19.6±2.5	0.7±0.3	0.3±0.2	0.5±0.2	0.2±0.2	0.3±1.0	0.2±0.1	0.3±0.7
II-E-1	5	Mean	19.8	0.06	0.06	0.08	0.04	0.14	0.16	0.20
(40.8)		Min.	15.8±2.7	ND	ND	ND	ND	ND	ND	ND
		Max.	22.8±2.5	0.3±0.3	0.2±0.2	0.3±0.3	0.2±0.2	0.5±0.8	0.4±0.1	1.0±0.5
II-W-1	4	Mean	18.2	0.09	0.08	0.02	0.08	0.19	0.12	0.15
(41.4)		Min.	16.2±2.3	ND	ND	ND	ND	ND	0.1±0.2	ND
		Max.	19.8±2.6	0.3±0.3	0.3±0.2	0.1±0.2	0.2±0.2	0.5±1.0	0.2±0.1	0.5±0.6
II-E-3	5	Mean	16.3	0.16	-	0.10	0.10	0.80	0.12	0.18
(43.7)		Min.	11.5±2.4	ND	ND	ND	ND	ND	ND	ND
		Max.	20.6±2.6	0.5±0.3	-	0.3±0.2	0.4±0.2	1.9±1.0	0.3±0.1	0.4±0.5
II-W-2	4	Mean	9.1	0.22	0.18	0.22	0.22	0.18	0.15	0.25
(45.2)		Min.	1.3±4.0	ND	ND	ND	ND	ND	ND	ND
		Max.	16.3±2.4	0.5±0.3	0.4±0.3	0.9±0.4	0.6±0.3	0.7±0.8	0.4±0.1	0.5±0.6
II-W-2A	4	Mean	2.3	0.12	0.15	0.02	0.05	0.25	0.18	0.15
(56.5)		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	6.1±2.3	0.3±0.3	0.4±0.2	0.1±0.2	0.1±0.2	1.0±0.9	0.3±0.2	0.6±0.6
III-W-2	4	Mean	1.6	0.10	0.08	-	0.10	0.25	0.15	0.20
(67.3)		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	2.7±2.4	0.2±0.3	0.2±0.2	-	0.4±0.2	0.7±1.0	0.3±0.2	0.8±0.5

Table I (Cont'd.)

Site	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}C
IV-W-1	4	Mean	0.6	0.18	0.10	0.05	0.12	0.80	0.02	0.25
(86-1)		Min.	ND	ND	ND	ND	ND	0.1±0.9	ND	ND
		Max.	1.9±2.3	0.6±0.3	0.3±0.2	0.2±0.2	0.4±0.2	2.4±0.9	0.1±0.2	0.4±0.
IV-W-2	3	Mean	2.5	0.20	0.13	0.10	-	1.00	0.03	0.23
(95.1)		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	5.0±2.5	0.6±0.3	0.4±0.2	0,3±0.2	-	2.1±1.0	0.1±0.2	0.6±0.
IV-W-3	3	Mean.	0.5	0.10	-	-	0.10	0.10	0.13	0.33
(100.5)		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	1.6±2.4	0.2±0.3	-	-	0.2±0.2	0.3±1.0	0.2±0.1	0.6±0.
IV-W-4	5	Mean	2.4	0.12	0.06	0.18	0.04	0.26	0.10	0.32
(104.7)		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	5.4±2.5	0.3±0.3	0.2±0.2	0.4±0.2	0.2±0.2	0.8±0.9	0.2±0.2	0.7±0.

ND = None Detected

TABLE II

Radionuclides in Hudson River Water 1967

Concentration in pCi/liter

Spectrographic Data

Site	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
I-W-3 (26.6)	5	Mean	14.1	0.52	0.26	0.14	0.22	0.42	0.40	0.70
		Min.	ND	ND	ND	0.1±0.3	0.1±0.2	ND	ND	ND
		Max.	37.4±6.6	1.9±0.3	1.1±0.2	0.2±0.1	0.4±0.2	1.0±0.6	1.8±0.1	2.7±1.1
II-W-1 (41.4)	5	Mean	4.6	0.10	0.04	0.12	0.08	0.46	0.08	0.12
		Min.	0.8±1.1	ND	ND	ND	ND	ND	ND	ND
		Max.	13.8±1.8	0.3±0.2	0.1±0.1	0.3±0.1	0.2±0.1	0.8±0.4	0.2±0.1	0.3±0.4
II-W-2 (45.2)	5	Mean	0.7	0.02	0.08	0.08	0.12	0.08	0.02	0.20
		Min.	ND	ND	ND	ND	0.1±0.1	ND	ND	ND
		Max.	2.0±1.0	0.1±0.1	0.1±0.1	0.2±0.1	0.2±0.1	0.4±0.2	0.1±0.1	0.6±0.3
II-W-2A (56.5)	5	Mean	0.4	0.06	0.02	0.04	0.04	0.34	0.02	0.16
		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	1.1±1.0	0.1±0.1	0.1±0.1	0.1±0.1	0.1±0.1	0.6±0.3	0.1±0.1	0.6±0.3
III-W-2 (67.3)	5	Mean	0.2	0.04	0.04	0.06	0.04	0.32	0.02	0.06
		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	0.8±1.0	0.1±0.1	0.2±0.1	0.2±0.1	0.2±0.1	1.0±0.4	0.1±0.1	0.2±0.3
IV-W-1 (86.1)	5	Mean	1.6	0.04	0.04	0.06	0.06	0.20	-	0.14
		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	4.7±1.0	0.1±0.1	0.1±0.1	0.2±0.1	0.1±0.1	0.6±0.3	-	0.4±0.2
Rondout (89.7)	5	Mean	1.1	0.04	0.08	0.04	0.06	0.30	0.02	0.10
		Min.	ND	ND	ND	ND	ND	ND	ND	ND
		Max.	2.0±1.2	0.1±0.1	0.2±0.1	0.1±0.1	0.2±0.1	0.8±0.4	0.1±0.1	0.2±0.2

TABLE II (Cont'd.)

Site	No.of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}C
Esopus (100.5)	5	Mean	0.6	-	0.06	-	0.08	0.22	0.06	0.08
		Min.	ND	ND	ND	ND	ND	ND	ND	ND
	—	Max.	2.4±1.0	—	0.1±0.1	-	0.1±0.1	0.5±0.4	0.1±0.1	0.3±0.

ND = None Detected

TABLE III

Radionuclides in Hudson River Sediments, 1966

Concentration in pCi/gm of Dry Weight

Spectrographic Data (± S.D.)

Site Miles From Batt.	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}C
I-W-3 (26.6)	2	Mean	12.3	1.00	1.04	0.07	0.07	-	0.43	0.12
		Min.	11.0±0.8	0.9±0.1	0.9±0.1	ND	ND	ND	0.3±0.1	ND
		Max.	13.6±0.9	1.1±0.1	1.1±0.1	0.1±0.1	0.1±0.1	-	0.6±0.6	0.2±0.
II-E-1 (40.8)	3	Mean	10.5	0.70	0.65	0.20	0.11	0.22	0.33	0.20
		Min.	8.1±0.9	0.5±0.1	0.6±0.1	0.1±0.1	ND	ND	0.2±0.1	ND
		Max.	11.9±0.8	0.8±0.1	0.7±0.1	0.3±0.1	0.2±0.1	0.5±0.3	0.4±0.1	0.3±0.
II-W-1 (41.4)	2	Mean	17.3	1.00	1.10	0.26	0.10	0.24	0.80	0.46
		Min.	16.6±1.2	0.9±0.1	1.1±0.1	0.1±0.1	ND	ND	0.7±0.1	0.4±0.
		Max.	18.0±1.2	1.1±0.1	1.1±0.1	0.4±0.1	0.2±0.1	0.5±0.4	0.9±0.1	0.5±0.
II-E-3 (43.7)	2	Mean	17.1	0.90	0.96	0.19	0.06	0.28	1.12	-
		Min.	16.1±1.1	0.8±0.1	0.9±0.1	ND	ND	ND	1.0±0.1	ND
		Max.	18.2±4.2	1.0±0.5	1.0±0.3	0.4±0.1	0.1±0.1	0.6±1.5	1.2±0.3	-
II-W-2 (45.2)	3	Mean	15.9	1.13	1.23	0.24	0.07	1.16	1.67	1.28
		Min.	14.7±1.4	0.9±0.2	1.0±0.1	ND	ND	ND	0.8±0.1	0.5±0.
		Max.	17.0±1.5	1.4±0.2	1.4±0.1	0.3±0.1	0.2±0.1	2.0±0.6	2.1±0.1	2.1±0.
II-W-2A (56.5)	3	Mean	11.1	1.06	0.97	-	0.03	0.23	0.57	0.58
		Min.	9.3±0.9	0.8±0.1	0.8±0.1	ND	ND	ND	0.3±0.1	0.4±0.
		Max.	13.0±0.9	1.3±0.1	1.2±0.1	-	0.1±0.1	0.3±0.5	1.0±0.1	0.8±0.
III-W-2 (67.3)	4	Mean	11.4	0.83	0.73	0.12	-	0.88	1.13	0.76
		Min.	9.3±3.1	0.7±0.4	0.5±0.2	ND	ND	0.5±0.4	0.9±0.2	0.4±0.
		Max.	15.3±1.1	1.0±0.2	1.0±0.1	0.3±0.1	-	1.4±0.5	1.3±0.1	1.0±0.

TABLE III (Cont'd.)

Site Miles From Batt.	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
IV-W-1 (86.1)	4	Mean	13.7	1.07	1.01	0.09	-	0.02	0.06	0.24
		Min.	12.6±1.0	0.9±0.1	0.8±0.1	ND	ND	ND	ND	ND
		Max.	15.0±0.9	1.2±0.1	1.1±0.1	0.2±0.1	-	0.1±0.4	0.2±0.1	0.4±0.2
IV-W-2 (95.1)	2	Mean	14.0	0.90	0.75	0.11	-	-	-	0.16
		Min.	13.2±0.8	0.8±0.1	0.7±0.1	ND	ND	ND	ND	ND
		Max.	14.8±0.8	1.0±0.1	0.8±0.1	0.2±0.1	-	-	-	0.3±0.2
IV-W-3 (100.5)	3	Mean	9.4	0.77	0.71	0.08	-	0.08	0.32	0.30
		Min.	8.5±0.7	0.7±0.1	0.6±0.1	ND	ND	ND	ND	ND
		Max.	9.8±0.8	0.8±0.1	0.8±0.1	0.2±0.1	-	0.2±0.5	0.5±0.1	0.5±0.2
IV-W-4 (104.7)	3	Mean	15.1	1.02	0.81	0.17	-	0.41	0.61	0.50
		Min.	14.7±0.9	0.8±0.1	0.7±0.1	0.1±0.1	ND	ND	ND	0.3±0.2
		Max.	15.8±1.0	1.2±0.1	0.9±0.1	0.2±0.1	-	0.6±0.4	0.9±0.1	0.8±0.2

ND = None Detected

TABLE IV

Radionuclides in Hudson River Sediments, 1967

Concentration in pCi/g of Dry Weight

Site Miles From Batt.	No. of Sample		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}C
I-W-3 (26.6)	3	Mean	10.5	0.53	0.70	0.03	0.03	0.07	0.23	0.07
		Min.	9.0±0.8	0.4±0.1	0.5±0.1	ND	ND	ND	0.2±0.1	ND
		Max.	11.6±0.9	0.8±0.1	1.0±0.1	0.1±0.1	0.1±0.1	0.2±0.3	0.3±0.1	0.1±0.
II-W-1 (41.4)	4	Mean	7.8	0.75	0.80	0.55	0.15	0.32	0.60	0.25
		Min.	3.5±1.3	0.4±0.2	0.7±0.1	ND	ND	ND	0.5±0.1	ND
		Max.	13.6±1.6	0.9±0.1	0.9±0.1	1.2±0.1	0.3±0.1	0.7±0.4	0.8±0.1	0.4±0.
II-W-2 (45.2)	5	Mean	15.0	1.06	1.16	0.32	0.10	1.00	1.36	0.42
		Min.	13.2±2.0	0.7±0.1	0.9±0.1	0.1±0.1	ND	0.4±0.3	0.4±0.1	0.1±0.
		Max.	20.5±1.8	1.3±0.2	1.6±0.2	0.6±0.1	0.2±0.1	1.8±0.6	2.5±0.1	0.8±0.
II-W-2A (56.5)	4	Mean	11.5	0.82	0.95	0.28	0.15	0.23	0.50	0.12
		Min.	7.3±1.6	0.6±0.1	0.8±0.1	ND	ND	ND	0.2±0.1	ND
		Max.	15.4±1.1	1.3±0.1	1.3±0.1	1.0±0.1	0.4±0.1	0.8±0.3	1.3±0.1	0.3±0.
III-W-2 (67.3)	4	Mean	9.2	0.65	0.60	0.08	0.02	0.15	0.42	0.05
		Min.	5.9±1.1	0.3±0.1	0.2±0.1	ND	ND	ND	0.1±0.1	ND
		Max.	11.8±1.1	1.0±0.1	1.1±0.1	0.2±0.1	0.1±0.1	0.4±0.3	0.9±0.1	0.2±0.
IV-W-1 (86.1)	3	Mean	11.6	0.73	0.80	0.07	-	0.13	0.37	0.13
		Min.	11.1±0.7	0.7±0.1	0.7±0.1	ND	ND	ND	ND	ND
		Max.	12.5±0.9	0.8±0.1	0.9±0.1	0.1±0.1	-	0.2±0.2	0.9±0.1	0.3±0.

TABLE IV (Cont'd.)

Site Miles From Batt.	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}C
Rondout (89.7)	3	Mean	7.6	0.73	0.67	0.03	0.03	0.03	0.10	0.23
		Min.	5.2±0.8	0.6±0.1	0.6±0.1	ND	ND	ND	ND	0.2±0.
		Max.	8.9±0.7	0.9±0.2	0.8±0.1	0.1±0.1	0.1±0.1	0.1±0.2	0.2±0.1	0.4±0.
Esopus (100.5)	4	Mean	7.0	0.70	0.68	0.02	0.02	0.05	0.10	0.22
		Min.	6.2±1.4	0.6±0.1	0.6±0.1	ND	ND	ND	0.1±0.1	ND
		Max.	8.0±1.0	0.8±0.1	0.8±0.1	0.1±0.1	0.1±0.1	0.2±0.2	0.1±0.1	0.4±0.

TABLE V

Radionuclides in Hudson River Fish, 1966

Concentration in pCi/g of Wet.Weight

Spectrographic Data ± S.D.

Species	No.of Samples (Wt. Gms.)		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
Roccus americanus	5	Mean	1.1	-	-	-	-	0.03	0.03	0.02
"White Perch"	(2770)	Min.	0.3±0.1	ND	ND	ND	ND	ND	ND	ND
(formerly Morone)		Max.	1.8±0.1	*	*	*	-	**	*	*
Fundulus heteroclitis	7	Mean	1.5	0.02	0.02	0.04	-	0.05	0.04	0.02
"Saltwater Killifish"	(1620)	Min.	1.0±0.1	ND	ND	*	ND	ND	*	ND
		Max.	3.1±0.1	**	**	**	*	**	**	**
Fundulus diaphanus	6	Mean	1.0	0.02	-	0.01	-	0.03	0.02	0.02
"Freshwater Killifish"	(1930)	Min.	0.7±0.1	ND	ND	ND	ND	ND	*	ND
		Max.	1.7±0.6	**	*	*	*	**	*	**
Roccus saxatilis	3	Mean	1.2	0.05	-	0.01	-	0.05	0.03	0.01
"Striped Bass"	(660)	Min.	1.1±0.1	*	ND	ND	ND	ND	*	*
		Max.	1.6±0.3	**	*	*	-	0.2±0.1	*	*
Menidia menidia	2	Mean	0.7	-	-	0.05	-	0.02	0.01	-
"Spearing"	(710)	Min.	0.6±0.1	ND	ND	*	ND	ND	*	ND
		Max.	0.9±0.1	*	*	**	*	*	*	*
Notropis hudsonus	3	Mean	1.1	0.04	-	0.05	0.01	0.02	0.01	0.01
"Spottail Shiner"	(620)	Min.	0.5±0.1	*	ND	*	ND	*	ND	ND
		Max.	2.0±0.3	**	*	**	*	*	*	*
Alosa sapidissima	2	Mean	0.9	0.04	-	0.01	-	-	0.02	-
"Shad"	(300)	Min.	0.5±0.1	*	ND	*	ND	ND	*	ND
		Max.	1.4±0.1	*	*	*	-	-	*	-

TABLE V (cont'd.)

Species	No.of Samples (Wt. Gms.)		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
Alosa asestivalis	2	Mean	0.7	-	-	-	-	-	0.02	-
"Blueback Herring"	(870)	Min.	0.6±0.1	ND	ND	ND	ND	ND	*	ND
		Max.	0.8±0.1	*	-	*	-	*	*	-
Notemigonus chrysoleucas	4	Mean	1.4	0.01	0.01	0.02	-	0.02	0.02	0.01
"Golden Shiner"	(1250)	Min.	0.4±0.1	ND	ND	*	ND	ND	*	ND
		Max.	2.0±0.1	*	*	*	-	**	*	*
Lepomis gibbosus	4	Mean	1.0	-	0.01	0.01	-	0.02	0.03	0.02
"Pumpkinseed"	(1530)	Min.	0.5±0.1	ND	ND	ND	ND	ND	*	ND
		Max.	1.2±0.1	*	*	*	-	**	**	*
Lepomis auritus	4	Mean	1.2	-	0.01	0.02	-	0.02	0.02	0.02
"Redbreast Sunfish"	(1260)	Min.	0.7±0.1	ND	ND	ND	ND	ND	*	*
		Max.	1.7±0.1	*	*	*	*	*	*	*
Anguilla rostrata	3	Mean	1.5	0.01	0.01	0.03	0.01	0.02	0.04	-
American Eel	(890)	Min.	0.9±0.1	ND	ND	ND	ND	ND	*	ND
		Max.	2.3±0.2	*	*	**	*	**	**	-
Carassius auratus	4	Mean	1.4	0.01	0.01	-	-	0.03	0.04	-
"Goldfish"	(1390)	Min.	1.0±0.1	ND	*	ND	ND	*	*	ND
		Max.	1.7±0.1	*	*	*	-	**	**	*
Cyprinus carpio	1									
"Carp"	(380)	-	0.8±0.1	*	ND	ND	ND	*	0.2±-.1	*

ND = None Detected
* = Less than 0.05
** = Less than 0.10

TABLE VI

Radionuclides in Hudson River Fish, 1967

Concentration in pCi/g of Wet Weight

Spectrographic Data ± S.D.

Species	No. of Samples (Wt. Gms.)		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
Roccus americanus "White Perch" (formerly Morone)	1 (370)		1.2±0.1	*	ND	ND	ND	**	0.10±0.01	ND
Fundulus diaphanus "Freshwater Killifish"	2 (1140)	Mean	0.6	-	-	-	-	-	-	-
		Min.	0.6±0.1	*	ND	ND	ND	*	*	ND
		Max.	0.7±0.1	*	*	*	*	*	*	*
Roccus saxatilis "Striped Bass"	2 (430)	Mean	0.7	-	-	-	-	-	-	-
		Min.	0.6±0.2	*	ND	ND	ND	*	*	ND
		Max.	0.7±0.1	*	*	*	*	*	*	-
Lepomis auritus "Redbreast Sunfish"	2 (640)	Mean	0.6	-	-	-	-	-	-	-
		Min.	0.6±0.1	*	ND	ND	ND	*	*	*
		Max.	0.7±0.1	*	-	-	*	*	*	*
Lepomis macrochirus "Bluegill Sunfish"	1 (370)		1.0±0.1	*	*	ND	ND	**	**	ND
Anguilla rostrata "American eel"	2 (1040)	Mean	0.3	-	-	-	-	-	-	-
		Min.	0.3±0.1	*	ND	ND	ND	*	*	ND
		Max.	0.3±0.1	*	-	*	*	*	*	*

TABLE VI (Cont'd.)

Species	No.Of Samples (Wt.Gms.)		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
Carassius auratus "Goldfish"	3 (1450)	Mean	0.9	-	-	-	-	-	-	-
		Min.	0.7±0.1	*	ND	ND	ND	*	*	ND
		Max.	0.9±0.1	*	*	*	-	**	*	*
Cyprinus carpio	1 (370)		0.6±0.1	*	ND	*	*	*	*	ND
Ictalurus nebulosus "Brown Bullhead"	2 (340)	Mean	0.5	-	-	-	-	-	-	-
		Min.	0.5±0.1	*	ND	ND	ND	*	*	ND
		Max.	0.5±0.1	*	*	*	-	**	*	*

ND = None Detected
* = Less than 0.05
** = Less than 0.10 pCi/g

TABLE VII

Radionuclides in Hudson River Vegetation, 1966

Concentrations pCi/g Wet Weight. Collected From All Sites

Spectrographic Data (±S.D.)

Species	No. of Samples		^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
Potamogeton perfoliatus	9	Mean	0.88	**	*	2.2	0.17	0.13	*	*
		Min.	0.43±0.10	*	*	0.55±0.01	*	ND	ND	ND
		Max.	1.2 ±0.13	0.37±0.17	*	7.9 ±0.35	0.40±0.01	0.65±0.48	*	0.15±0.
Potamogeton crispus	5	Mean	1.2	**	*	0.80	0.12	**	**	*
		Min.	0.91±0.06	*	*	**	ND	**	*	ND
		Max.	1.5 ±0.17	0.15±0.01	*	2.6±0.06	0.43±0.02	0.13±0.02	0.23±0.01	*
Myriophyllum sp.	10	Mean	0.98	*	*	2.0	0.11	**	*	*
		Min.	0.29±0.04	*	ND	*	ND	*	ND	ND
		Max.	1.8 ±0.12	**	*	16±0.21	0.64±0.04	0.22±0.23	*	*
Valisneria sp.	12	Mean	1.7	*	*	0.19	*	*	*	*
		Min.	1.2± 0.06	ND	ND	*	ND	ND	ND	ND
		Max.	1.9± 0.06	0.06±0.01	*	0.68±0.01	**	**	*	*
Elodea sp.	8	Mean	1.2	**	*	0.70	**	*	*	*
		Min.	0.34±0.15	*	ND	*	ND	*	*	ND
		Max.	1.9 ±0.06	0.15±0.01	*	3.2 ±0.05	0.27±0.02	0.14±0.03	**	*

ND = Not Detected
* = 0.05 pCi/l or less
** = 0.10 pCi/l or less

APPENDIX C

TABLE VIII

RADIONUCLIDES IN HUDSON RIVER VEGETATION, 1967

All Samples Collected in September — Values Corrected to Two Significant Figures

Collecting Site	Approx. Miles from Battery	Species	Spectrographic Data (Concentrations pCi/g) Wet Weight ± S.D.							
			^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
#1	56	Myriophyllum sp.	1.4 ± 0.10	-	0.05 ± 0.01	0.08 ± 0.01	0.01 ± 0.01	0.02 ± 0.03	0.03 ± 0.01	0.01 ± 0.02
		Potamogeton sp. ("Grass")	2.8 ± 0.29	-	0.06 ± 0.02	0.14 ± 0.02	0.03 ± 0.02	0.05 ± 0.07	0.02 ± 0.01	0.06 ± 0.04
#2	55	Myriophyllum sp.	1.6 ± 0.12	0.01 ± 0.01	0.06 ± 0.01	0.16 ± 0.01	0.01 ± 0.01	0.08 ± 0.03	0.03 ± 0.01	0.01 ± 0.02
		P. perfoliatus	1.9 ± 0.18	0.02 ± 0.02	0.07 ± 0.01	0.14 ± 0.01	0.03 ± 0.01	0.09 ± 0.04	0.03 ± 0.01	0.01 ± 0.02
#3	54	Potamogeton sp. ("Grass")	2.2 ± 0.17	-	0.04 ± 0.01	0.08 ± 0.01	0.02 ± 0.01	0.01 ± 0.04	0.02 ± 0.01	0.05 ± 0.02
#4	54,	Myriophyllum sp.	1.6 ± 0.13	0.00 ± 0.01	0.05 ± 0.01	0.26 ± 0.01	0.02 ± 0.01	0.06 ± 0.03	0.03 ± 0.01	0.03 ± 0.02
		P. perfoliatus	2.6 ± 0.19	0.01 ± 0.02	0.07 ± 0.01	0.19 ± 0.01	0.02 ± 0.01	0.06 ± 0.04	0.03 ± 0.01	0.03 ± 0.03
		P. crispus	1.7 ± 0.26	0.03 ± 0.03	0.03 ± 0.02	0.11 ± 0.02	0.01 ± 0.02	0.07 ± 0.06	0.02 ± 0.01	0.01 ± 0.04
#5	53	Myriophyllum sp.	1.7 ± 0.18	0.04 ± 0.02	0.06 ± 0.01	0.28 ± 0.02	0.03 ± 0.01	0.05 ± 0.04	0.02 ± 0.01	-
		P. crispus	1.8 ± 0.13	0.02 ± 0.01	0.02 ± 0.01	0.12 ± 0.01	0.01 ± 0.01	0.08 ± 0.03	0.04 ± 0.01	0.01 ± 0.02
#6	53	Potamogeton sp. ("Grass")	2.4 ± 0.19	0.03 ± 0.02	0.07 ± 0.01	0.22 ± 0.01	0.02 ± 0.01	0.03 ± 0.04	0.05 ± 0.01	-
#7	52	P. perfoliatus	1.6 ± 0.18	0.04 ± 0.02	0.06 ± 0.01	0.30 ± 0.02	0.03 ± 0.01	0.06 ± 0.04	0.03 ± 0.01	-
#8	52	Myriophyllum sp.	2.0 ± 0.21	0 ± 0.02	0.05 ± 0.01	0.24 ± 0.02	0.01 ± 0.01	0.13 ± 0.05	0.03 ± 0.01	0.02 ± 0.03
		P. crispus	1.9 ± 0.15	-	0.04 ± 0.01	0.10 ± 0.01	0.01 ± 0.01	0.02 ± 0.03	0.03 ± 0.01	0.02 ± 0.02
#9	51	Myriophyllum sp.	1.7 ± 0.18	0.02 ± 0.02	0.05 ± 0.01	0.22 ± 0.02	0.02 ± 0.01	0.04 ± 0.04	0.03 ± 0.01	0.01 ± 0.03
		P. crispus	2.4 ± 0.20	-	0.04 ± 0.01	0.15 ± 0.01	0.02 ± 0.01	0.03 ± 0.04	0.02 ± 0.01	-
		Potamogeton sp. ("Grass")	2.4 ± 0.21	0.04 ± 0.02	0.05 ± 0.01	0.46 ± 0.02	0.03 ± 0.01	0.11 ± 0.05	0.02 ± 0.01	0.02 ± 0.03
#10	48	Myriophyllum sp.	1.7 ± 0.20	0.02 ± 0.02	0.04 ± 0.01	0.29 ± 0.02	0.03 ± 0.01	0.07 ± 0.05	0.12 ± 0.01	0.02 ± 0.03
		P. crispus	1.5 ± 0.18	0.02 ± 0.02	0.02 ± 0.01	0.15 ± 0.01	0.02 ± 0.01	0.02 ± 0.04	0.02 ± 0.01	0.03 ± 0.03
#11	48	P. perfoliatus	1.9 ± 0.22	0.04 ± 0.02	0.03 ± 0.01	0.32 ± 0.02	0.04 ± 0.01	0.07 ± 0.05	0.02 ± 0.01	0.01 ± 0.03
#12	45	Myriophyllum	2.2 ± 0.23	0.01 ± 0.02	0.06 ± 0.02	0.76 ± 0.03	0.09 ± 0.01	0.09 ± 0.05	0.02 ± 0.01	0.01 ± 0.03
		P. perfoliatus	2.4 ± 0.28	0.04 ± 0.03	0.11 ± 0.02	1.12 ± 0.04	0.11 ± 0.02	0.13 ± 0.07	0.03 ± 0.01	-
#13	44	P. perfoliatus	1.3 ± -.24	0.05 ± 0.03	0.07 ± 0.02	0.75 ± 0.03	0.07 ± 0.02	0.19 ± 0.06	0.02 ± 0.01	0.01 ± 0.04

(Cont'd.)

Collecting Site	Approx. Miles from Battery	Species	Spectrographic Data (Concentrations pCi/g) Wet Weight ± S.D.							
			^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce
#14	44	P. perfoliatus	2.0 ± 0.20	0.01 ± 0.02	0.05 ± 0.01	0.31 ± 0.02	0.06 ± 0.01	0.05 ± 0.04	0.02 ± 0.01	0.01 ± 0.03
		P. crispus	1.7 ± 0.20	0.00 ± 0.02	0.04 ± 0.01	0.33 ± 0.02	0.05 ± 0.01	0.09 ± 0.05	0.03 ± 0.01	-
#15	42	P. perfoliatus	2.0 ± 0.50	0.47 ± 0.06	0.02 ± 0.04	1.8 ± 0.08	0.33 ± 0.04	0.29 ± 0.13	0.04 ± 0.03	-
		Potamogeton sp. ("Grass")	1.9 ± 0.36	0.41 ± 0.04	0.03 ± 0.03	1.1 ± 0.05	0.14 ± 0.03	0.11 ± 0.09	0.01 ± 0.02	0.05 ± 0.06
#16	42	Myriophyllum	1.3 ± 0.26	0.12 ± 0.03	0.05 ± 0.02	0.71 ± 0.03	0.07 ± 0.02	0.13 ± 0.07	0.02 ± 0.01	0.05 ± 0.04
		P. perfoliatus	1.8 ± 0.22	0.07 ± 0.02	0.03 ± 0.01	0.39 ± 0.02	0.06 ± 0.01	0.10 ± 0.05	0.02 ± 0.01	0.01 ± 0.03
		P. crispus	1.8 ± 0.20	0.05 ± 0.02	0.07 ± 0.01	0.32 ± 0.02	0.05 ± 0.01	-	0.04 ± 0.01	-

Appendix C

TABLE IX

MIXED VEGETATION SAMPLES, HUDSON RIVER 1967

All Samples Collected in October — Values Corrected to Two Significant Figures

Approx. Miles from Battery.	^{40}K	^{226}Ra	^{228}Ra	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs
52	1.9 ± 0.12	0.20 ± 0.01	0.03 ± 0.01	0.84 ± 0.01	0.08 ± 0.01	0.09 ± 0.03	0.05 ± 0.01
48	2.3 ± 0.13	0.12 ± 0.01	0.05 ± 0.01	0.82 ± 0.02	0.12 ± 0.01	0.11 ± 0.03	0.04 ± 0.01
48	2.0 ± 0.15	0.05 ± 0.02	0.03 ± 0.01	0.42 ± 0.01	0.05 ± 0.01	0.08 ± 0.04	0.03 ± 0.01
45	2.7 ± 0.19	0.19 ± 0.02	0.03 ± 0.01	1.3 ± 0.03	0.18 ± 0.01	0.12 ± 0.05	0.02 ± 0.01
44	1.8 ± 0.20	0.16 ± 0.02	0.04 ± 0.01	1.4 ± 0.03	0.17 ± 0.01	0.13 ± 0.05	0.04 ± 0.01
41	2.0 ± 0.20	0.12 ± 0.02	0.03 ± 0.01	1.0 ± 0.03	0.15 ± 0.01	0.11 ± 0.05	0.02 ± 0.01
41	2.0 ± 0.24	0.13 ± 0.03	0.03 ± 0.02	1.4 ± 0.03	0.22 ± 0.02	0.12 ± 0.06	0.02 ± 0.01
Mean	2.0 ± 0.04	0.07 ± 0.004	0.05 ± 0.002	0.51 ± 0.004	0.07 ± 0.002	0.08 ± 0.008	0.03 ± 0.002
Range	1.3 - 2.8	ND - 0.47	0.02 - 0.11	0.08 - 1.8	0.01 - 0.33	ND - 0.29	0.01 - 0.12

ND = Non detectable

ENVIRONMENTAL TRITIUM MEASUREMENTS

By: Frank J. Cosolito

Introduction

Since 1964 the Institute of Environmental Medicine has been studying the radioecology of the Hudson River. In order to round out this program, monitoring of tritium levels was initiated in 1966. During the period covered by this report, (July 1, 1965 to December 31, 1966) analytical methods and equipment were developed to implement an environmental tritium study. This report presents a brief discussion of the sources and amounts of tritium currently in the environment. A recently developed electrolysis cell is described and a summary of analytical techniques and data collected are also presented.

Discussion

Tritium is produced in the upper atmosphere by several interactions of cosmic rays with gases. Kaufman and Libby [1] reported the abundance of cosmic-ray produced tritium in natural water as ranging between 1.6 to 210 pCi/l. Since 1952 the tritium concentration of environmental waters has increased considerably. Tritium in the surface waters of New York State in 1965 has been reported as high as 4160 pCi/l by the Bureau of Radiological Health Services [2]. While this concentration is high compared to pre-

1952 concentrations it is only a fraction of the MPC_w * of 3×10^6 pCi/l. The increase in tritium in the environment is primarily due to thermonuclear detonations. In the fusion reaction, tritium is produced to the extent of 6.7×10^6 curies per MT of fusion [4]. Since there has been about 300 MT of fusion since 1952, [5] approximately 2×10^9 curies of tritium have been produced from this source alone.

Tritium is also produced to a lesser extent in nuclear fission as a product of the relatively rare occurrence of ternary fission and by neutron activation of ^6Li in the soil [6]. Present estimates of tritium production in fission are 1.25 tritons per 10,000 fissions [7]. This results in about 1000 curies of tritium per MT of fission.

Although the production of tritium in fission reactions is small compared to its production in fusion reactions, this source may be important in specific localities. For example, the Consolidated Edison Plant at Indian Point, New York released 455 curies of tritium into the Hudson River during 1965 [8]. Although the tritium presently discharged by Consolidated Edison is negligible, the planned construction of additional nuclear plants

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* MPC_w = maximum permissible concentration in water (Ref. 3).

necessitates the establishment of present tritium background concentrations in Hudson River water, against which future changes can be compared.

Laboratory procedures for evaluating tritium at present environmental concentrations have been developed. In order to estimate accurately the tritium burden of environmental samples within a reasonable counting time, enrichment of samples is required. Several modifications of the electrolytic enrichment apparatus have considerably reduced the time required for tritium analyses. With the new apparatus, enrichment factors of 7-8 are obtained in 24 hours. A factor of 7 has been found sufficient for the determination of present environmental tritium concentrations with a precision of $\pm$ 2% for a 400 minute count.

Under conventional counting conditions a 3 ml aliquot of water can be counted with an efficiency of 10.7%. With a background of 5.50 $\pm$ 0.08 cpm this permits the detection of 1550 pCi/l $\pm$ 10% with a 1000 minute count. These conditions not only limit the accuracy of determinations, but also limit the number of analyses to 10 per week.

By enriching the water concentrations by a factor of 7 the conditions for analysis are greatly improved. For instance, the counting time in the above example can be reduced to 140 minutes

for the same degree of precision or, if a 400 minute count is employed, the precision is increased to ± 2.3%. The decrease in counting time from 1000 to 400 minutes also increases the number of potential samples to 25 per week.

Electrolytic Enrichment

In order to obtain the desired enrichment, a simple electrolysis cell was developed. This cell was designed specifically to facilitate rapid enrichment with a minimum of effort. Efficient tritium enrichment factors are not obtained at high current densities. Thus, in parallel-plate-type electrolysis cells the input current must be decreased as the aqueous volume recedes down the length of the electrodes during electrolysis [9,10]. This problem has been eliminated by confining the entire electrode surface required for the electrolysis to the final sample volume. To accomplish this, coil electrodes are used, which have a high surface area to volume ratio. Application of this modification has resulted in the cell shown in Figure 1. Although this cell was designed specifically with the intent of obtaining an enrichment factor of about 7 (in approximately 24 hours), it has proven to be exceptionally versatile. Experiments at high currents (15 amps) indicate that the same enrichment can be obtained in as little as eight hours. Thus, the possibility of obtaining high enrichment factors in relatively short

periods of time is clearly evident. With further experimentation it may be possible to extend the use of this cell to the analysis of low level tritium samples ($\lesssim$ 32 pCi/l) with relatively short enrichment times in contrast to present electrolytic concentrating techniques. The major components of the cell are described below.

Glassware

Construction materials were restricted to standard glass tubing and ground glass joints to reduce costs. The lower portion of the cell is made of 57 mm O. D. tubing which is fused to a 60/50 female joint to form the cell body. To permit the introduction of a polyethylene splatter guard, the minimum body diameter is located below the joint. The bottom of the cell is an annular well which acts as a support for the electrodes and permits efficient heat transfer. Although the well is designed for a maximum capacity of 10 ml the electrodes used at present occupy only one-third of this volume.

The cell head consists of a sealed 60/50 male joint with a 24/40 female joint attached to the outside and two 1. 5 mm I. D. glass capillary tubes attached to the inside. The 24/40 joint in the cell head is used for introducing additional sample during batch electrolysis and as a support for a suitable device to prevent exchange with atmospheric moisture. The glass capillaries provide

a convenient rigid support for both the electrode leads and splatter guard. These capillaries facilitate introduction of electrodes into the cell and eliminate the need for grommets or platinum-to-glass seals. During operation of the cell, the small annulus around the electrode leads is capped with ordinary putty. The annulus is sufficiently small to permit vacuum distillation when sealed with vacuum grease. Total cost of a single cell is approximately $50.00.

Splatter Guard

A 1/16" thick polyethylene disc is used as a splatter guard to confine the sample to a small volume during electrolysis. For a splatter guard to be effective there should be almost zero clearance between the guard and the cell wall. The use of rigid materials is avoided since these have been found to jam, causing breakage of the capillaries which act as a support. The splatter guard is held in position by two O-rings which are slid on to the capillaries.

Electrodes

Platinum wire is used as the electrode material because of its durability and excellent structural characteristics. Highly refined gold and silver (99.99%) have been tried; but besides limiting the choice of electrolyte, these materials have the additional disadvantage of lacking good structural characteristics. While the platinum wire is soft enough to be formed by hand, the resulting

coils are highly resilient and have maintained their form during six months of operation. Each electrode is constructed of 0.051" diameter platinum wire. The cathode consists of a 56 cm length of wire of which 36 cm is wound into a coil that lines the inside of the outer wall of the well. The anode is a 39 cm length of wire of which 19 cm is wound into a coil which slides down over the center glass support in the well. The surface areas of the electrode coils are 14.4 and 7.6 cm^2 respectively. Both coils are contained within a volume of 3.5 ml. Since an initial volume of 50 ml only covers about 3 cm of the coil leads, the change in current density during the entire electrolysis is only a few percent. In addition, since one oxygen atom is discharged at the anode for every two hydrogen atoms released at the cathode, the anode surface area is only one-half that of the cathode. With this surface area, the input current can be as high as 7.2 amps, without exceeding a current density of 500 ma/cm^2 at the cathode. Samples electrolyzed at current densities of from 49 to 208 ma/cm^2 show a linear relationship between enrichment factor and volume concentration factor. Figure 2 presents this data and also indicates a decrease in enrichment factor vs. volume concentration factor at higher current densities. Two experiments were performed with twice the electrode surface areas at 15 amps (535 ma/cm^2), demonstrating that the operation at 15 amps can be made equally efficient by using larger electrodes.

Analytical Procedures

To check for reproducibility, six cells were run in series at a current of 5 amps using standardized tritiated water. The individual results were found to agree within 1.56%, which is within the limit of experimental errors in overall sample preparation and counting. During the electrolysis of environmental samples, one spiked cell is electrolized in a series of 6 cells containing the unknown samples. Electrolysis is performed in a constant temperature bath at 10 $\pm$ 1°C.

Sulfuric acid is used as the electrolyte at an initial concentration of 2.6%. The addition of this amount of sulfuric acid introduces only 0.5% of hydrogen to a 50 ml sample. Even if the sulfuric acid were contaminated to a level of 3200 pCi/l the contribution to the activity of the samples reported would be only 1%. The use of sulfuric acid considerably reduces power requirements for electrolysis. At the above concentration the voltage requirement after 15 minutes of operation is only 5 volts per cell at 5 amps. A typical electrolyte such as sodium sulfate has twice the voltage requirement under the same conditions.

During experiments to determine the variation of enrichment factor with volume change, sulfuric acid as an electrolyte has an additional advantage. By using an acid, a quantity proportional to the volume concentration factor can be obtained very accurately by titration against a base. If an aliquot of the sample is titrated

against standardized sodium hydroxide solution before and after electrolysis, then the ratio of the change in acid concentration is proportional to the volume change. This eliminates the need for completely recovering the final sample by vacuum distillation, and determining the final volume gravimetrically. A tritration can be performed to better than 1% accuracy by choosing the appropriate normality of the titrant. In addition, a known fraction of the sample can be easily and rapidly recovered directly from the acid by ordinary distillation (in a system sealed from atmospheric moisture). Tritium recovery is then corrected for fractionation during distillation [11].

Using the above method, spiked samples were concentrated for various times at currents ranging from 0.7 to 15 amps (see Figure 2). The data indicate that at currents ranging from 0.7 to 3 amps the tritium enrichment factor is proportional to volume change. As indicated previously, decrease in enrichment factor versus volume change at the higher currents can be eliminated by simply increasing the size of the electrodes. The results indicate that enrichment factors close to those obtained at the lower currents are possible. Electrolysis at 15 amps is particularly attractive because at this high current, a volume change of 10 (from an initial volume of 50 ml) can be obtained in as little as eight hours.

Results

Tritium concentrations in the Hudson River and environs are presented in Table 1. The error quoted is ± 4% and was calculated to include a ± 3% uncertainty in the tritium standard obtained from the Nuclear Chicago Corporation. These results agree with those published in 1966 by the Bureau of Radiological Health Services of the New York State Department of Health. No significant increase in the tritium concentration in the vicinity of the Consolidated Edison Plant at Indian Point can be seen. Moreover, samples from lakes and streams extending up to 100 miles north of Troy, New York show essentially the same tritium concentrations were within the narrow range of from 1580 to 2290 pCi/l.

Acknowledgement

The author wishes to express his gratitude to James Miller for his invaluable assistance in the laboratory.

FIGURE 1. CROSS SECTION OF ELECTROLYSIS CELL.

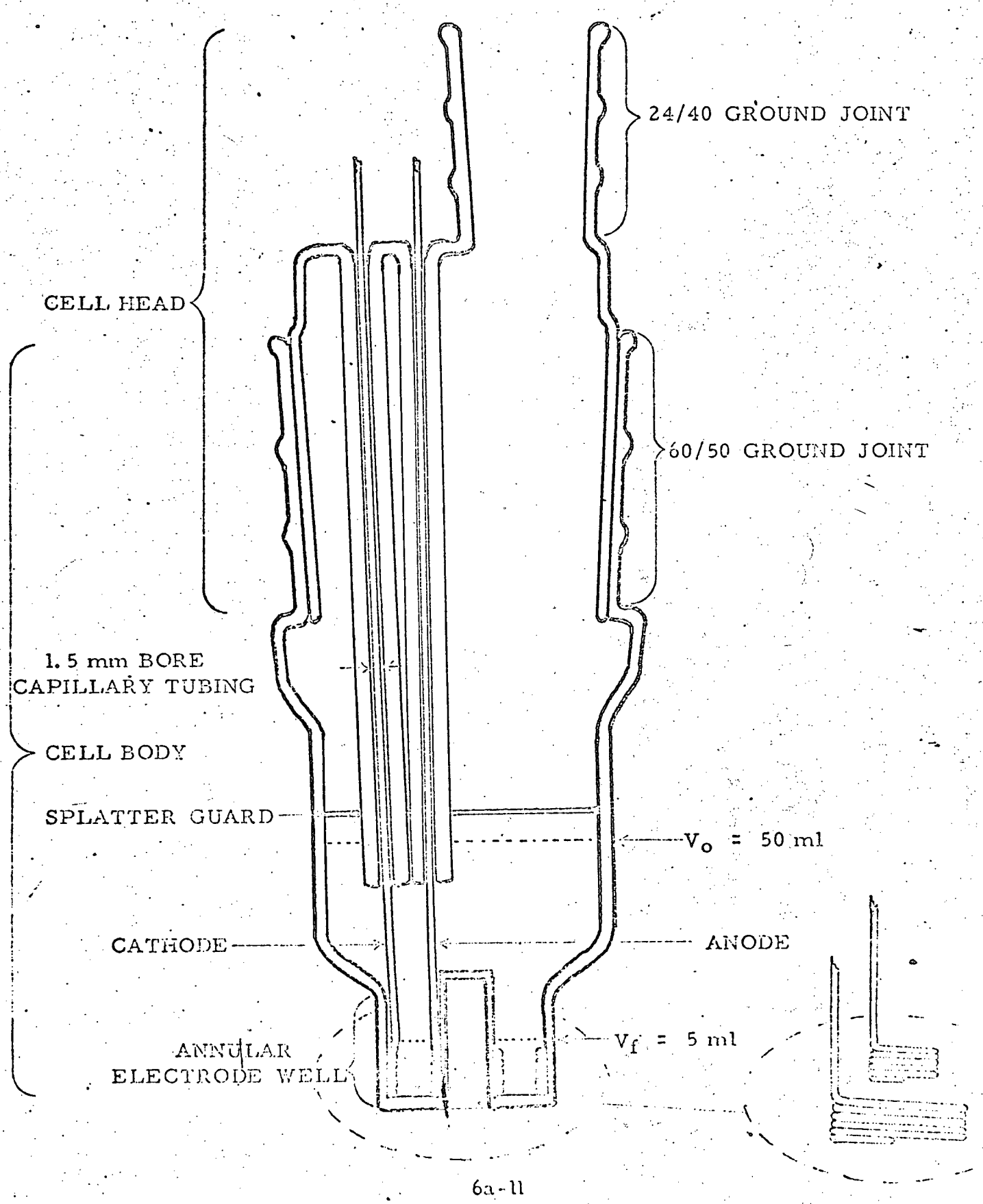

FIGURE 2. TRITIUM ENRICHMENT FACTOR VS. CHANGE IN NORMALITY.

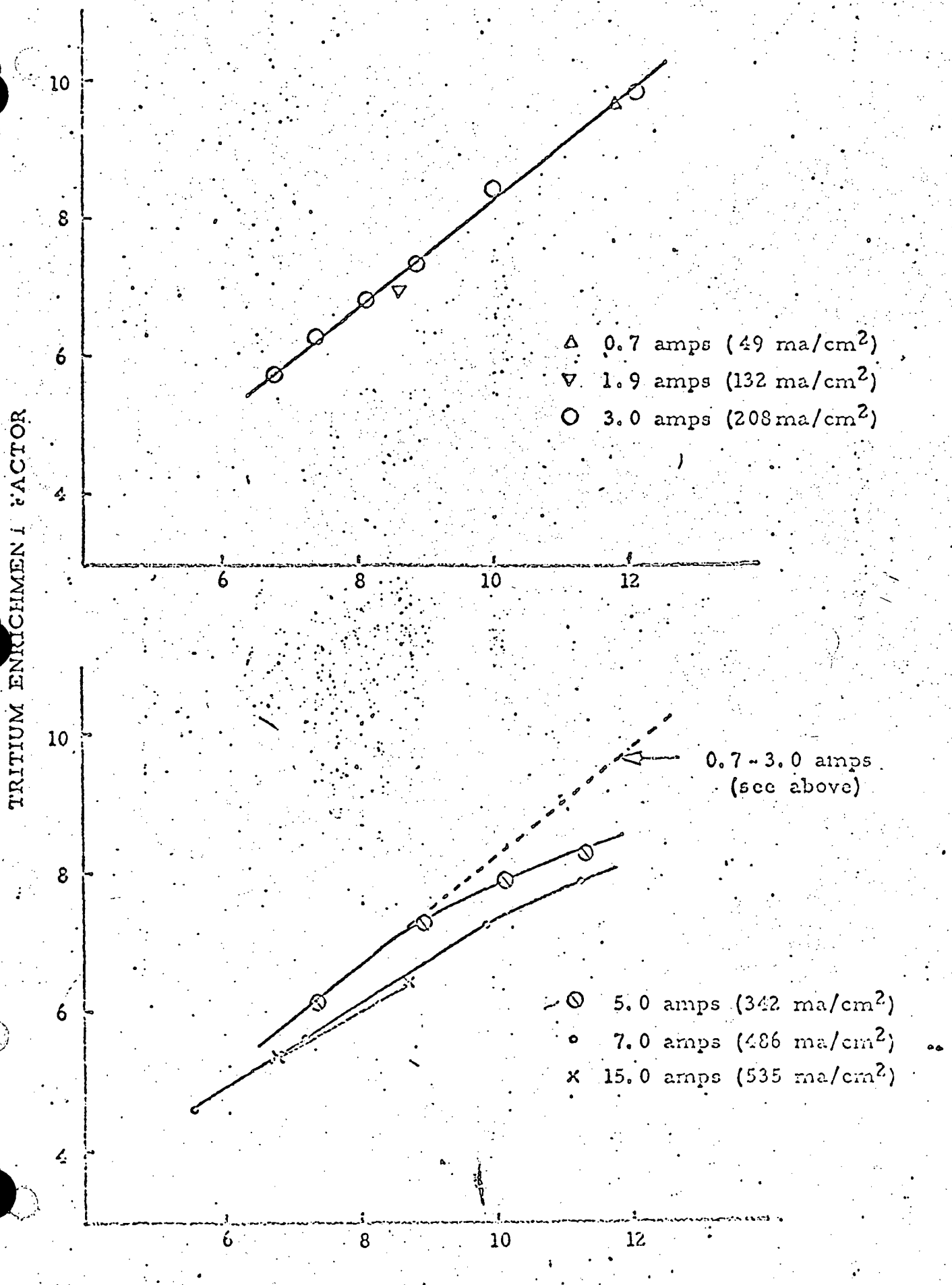

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Table 1

Tritium Concentrations in the Hudson River and Environs

Date	Sampling Site	Mile No. (1)	Result pCi/l
		(Hudson River)	
8/8	I-W-3	26.6	1720±70
	II-E-1	40.8	1820±74
	II-W-1	41.4	1920±77
	II-E-3	43.7	1750±70
	II-W-2A	56.5	1890±77
	III-W-2	67.3	2080±83
	IV-W-1	86.1	2080±83
	IV-W-2	95.1	2170±86
	IV-W-3	100.5	2290±93
	IV-W-4.	104.7	2010±80
11/1	II-W-1	41.4	1840±74
	II-W-2	45.2	1840±74
	II-W-2A	56.5	1760±70
	III-W-2	67.3	1660±67
	IV-W-1	86.1	1650±67
		(Sterling Lake)	
8/4	Surface	-	1920±77
	Bottom	-	1800±74
	Meadows	-	1970±80
		(North of Troy, New York)	
9/3	Schroon River (at Route 87)	200(2)	1980±80
	Schroon Lake (2 mi. N. of Pottersville	215(2)	2270±90
	Lake Champlain (at Valcour)	245(2)	2100±83
	Ausable River (S. of Upper Troy)	260(2)	1580±64

(1) Indicates miles from Battery Park, New York
(2) Cross-flight distance to Battery Park, New York

TRITIUM CONTENT OF STERLING FOREST WATERS

By: Thomas A. Janke

Introduction

Tritium, the radioactive isotope of hydrogen, has been identified as a valuable tool in environmental and biosphere studies. Examination of the tritium content of precipitation, surface water and ground water has provided information required in evaluating hazards from tritium, and also hydrological, meteorological and radiological health information.

A study of the tritium content of the waters of Sterling Forest is a necessary component of an environmental study of the area. In an era of increasing use of atomic energy and radioisotopes, base, reference and monitoring measurements are increasingly important.

The objectives of this survey are complementary. First is an evaluation of the tritium content of the waters in Sterling Forest. Second is an interpretation of the data and correlation with possibly influential environmental conditions.

Area of Survey

Sterling Forest is located in Orange County, New York,

approximately 50 miles northwest of New York City [16]. The area is hilly, forested and generally sparsely populated, with a few research, cultural and industrial facilities and residential sections scattered within its confines. Of particular interest in this survey are the five megawatt reactor operated by Union Carbide Corporation, and the New York University Institute of Environmental Medicine.

Sterling Forest lies primarily within the Greenwood - Sterling Lake drainage basin. The remaining northern portion of the forest drains into Mombasha Lake and the Ramapo River basin [12]. Much of the flow in the basin is due to precipitation, surface runoff and surface streams. Underground streams also contribute to the flow. This is because the underlying area is predominantly metamorphic rock, a factor which partially explains the numerous springs in the area [24]. Sterling Forest itself encompasses an area of approximately 30 square miles [21]. Figure 1 is a map of the area, with sampling sites indicated.

Literature Review

Since 1952, the levels of tritium in the environment have been recorded as increasing by several orders of magnitude due largely to the production of tritium in thermonuclear detonations. It has been estimated that 6.7×10^6 curies of tritium, most of

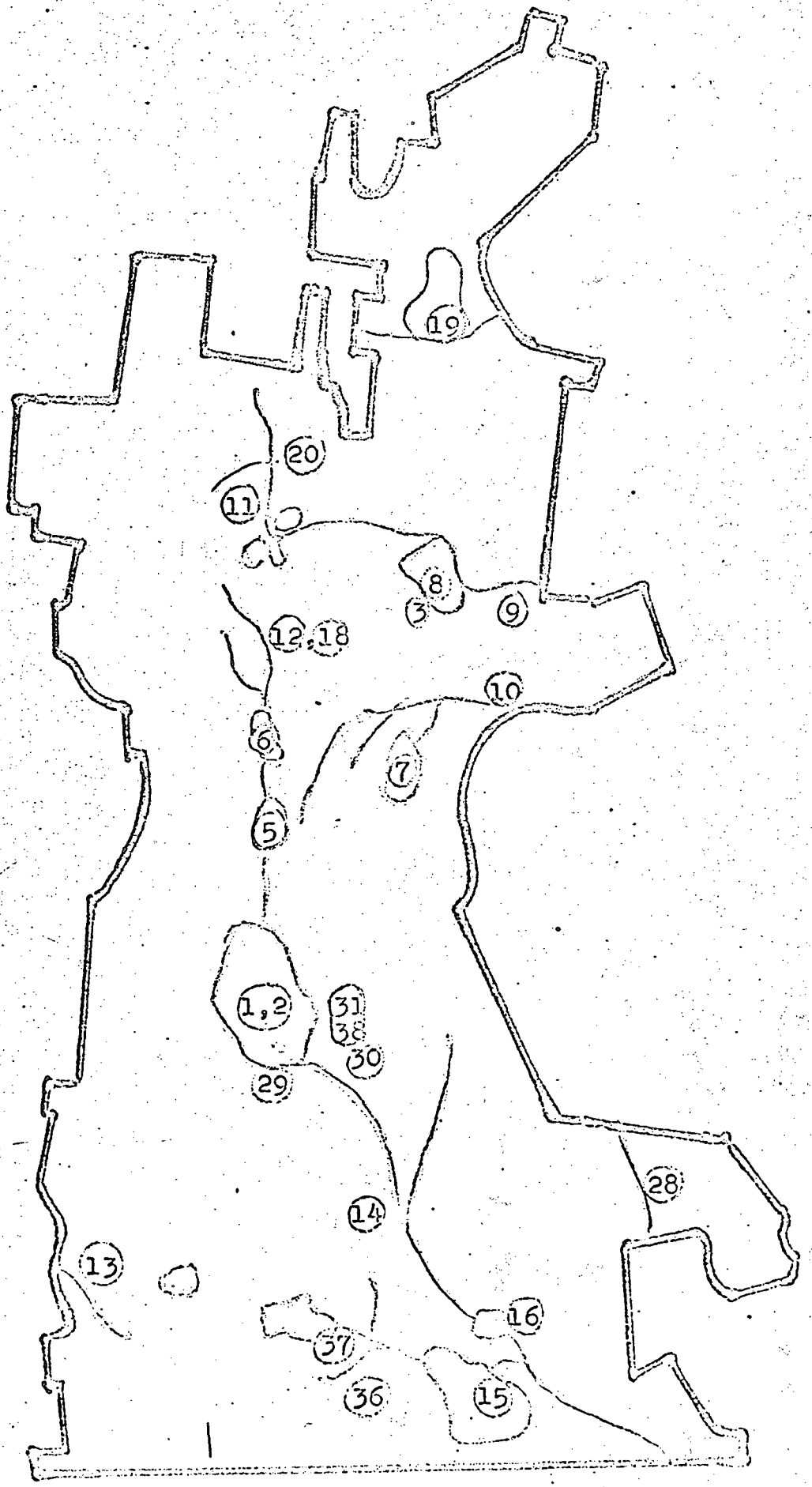

Figure 1 --Survey Sampling Sites (21,26)

which is injected into the stratosphere, are produced per megaton of fusion [4]. A less influential source of environmental tritium has been nuclear fission. It has been estimated that 10^3 curies of tritium are preduced per megaton of fission [4]. Although the impact of fission yield per se is not as great as that of fusion, it is attracting more attention because of the increased use of fission energy for power.

Most tritium is formed under oxidizing conditions and appears as HTO. In the troposphere this tritium is subject to fairly rapid mixing and deposition, whereas in the stratosphere it may exist for years [5,11,15]. Tritium has, as HTO, a biological half-life of 13 days once it enters the environmental troposphere [5]. Oceans, which act as sinks for tritium, contribute to this because of their rather high efficiency for removing HTO from the atmosphere.

To date, tritium in the environment is derived from detonatior of thermonuclear devices. In general, investigators have indicated that environmental tritium levels have increased step-wise, doubling every two to three years since the advent of thermonuclear testing in 1952. Table I is a representative list of some of the tritium measurements.

A fluctuation of tritium concentration in precipitation from

YEAR	SAMPLE	CONCENTRATION pCi/l
1951	RAIN	3.2 - 32
	SURFACE WATER	3.2 - 19
	GROUND WATER	0 - 19
1954	NATURAL WATER	1.6 - 216
	ATMOSPHERIC HYDROGEN GAS	4.8×10^4
1959-1960	RAIN AND SNOW	96 -2960
	SURFACE WATER	64 -1060
	GROUND WATER	0 - 32
1961-1962	RAIN AND SNOW	64 -4800
	SURFACE WATER	96 -1620
	GROUND WATER	0 - 96
	ATMOSPHERIC HYDROGEN GAS	3.2×10^6
1963	RAIN AND SNOW	320 -3200
	SURFACE WATER	32 -3200*
	GROUND WATER	0 - 320**

TABLE 1 - ENVIRONMENTAL TRITIUM CONCENTRATIONS (4, 5, 14, 20)

* Some unique readings to 4.8×10^4 pCi/l.

** Some unique readings to 3.2×10^3 pCi/l.

month to month has been noted. Peak concentrations occur during the spring of each year during the so called "spring leak" and are related to the injection of stratospheric debris into the troposphere near the polar regions [11, 12]. Short term variations in surface water concentration are not as detectable as those in precipitation, but seasonal variations are seen, generally following the spring increase in precipitation concentration. Approximately 70% of the year's total is expected in the first six months of the year [6].

Although the bulk of tritium literature concerns itself with the build-up of tritium in the environment, a few sources have made qualified predictions about a decrease in fallout. These, unfortunately, do not mention tritium per se, but refer to Strontium-90 deposition. In general, the predictions for ^{90}Sr have been that the deposition after 1963 will be about half that of the preceding year for each of the following years with an equilibrium between ground inventory and atmospheric deposition occurring in 1967 [6, 11]. Brookhaven National Laboratory, monitoring gross beta activity for several years, has observed a decrease from 1963 to 1965, but no great change since then [10, 23].

From an estimate of approximately two years' mean deposition time for tritium in the stratosphere [22] and from the

SURVEY	SAMPLE	CONCENTRATION pCi/l
DEPT. OF HEALTH (1965)	GENERAL SURFACE WATER	480 - 3550
	LARGE LAKES	480 - 2250
	NUCLEAR FUEL SERVICES AREA	<1600 - 4200
	GROUND WATER	9.7 - 225*
	RAIN (ALBANY)	1500 ± 80
	INDIAN KILL	<1600
DEPT. OF HEALTH (1967)	RAIN	ca 1600
NYU Aug.1966	STERLING LAKE - SURFACE	1900 ± 77
	STERLING LAKE - BOTTOM	1800 ± 74

TABLE 2 - NEW YORK STATE WATERS TRITIUM SURVEY[1,4]

* One unique result of 1560 pCi/l

CATEGORY OF WATER	PREDICTED pCi/l.
PRECIPITATION	1300-1600
SURFACE WATER	1600-1900
GROUND WATER	< 320

TABLE 3 - PREDICTED STERLING FOREST TRITIUM CONTENT

measurements made by the New York State Department of Health (see below), it seems that the tritium content of precipitation has fallen since 1962-1963, but now shows a more gradual decrease. Values for the tritium content of the waters of New York State for 1965 have been reported (Ref. 1, Table 2). Waters of the Hudson River in 1966 contained 1600-2300 pCi/l [4] and the local Sterling Lake about 1800 pCi/l with little difference between surface and bottom water [4].

Using the published data, it is possible to predict the values in Table 3 for the tritium content of Sterling Forest waters. Predictions were made for all three categories of water, although the original intent was to concentrate on surface water, and to approximate and identify the relationship of expected surface water tritium content to the two other local categories in the hydrological cycle.

The generally low concentrations of tritium present a problem of measurement. Acceptable results can be produced by increasing the counting time, decreasing the counting rate from the background or increasing the counting rate from the source. The count rate of a tritiated water sample can be increased by enriching the sample. The four main methods of enrichment are electrolysis, distillation, thermal diffusion and gas chromatography

(2). Of these, the electrolysis of water is usually employed for enrichment of the tritium in the sample. The heavier isotope, tritium, is discharged more slowly at the cathode than is hydrogen and tends to concentrate in the residue. This is the method chosen.

Following enrichment, the detection system must be carefully selected because of the low energy of the tritium beta. Due to its short range, tritium is generally incorporated directly into the detection system. This is normally accomplished by placing tritium in a liquid scintillator for scintillation counting or converting the tritium to a gas for counting in an ionization chamber or proportional counter (2). For this survey, liquid scintillation counting was employed.

Procedures

After selecting the equipment and methods to be used, the sampling site locations were chosen. The sites were selected to fulfill the gollowing general criteria:

1) Suitable cross section of the Sterling Forest waters to insure a random sample of all major systems.

2) Specific examination of the Union Carbide and New York University Lanza Laboratory influence on the tritium content of adjacent waters.

3) Verification of the absence of stratification of tritium in Sterling Lake (and hence other smaller bodies of water).

As the survey progressed, other sites were added to a total of 25 samples from the following locations:

Sterling Lake (2)	Indian Kill	Ltl. Sterling Lake
Rain (Union Carbide)	Warwich Brook	NYU Aparts. (2)
Snow (Sterling Furn.)	Sterling Forest Gard.	Swan Lake
Ashman Pond	NYU (Lanza) Lab. (3)	Bramertown Road
Mystic Pond	Forest Knoll	Maple Brook
Four Corners Pond	McKeags Meadow	Sandy Beach Lake
Indian Lake Reservoir	Blue Lake	Cedar Pond Creek

TABLE 4 - SAMPLING SITES (See Figure 1)

Sampling was conducted over the period 26 March 1967 to 18 April 1967, primarily on weekends. The samples were collected in 100 ml bottles which had been previously rinsed with water and oven dried at 300° F for 30 minutes. On site they were rinsed several times with the sample being collected. Sampling was conducted moving upstream wherever possible to avoid sampling the same portion of water twice.

After sampling, processing (see Table 5) was usually begun within three days. The initial step was a distillation to remove minerals and other contaminants. Potassium permanganate and sodium hydroxide were added to a 70 ml sample which was then

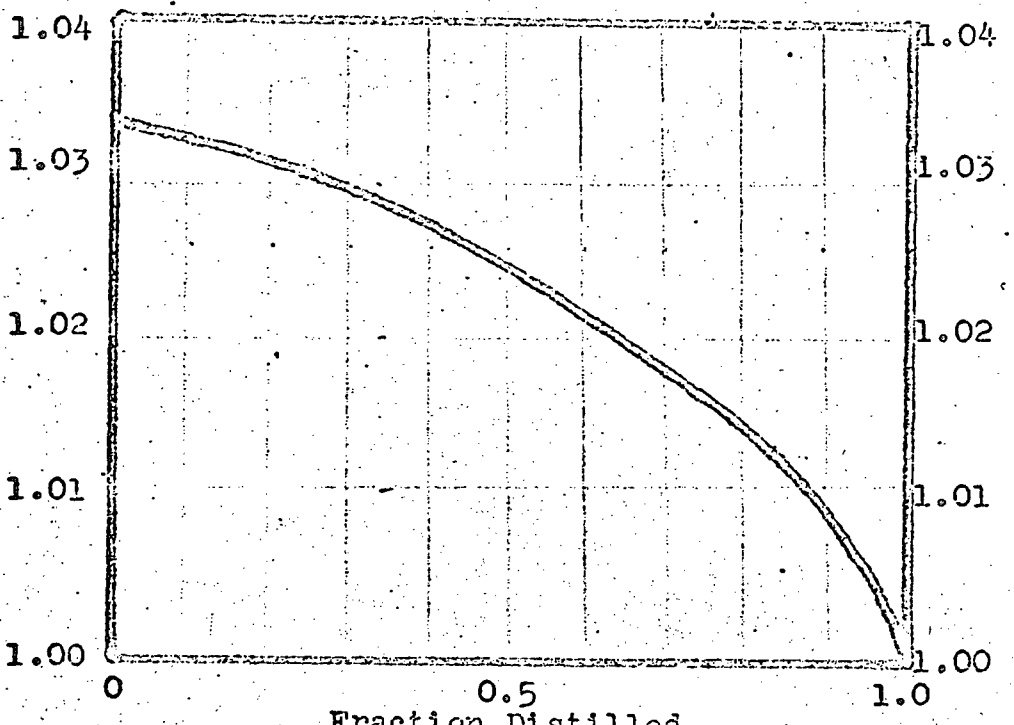

Figure 2--Distillation Correction Factor[18]

PROCESS	PURPOSE
1st DISTILLATION ($KMnO_4$, NaOH)	Provide common initial base for all samples by the removal of extras
ELECTROLYSIS (H_2SO_4)	Concentration
2d DISTILLATION	Remove H_2SO_4
COUNTING (Cocktail)	Detection of tritium

Table 5--Summary of Sample Processing

distilled to provide 35 ml of distilled water, free of contaminants. Potassium permanganate and sodium hydroxide are added to convert interfering organic substances to water and carbon dioxide. Samples that contained excessive suspended matter were prefiltered before distillation. Between samples, the apparatus was flushed with acetone and vacuum or air dried.

It was not necessary to distill to dryness, but only to determine a fraction distilled because of the use of a correction factor (F) developed by Riley and Brooks [18] based on the ratio of concentration of tritium in tritiated water to that in the vapor phase at equilibrium.

After the first distillation, the tritium was concentrated by electrolysis utilizing a unique electrolysis cell [4]. The electrodes in this cell are confined to the final volume well, thus eliminating the requirement for adjusting current as the volume of the sample decreases during electrolysis. Sulfuric acid (0.4 ml), was added as an electrolyte to 25 ml of the sample and the sample was electrolyzed for 19 hours with a current of 3 Amps. This combination was selected as giving the best enrichment, for the least time expended, for the maximum number of cells used. It also allowed for electrolysis overnight without attendance. The Kepco Constant Current DC Power Supply automatically varies

voltage to maintain a steady current of 3 Amps. Six electrolysis cells were connected in series allowing for the processing of five samples and a spiked tritium standard.

After electrolysis, the samples (and the standard) were distilled to remove sulfuric acid. During this operation, although the samples were not distilled to dryness, no separate distillation correction factor was computed because, by insuring that equal volumes of each sample were distilled, the enrichment factor computed later incorporated the distillation correction factor applicable to all samples. Between samples, the apparatus was flushed with acetone and dried.

Three ml of the distillate were then placed in a polyethylene vial containing a liquid scintillation cocktail of dioxane/naphthalene/PPO/POPOP [7].

The Nuclear Chicago Mark I Liquid Scintillation Computer was used for counting the samples. Samples were grouped as five samples, the concentrated standard, unconcentrated standard, and a tritium free sample. Samples were equilibrated for up to 10 hours to eliminate counts induced by sample exposure in the cocktail to artificial light or sunlight in the laboratory.

Samples were counted repetitively, usually over a weekend, for 200 minutes.

The Nuclear Chicago Liquid Scintillation Computer [13] is essentially three single channel analyzers. Each channel has an adjustable base and window width and the tritium channel was selected to maximize the figure of merit $\frac{S^2}{B}$*. A second channel was calibrated for a ^{133}Ba external standard incorporated in the counter. This external standard was counted in all channels for one minute following each 200 minute sample count in order that computation of counting efficiency by the channels ratio-quench correction method could be made.

After counting, the sample vials were stored and the final computations made. Background was determined from tritium free water, the enrichment factor (which was from three to four for the samples in this survey) was determined from the dpm/ml for the concentrated and unconcentrated standards, after correcting for slight differences in counting efficiency.

A quench correction curve was prepared by incorporating from one to five ml standard tritiated water with "cocktail" to a constant 25 ml volume [9]. Background was measured concurrently and subtracted before computations were made. The resulting curve is shown in Figure 3.

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*S = sample count, B = background count

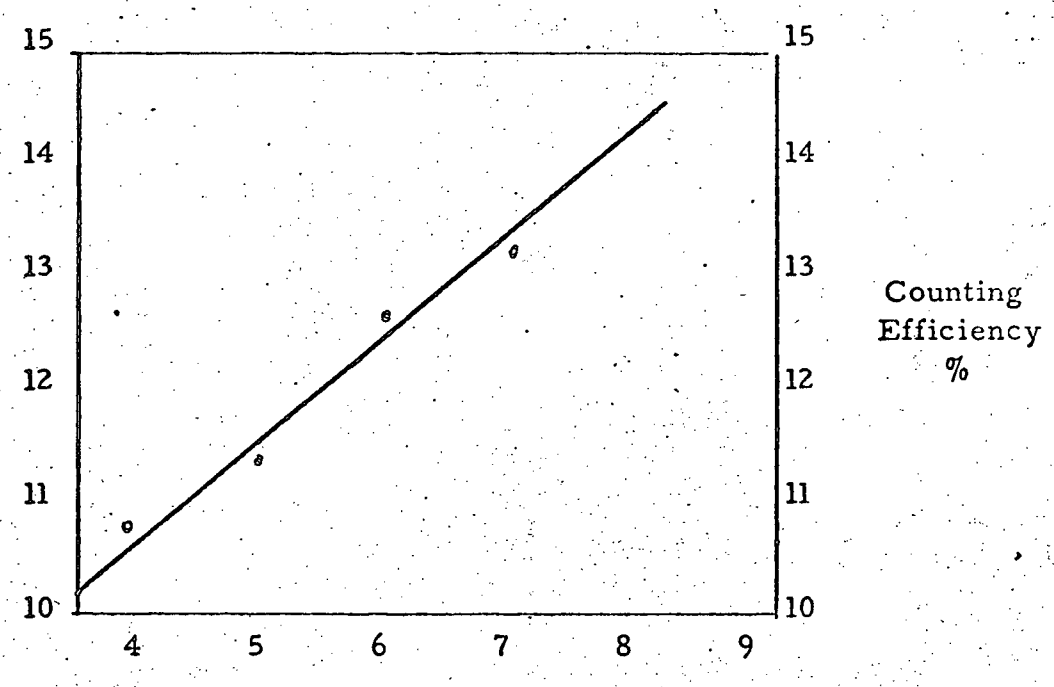

FIGURE 3 - QUENCH CORRECTION CURVE

The overall error for the system has been estimated at ± 4% [4]. This is primarily due to inequities in measurement during sample transfer, addition of tritium in H_2SO_4, and confidence in the known standards used for the determination of enrichment factor and the quench correction curve.

Accuracy and efficiency in the enrichment process was verified by counting a 3 ml volume of a distilled sample without enrichment and comparing with the enriched sample count. Both counts agree within 1 standard deviation and the system was considered to be producing accurate counts. Secondly, a planchet was prepared with one ml of distilled sample and evaluated for

both alpha and beta activity on the Nuclear Measurement Corp. Gas Flow Proportional Counter. In addition, two ml of the distilled sample were evaluated for X and gamma activity on the Nuclear Data Multichannel Analyzer. In all three cases it was determined initially that no other radionuclides were present. Since radioactivity had been detected for this sample on the liquid scintillation counter, it was assumed that tritium, which would not register on the multichannel analyzer and which had evaporated from the planchet, was the only radionuclide present. A slight, low energy peak in the γ - spectrum was attributed to tritium bremsstrahlung.

Results and Discussion

The results obtained in this survey are listed in Table 6. The sampling sites are located on Figure 1. It was sometimes necessary to identify the sampling site by the nearest recognizable topographic feature. Thus sample 30 (Lakeville) was taken several hundred feet east of Lakeville, sample 13 (Forest Knoll) was taken several hundred feet north of Forest Knoll at the Sterling Forest Boundary.

Several measurements are significantly higher than the remainder, specifically samples 30, 31, and 38. Samples 31 and 38 were taken at what appeared to be a small spring approx-

SAMPLE	DATE	LOCATION	TRITIUM CONTENT*
1	4/12	STERLING LAKE (SURFACE)	1190 ± 84
2	4/12	STERLING LAKE (BOTTOM)	1210 ± 84
5	4/2	ASHMAN POND	725 ± 58
6	4/2	MYSTIC POND	940 ± 58
7	3/26	FOUR CORNERS (POND)	785 ± 61
8	3/26	INDIAN LAKE RESERVOIR	680 ± 51
9	3/26	INDIAN KILL	595 ± 58
10	3/26	WARWICK BROOK	790 ± 64
11	3/26	STERLING FOREST GARDENS	770 ± 61
12	3/26	NYU APARTMENTS (MARSH)	850 ± 58
13	4/2	FOREST KNOLL	630 ± 58
14	3/26	MCKEAGS MEADOW	1060 ± 64
15	3/26	BLUE (STERLING FOREST) LAKE	750 ± 61
16	3/26	LITTLE STERLING LAKE	1150 ± 67
18	3/26	NYU APARTMENTS (TAP WATER)	1080 ± 64
19	4/2	SWAN (LITTLE DAM) LAKE	910 ± 64
20	4/2	BRAMERTOWN ROAD (CREEK)	650 ± 64
28	4/9	SUMMIT BROOK	550 ± 71
30	4/9	LAKEVILLE	$18 \times 10^3 \pm 180$
31	4/9	NYU LANZA LABORATORY	$32 \times 10^3 \pm 320$
36	4/16	SANDY BEACH LAKE	740 ± 67
37	4/16	CEDAR POND (OUTLET)	780 ± 71
38	4/18	NYU LANZA LABORATORY	$22 \times 10^3 \pm 220$
3	4/12	RAIN WATER (UNION CARBIDE)	970 ± 77
29	4/7	SNOW (STERLING FURNACE)	610 ± 74

TABLE 6 - TRITIUM CONTENT OF STERLING FOREST WATERS

* Expressed as pCi/l.

imately 100 yards below the waste water outlet of the southern wing of the New York University Lanza Environmental Medicine Laboratory. Sample 30 was taken approximately 500 yards farther down hill, below a considerable marshy area, but uphill from the Sterling Lake outlet stream. Although uniquely high in relation to the other samples, the measurements do not indicate a large source of tritium (approximately 1% MPC_w for the general population). The obvious explanation for the high values is tritium in the effluent from the Lanza Laboratory. After entering the Sterling Lake outlet stream, the water is quickly diluted by the much greater volume of the stream (see samples 14 and 16). During the time of sampling there was no measurable outlet flow and it was not possible to estimate the tritium concentration at the outlet.

It is worthwhile to refer back to the previous reference measurements and the predicted values for this survey as noted in Table 2 and Table 3: most of the tritium measurements are lower than predicted. The values measured for Sterling Lake in April are lower than in August 1966. The readings do, however, verify the absence of tritium stratification reported in 1966. It seems reasonable to assume that the individual waters in

Sterling Forest have an homogeneous tritium content and since each specific body of water has a uniform distribution of tritium it is acceptable to take a single sample to evaluate the tritium content (excluding statistical requirements).

Samples 8 and 9, collected from waters near Union Carbide, show no significant variation from other samples.

The fact that the waters in Sterling Forest have less tritium then predicted warrants some explanation. However, the possibility that the prediction was a bad guess and that the waters were always low in tritium is precluded by the Sterling Lake measurements. Two possible explanations are, first that the survey reflects a seasonal change, and second that the waters are being diluted by a precipitation input with a relatively rapidly decreasing tritium content.

Examining the possibility of a seasonal change, i. e. a winter decrease in tritium content, it should be noted first that many of the waters sampled were still covered with ice and so were cut off from direct precipitation and exposed to very limited surface run-off. Most of their input, then, would appear to be from the many underground sources in the area (allegedly of the lowest tritium content in the hydrological cycle). However, this possibility can be quickly eliminated. Although many of the

waters were covered with ice, at least as many were not, particularly streams feeding ice-covered ponds and lakes. Some may have been ice-free throughout the winter. Also during the sampling period, a considerable input to the general water system was from precipitation and surface flow. In fact, the sampling period included the height of the spring runoff, as well as the initial period of the "spring leak". If the change were seasonal, a general increase in tritium content should have been from smaller, more rapidly displaced bodies of water. This increase was not observed.

Another alternative precipitation exhibiting a decreasing tritium content remains the only possibility. Measurements of rain at Albany [1] indicate a 1967 precipitation tritium content too high to effect the change, but this does not negate this premise. Although the 1965 measurements are exact, the 1967 figure is reported as "slightly below 500 TU" (< 1600 pCi/l), an inaccurate result at best. The measurement of precipitation in Sterling Forest is of greater value in examining this alternative.

Samples 3 and 29, averaged, indicate that the tritium content of the precipitation that fell on Sterling Forest in the recent past was 790 ± 106 pCi/l, only slightly more than half of the 1965 Albany figure. A mathematical model can be devised with this level and the readings noted for Sterling Lake (the only ones available for

comparison). The method employed was originally presented by R. H. Rainey of Oak Ridge National Laboratory [17].

Several assumptions must be made:

a) Input equals output

b) Concentration is uniform throughout the lake

c) Addition or elimination of contaminant is constant (in this case, recovery is based on a zero tritium content in the input waters).

After making these assumptions, the following relationship of the change in the concentration of pollutant (tritium) in the lake with time (T) was developed:

$$C_2 = C_2^o \exp(-RT/V)$$

where

C_2 is the concentration in the lake

C_2^o is the concentration in the lake at time T_o

R is the input (output) rate

T is the length of time considered

V is the voume of the lake

Applying these functions to Sterling Lake and assuming, for purposes of this exercise, that:

a) All imput is due to precipitation and surface run-off (since neither the volume nor the tritium content of ground water is known).

b) 784 pCi/l is accepted as the level of no contamination.

$$C_2 = \frac{\text{sample 1 + sample 2}}{2} = 784$$

$$= \frac{1190 + 1210}{2} - 784 = 416$$

$$C_2^o = \frac{\text{1966 sample 1 + 1966 sample 2}}{2} - 784$$

$$= \frac{1805 + 1920}{2} - 784 = 1078 \text{ pCi/l}$$

V = (surface area of the lake) (average depth)

$= (1.188 \times 10^7 \text{ ft}^2)\ (50 \text{ ft}) = 5.94 \times 10^8 \text{ ft}^3$

RT = area of Sterling Lake drainage basin x total precipitation during period (Sept. -April)

$= 1.54 \times 10^8 \text{ ft}^2\ (12) \times 2.8 \text{ ft}\ (25) = 4.31 \times 10^8 \text{ ft}^3$

$$C_2/C_2^o = \frac{416}{1078} = 0.38$$

$$\frac{RT}{V} = \frac{4.31 \times 10^8}{5.94 \times 10^8} = 0.73$$

By reference to Figure 5, a graphical expression of the function, it appears that, in order to obtain a C_2/C_2^o ratio of 0.38, an RT/V ratio of 1 is required (one volume change). The RT/V ratio obtained by our model (0.73) is within a factor of one and a half of the theoretical value and therefore it is reasonable to assume that the decrease in the measured tritium content of Sterling Lake

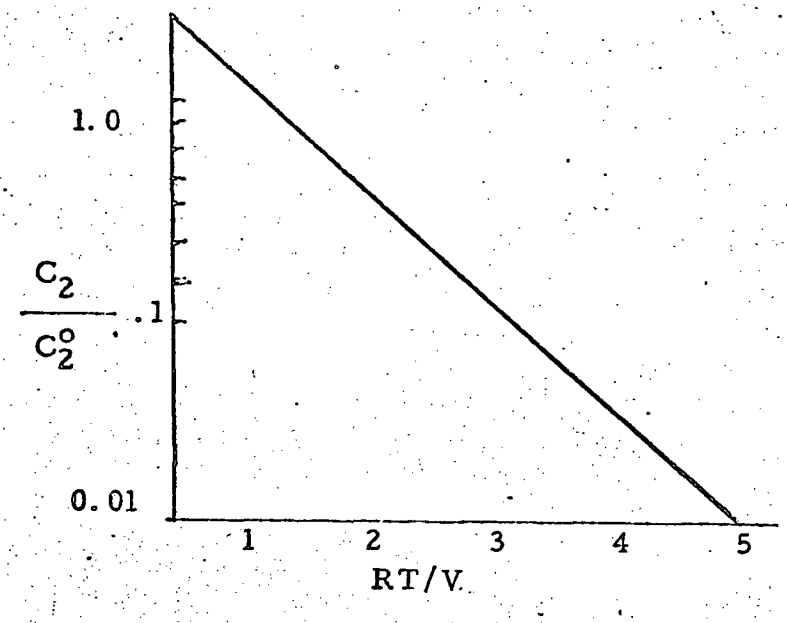

FIGURE 5 - Simplified Mathematical Model

and the probable decrease in the tritium content of other Sterling Forest waters is due to a rapidly decreasing tritium content in the precipitation.

In addition to supporting the premise that the tritium content of precipitation is decreasing, this exercise displays what may be accomplished in the field of hydrology with tritium measurements. With measurements of tritium content alone, it has been possible to provide a reasonable estimate of the water displacement rate of the lake. With the additional precise measurements of total rainfall, volume of the lake, area of drainage basin and tritium content of the precipitation, an approximation of the contribution to lake volume of precipitation and surface water and ground water can be made.

5.94×10^8 ft^3	required for one volume change
-4.31×10^8 ft^3	due to precipitation
1.63×10^8 ft^3	ground water required "at the same concentration" (lower concentration requires less volume)

Since ground water is expected to be lower in tritium content than precipitation, a smaller volume would be needed and it would be logical to assume that the greatest volume of Sterling Lake input is precipitation and surface run-off.

If, instead of accepting 790 pCi/l as the level of no contamination, the real concentrations are applied, the following relationship can be used to evaluate C_2.

$$C_2 = C_2^o \exp(-RT/V) + \left[(C_1+Q/R)\right]\left[(1-\exp(RT/V)\right]$$

where: Q is the rate at which pollutants are added

C_1 is the concentration of pollutants added

Using the real concentrations, the RT/V of 0.73 calculated earlier and disregarding Q/R which is very small, the formula becomes:

$$C_2 = 1862\ (.48) + 784\ (.52) = 1302\ \text{pCi/l}$$

This value is only 10% greater than the concentration actually measured, ca 1200 pCi/l. Again, it is concluded that the declining tritium content of the lake is due to dilution by precipitation which is the greatest contributor to lake input, the remainder being a small volume of ground water relatively lower in tritium content.

This is not a unique position, since it has been estimated that the ratio of surface run-off to ground water recharge is, or more correctly may be, as high as 20/1 in this area [8]. A measure of ground water tritium concentration will be a basis for computing ground water input volume. Conversely, a measurement of the volume of ground water input will lead to a calculation of its tritium content. These computations would have to be based on increasing hydrogen content (decreasing tritium content) i.e. increasing dilution. In similar circumstances, an estimate of the size of the drainage basin can be made from tritium measurements of the lake and precipitation, amount of rainfall and volume of the lake.

It is expected, of course, that the mathematical model based on total precipitation input is not completely accurate because some of the precipitation, as indicated, percolates into the ground. Some of it may actually flow through the metamorphic rock and leave the area of the forest completely [24]. The deficit, if it does exist, may come from ground water flowing into the forest. A compensating factor to consider is that the rain sample, which was collected over the period 3/7 to 4/12, may have begun responding to the spring leak, making the average precipitation value used higher than that used for the period considered. In

any event, it must be assumed that the waters in Sterling Forest are in equilibrium (input equals output) with a precipitation input, part of which spends an unknown amount of time underground.

A consideration of ground water and underground stay time leads to an interesting hypothesis.

Excluding samples 3 and 29 (precipitation) and 30, 31 and 38 (Lanza Laboratory effluent), and plotting a histogram of the 20 samples remaining, it appears that the samples were not randomly selected from a normal population, but rather from two populations.

In examining the hypothesis that two populations were sampled, an identification of the two populations is required. Reference to Table 6 indicates that the largest separation between

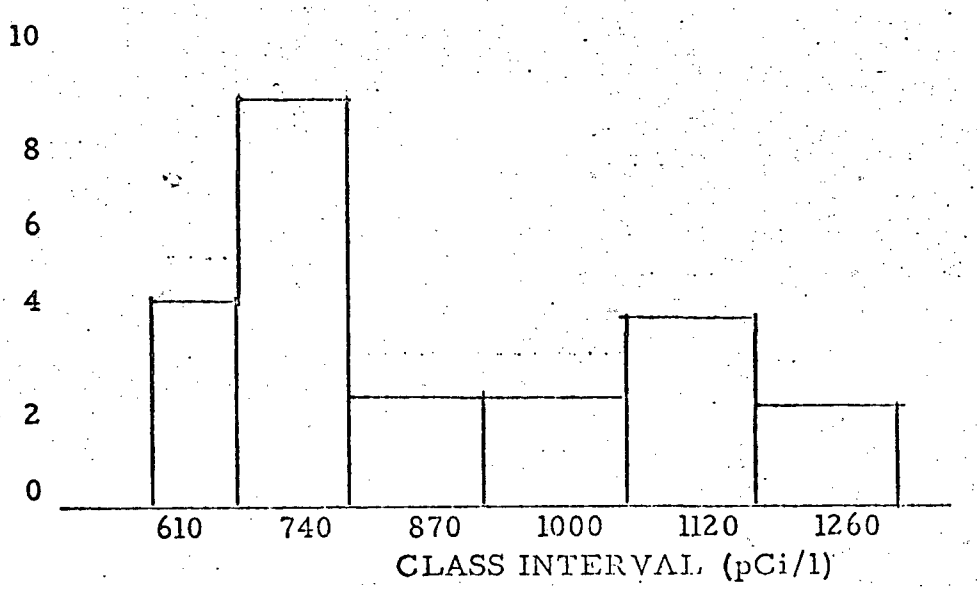

FIGURE 6 - HISTOGRAM OF SAMPLE MEASUREMENT

consecutive sample measurements occurs between sample 6 (940) and sample 14 (1060). This separates two populations, with 15 in the first and five in the second. (Figure 6).

Utilizing Student's distribution [19], a significant difference exists between the first population (mean-750, S. D. 116) and the second population (mean-1130, S. D. 64) even at 99% confidence. A systematic difference between the two populations might be suspected. Table 6 identifies the five samples in the second (higher) population as sample 1 (Sterling Lake surface), sample 2 (Sterling Lake bottom), sample 14 (McKeags Meadow), sample 16 (Little Sterling Lake) and sample 18 (NYU Apartment tap water). These are either in Sterling Lake or its drainage basin. This seems to contradict a general theory that larger lakes have a lower tritium content because their longer mean residence time allows for increased dilution with older ground water [1]. When one considers, however, that this theory was developed when the tritium content of precipitation was increasing, or at least much higher than surface water, in an environment in which the precipitation is "cooling", the opposite effect, as measured, seems logical for the same longer residence time and slower reaction rate. Sterling Lake, having the largest volume of water of the sites studied, does not reflect as rapidly as the smaller bodies

the dilution effect from the decline in precipitation tritium content because of its slower volume change.

Sample 18, from an artesian well, if it were to reflect the traditionally lowest content, should be the lowest of any sample measured but is, instead, one of the highest. However, as a single measurement in the light of the preponderance of other reference ground water measurements, it does not suggest a general increase in ground water tritium content. It would seem profitable to examine the underground residence time of ground water (displacement rate) and the volume of the ground water in the Sterling Forest area. The depth of the water table is not as great in hilly areas as it is in level areas and the amount of ground water available on hills is limited to that reaching the saturation zone from uphill [8]. Ground water from surrounding hills flows into valleys and valley lakes. Thus the input of ground water into Sterling Lake may have had an underground residence time of only a few years. A rapidly rotating ground water supply could still retain much of its activity (for example - 71% for six years) but would not reflect very quickly a declining tritium content in precipitation. It should be noted that the unique high measurement of ground water [1] was from the most shallow well

and seemed to reflect a high turnover rate.

In conclusion, the facts and hypotheses developed by this survey suggest further valuable hydrological and environmental transport and hygiene studies can be conducted through examination of the tritium content of the waters of Sterling Forest.

Summary

Union Carbide Corporation has, apparently, little effect on the tritium content of the waters in Sterling Forest; NYU Lanza Environmental Medicine Laboratory has a localized elevating effect due to waste water effluent.

The tritium content of the waters in Sterling Forest are lower than predicted from comparable reference measurements except for the single ground water sample which was higher.

There is apparently no tritium stratification in the waters in Sterling Forest.

From these results and various mathematical models, it seems reasonable to suggest that the tritium content of precipitation is delining. Further studies are suggested utilizing tritium measurements as a method of choice with particular emphasis directed toward the examination of ground water.

Acknowledgements:

My thanks are due to Frank J. Cosolito for advice and assistance in this program.

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