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IMPACTS OF ALUM SLUDGE ON TIDAL FRESHWATER STREAMS

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ABSTRACT

Alum sludge, generated in the processing of surface water for drinking water supplies, has traditionally been discharged into nearby streams in Virginia and elsewhere. Alum sludge contains aluminum in an insoluble and non-toxic form. There remains concern, however, that alum sludge may have a negative impact on receiving waters.

The distribution of aluminum-enriched sediments was determined as the change in aluminum:silicon ratio in three tidal freshwater streams receiving alum sludge discharges. Primary production, marsh community status, and benthic invertebrate community composition were determined along each stream. Primary production of phytoplankton and benthic algae was lower at an upstream station than at a downstream station in two streams. Marsh communities were judged to be typical for streams of this type. Benthic invertebrate communities increased in species richness and total abundance with increasing distance from the discharge point in all streams. The biological parameters were compared with aluminum:silicon ratio and salinity gradients and with biological communities along similar streams not receiving alum sludge. Changes in the biological community were concluded to be more closely related to salinity structure of the systems than to introduction of alum sludge.

INTRODUCTION

Alum flocculation has proven to be an effective method to purify surface waters for municipal drinking water supplies. Water treatment facilities must ultimately dispose of an alum sludge, a waste consisting of aluminum hydroxide plus various inorganic and organic particles. While not considered toxic (Burrows, 1977), alum sludge is bulky with a high water content. A long-standing method of disposal has been discharge into receiving streams downstream of the water treatment plants. Alum sludge remains in suspension for some time during which it is carried downstream before being incorporated into the bottom substrate.

In tidewater Virginia, the Cities of Norfolk and Newport News both utilize alum flocculation at several water treatment plants. The resultant sludge has for as many as 80 years been discharged into various subestuaries of the Chesapeake Bay system. In Norfolk, the Moores

Bridges plant discharges into Broad Creek, a tributary of the Elizabeth River Eastern Branch (Blair et al., 1983). In Newport News, the Harwoods Mill plant discharges into the Poquoson River, the Lee Hall plant into the Warwick River.

The focus of the present report is the ecological effects of alum sludge in the streams near the point of discharge. Ecological effects might include: 1) changes in primary production, 2) changes in the fringing marsh community, and 3) impacts on the benthic invertebrate community. We defined the distribution of alum sludge and evaluated the effect of the discharge in several components of the stream ecosystems; phytoplankton, benthic algae, marsh community development and benthic invertebrate community structure.

MATERIALS AND METHODS

A series of stations were sampled extending downstream from the discharge point in each of three streams receiving alum sludge, the Poquoson River, the Warwick River, and Broad Creek in tidewater Virginia (Figure 1). Stations extended three to five miles downstream in each of the streams to a point where the stream either widened and deepened dramatically or until it discharged into a larger stream. Station density was greater at upstream locations where changes in impacts were expected over short distances.

In March 1984, long (ca 1 m) sediment cores, 10 cm in diameter, were collected primarily to determine the distribution of alum. Several other geochemical and geological parameters were evaluated to define the general nature of the substrate; these have been discussed elsewhere (Diaz and Roberts 1985; Diaz et al. 1985; Roberts and Diaz, 1985). Enrichment of sediments with aluminum was determined as the Al:Si ratio. Samples from selected depths in each sediment core were analyzed for silicon and aluminum with a PGT Model 342 X-ray Dispersive Spectroscope coupled with a computer. The ratio of the elements was selected as the data output from the analytical system.

Primary production by the surface phytoplankton community was determined at two stations each in the Poquoson and Warwick River systems, one near the discharge point, the second at a downstream site . Production was estimated by a modification of the ^{14}C-uptake method (Strickland, 1960; Diaz et al., 1985). At the same time, primary production of the benthic algal community was determined using a light and dark chamber method (Rizzo, 1977). Phytoplankton samples were incubated in situ at the collection site at about 15 cm depth. Immediately after starting the phytoplankton incubation, the benthic algal incubation was initiated. After establishing the upstream station, the downstream station was sampled before returning to the upstream station to terminate both incubations. Productivity was measured in winter (March) and again in late spring (early June). The early sampling period approximately corresponded to the "spring bloom" of the estuarine phytoplankton community. The second sampling might better have been delayed until late July or August to observe extreme summer conditions, but this was not possible within the schedule of the contract funding this study.

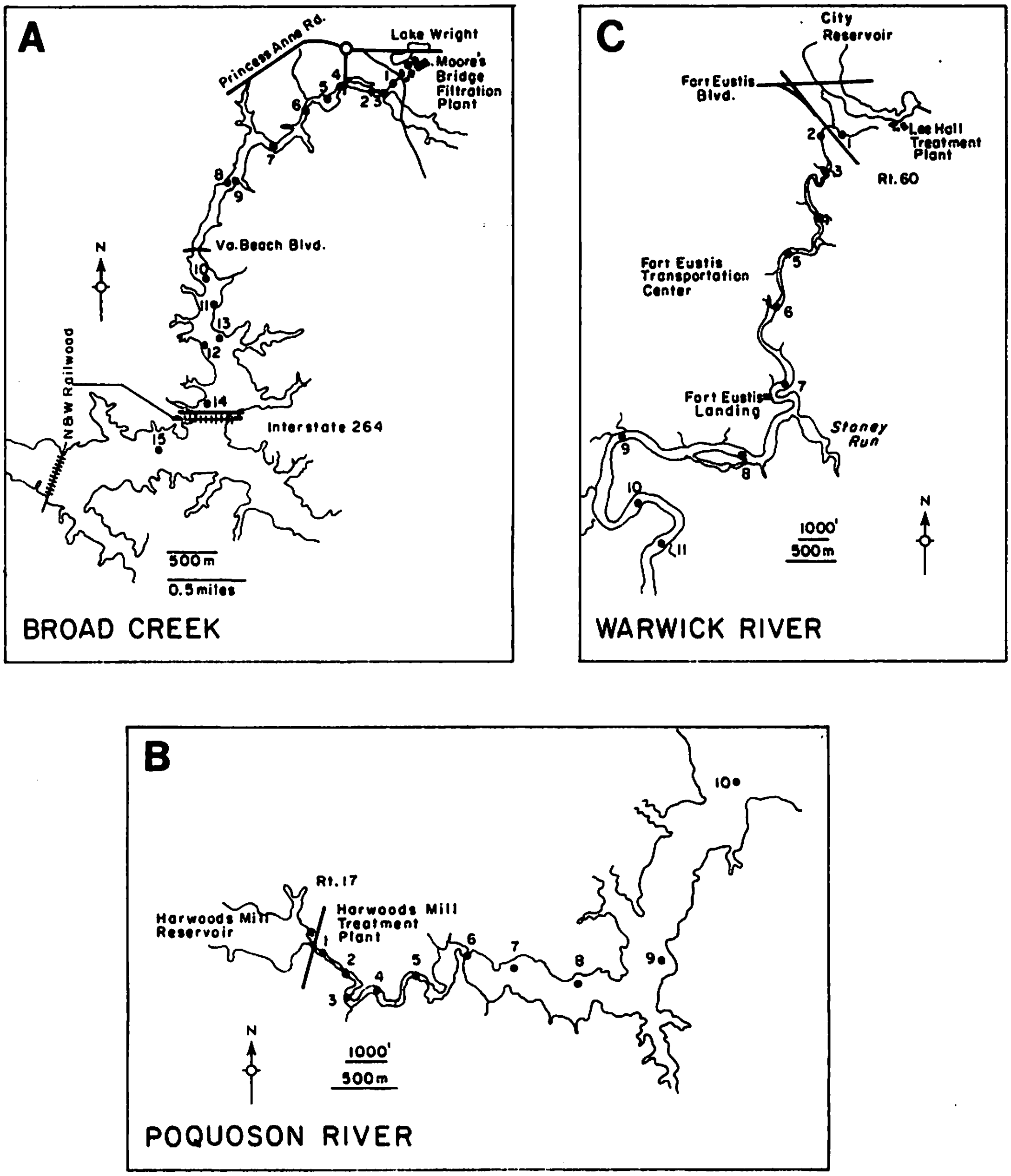


Figure 1 Station maps for the three estuaries studied. A) Broad Creek in Norfolk, VA; B) Poquoson River in York County, VA; C) Upper reach of Warwick River, Newport News, VA.

Chlorophyll concentration in the surface water at each station and the chlorophyll content of the sediment surface were determined fluorometrically after extracting samples in a DMSO:acetone:water:DEA mixture at room temperature in the dark for 24 hours (Burnison, 1971). Temperature, salinity and carbonate alkalinity were measured at each station during the productivity studies (Strickland and Parsons, 1972).

The marsh community fringing all three streams was examined visually. The species composition in each area was determined along with estimates of the areal coverage by definable community types. These observations were compared to historical data for each stream found in Moore (1977) and Silberhorn (1974).

The benthic communities in the three streams were sampled in late May/early June. Five to ten cores (5 cm diameter) were preserved and returned to the laboratory for analysis. Core samples were sieved to 250 um; the invertebrates were then hand picked and identified to the lowest taxon possible; most marine and freshwater macroinvertebrates were identified to species. Each species was enumerated individually in each core.

RESULTS AND DISCUSSION

Aluminum is a natural constituent of clay minerals, and therefore, one would expect some specific background concentration based on the type of clay mineral present. To define a background Al:Si ratio for the study sites in Virginia, the ratio for samples from an area in the York River not receiving alum sludge as well as pure samples of kaolinite and montmorillonite were analyzed. A ratio of 0.2 was accepted as representative of the probable background.

Aluminum was clearly enriched in surface sediments near the point of sludge discharge in all three streams (Figure 2). The proportion of aluminum in sediment samples generally declined with distance downstream and with depth in the sediment. Background Al:Si ratios were found in samples from a 1 m depth in the sediment cores from every station, with background levels generally being found at shallower depths as one proceeds downstream. This is the general type of distribution which one would expect with frequent, though discontinuous introduction. The Warwick River exhibited greater enrichment than either of the other streams, reflecting a greater input into the Warwick than other streams.

Phytoplankton productivity was measured before and during an alum sludge discharge event in the Poquoson River. In the Warwick River, a single measurement was made at each station since there was high turbidity associated with alum floc whenever the sites were visited regardless of the timing of discharge.

In the Poquoson River, phytoplankton productivity at Station 1 was extremely low (<2 mg $C/m^3/h$) on the day prior to discharge of the alum sludge both during March and June sampling. At both sampling times, the low productivity corresponded to a low standing crop of algae as indicated by chlorophyll a concentrations at or below 1.1 mg/m^3. On the day of sludge discharge in both March and June, productivity measured at

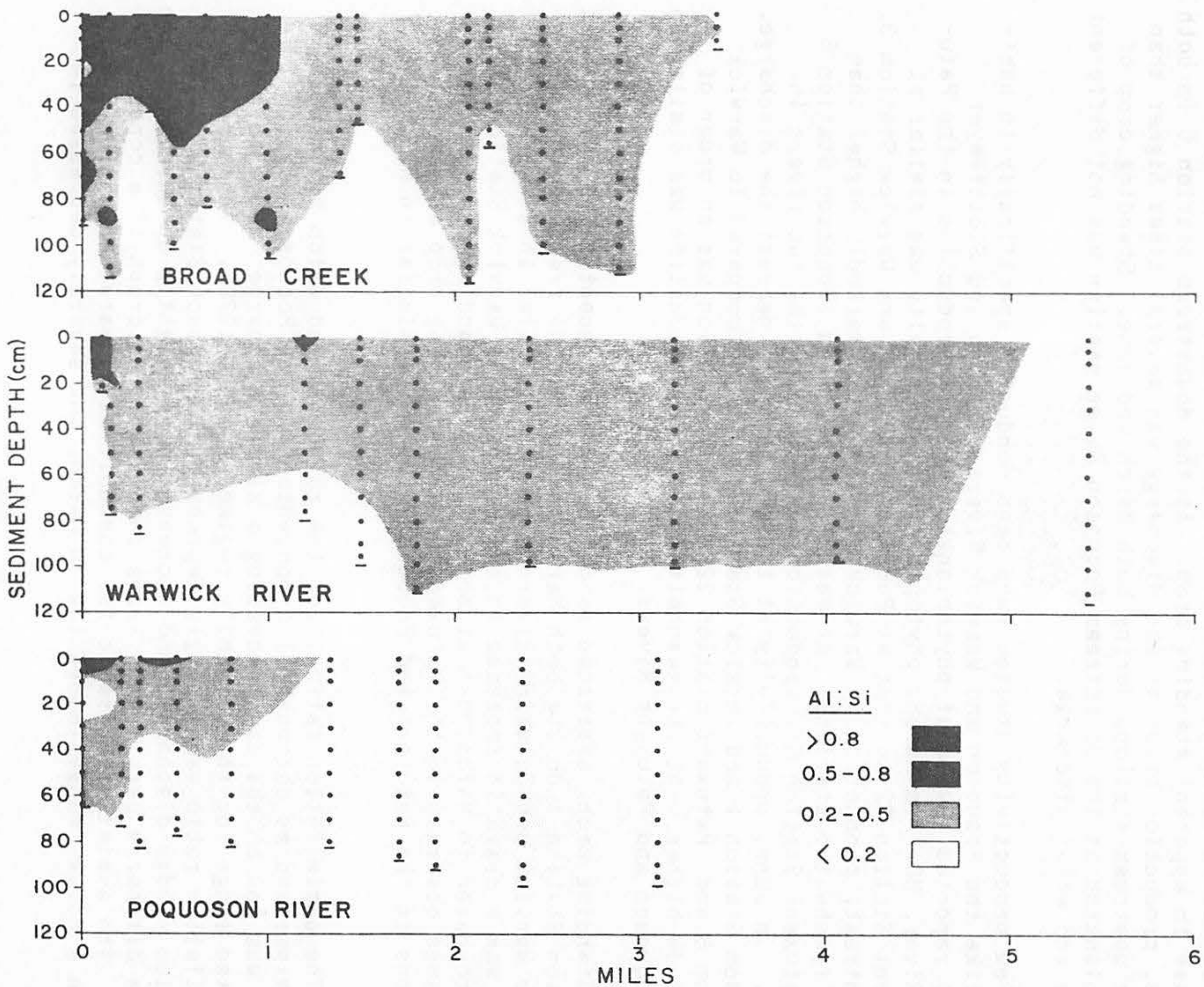


Figure 2 Graphical presentation of the distribution of aluminum enrichment in bottom sediments of the three estuaries studied.

Station 1 was increased 10-fold corresponding to a large increase in standing crop (4-fold in March and 57-fold in June). The dramatic increases in standing crop and corresponding increases in primary production assuredly reflect the presence of algal material in sludge derived originally from the reservoir.

At the upstream Warwick Station 3, primary production in March was low corresponding to a low standing crop. In June, primary production was essentially unchanged from that in March despite the nearly 10-fold increase in apparent standing crop. At the downstream station 6 in both rivers, production prior to the discharge was several times higher than at the upstream stations during both March and June. Standing crop of phytoplankton at the downstream Poquoson River station was not different before and after discharge.

Few productivity studies have been conducted specifically in habitats like the Poquoson and Warwick Rivers. Stross and Stottlemyer (1965) reported levels of phytoplankton primary production in the Patuxent River, MD. In March, phytoplankton productivity was similar at Patuxent Station 22 to that at Poquoson Station 1 and Warwick Station 3. In contrast, production at Warwick Station 6 was markedly higher than other freshwater stations. At mesohaline stations (Poquoson Station 6 and Patuxent Station 6), production was equal for the two rivers in March. In June, productivity at the two stations nearest the discharge, Poquoson Station 1 and Warwick Station 3, was low compared to Warwick Station 6 and Patuxent Station 22, where production was an order of magnitude higher. At the mesohaline stations, production was similar in the Poquoson and Patuxent Rivers.

Standing crop, expressed as chlorophyll a concentration, was low at Poquoson Station 1 during both March and June. The freshwater stations in the Warwick and Patuxent Rivers were quite similar in standing crop. There was a dramatic increase in standing crop at Warwick Station 3 in June compared to March, but at both times, the standing crop was within the range observed in the Patuxent River. Standing crop at mesohaline stations in the Patuxent and Poquoson Rivers was similar in March and June.

The assimilation ratio (i.e. the ratio of production to standing crop expressed as chlorophyll a concentration) at Poquoson Station 1 in March was low on the day preceeding a sludge discharge but within the expected range for this salinity regime (Flemer, 1970). In June, the assimilation ratio was strongly depressed at Poquoson Station 1 before the alum sludge discharge, and increased only slightly on the day of the sludge discharge despite the large increase in chlorophyll a concentration. The assimilation ratio for communities at Warwick Station 3 was within a normal range though low in March, but severely depressed in June.

The high sediment loads in the upper reaches of the Poquoson and the Warwick produce a severe, albeit not demonstrably toxic, effect on primary production. At best, primary production is restricted to the upper 5 to 10 centimeters of the water column. This condition gradually improves as one progresses downstream.

Gross production by benthic algae at the Poquoson River stations was extremely low in March, reflecting low light availability on both sampling days which were heavily overcast with occasional light to heavy rain. Despite the poor conditions, it is clear that gross production was increased at both stations on the day of sludge discharge; this may be an artifact of increased light availability. Similarly, gross production by the benthic algal community at both Warwick Stations 3 and 6 was low and net production was essentially zero, despite adequate light intensity. In June, gross production, respiration, and net production at Poquoson Stations 1 and 6 were nearly the same on the day preceeding the sludge discharge. No comparison is possible for the day of discharge because some material in the effluent (aluminum hydroxide?) interfered with the Winkler oxygen method. Thus there is no clear evidence of any impact of the alum sludge discharge on the benthic algal community as measured by primary production rate during June, although there was a difference in March.

Gross and net production of benthic algae in the Poquoson and Warwick rivers were similar at both sampling times. There did not appear to be any impact of the sludge discharge on the productivity of the benthic algal community at the downstream stations. Gross production of benthic microalgae is reported to range between 10 and 190 mg $C/m^2/h$ (Gallagher and Daiber, 1974). Gross production at Poquoson Station 1 and Warwick Station 3 was low, but within the range of values observed in other shallow subtidal mudflats adjacent to marshes. Gross production at both downstream stations was at the high end of previously reported range of production rates.

The concentrations of chlorophyll a (2-27 mg/m^2) in sediments at Poquoson Station 1 and Warwick Stations 3 and 6, all freshwater habitats, are low in comparison to data from a similar habitat in the James River (50 to 60 mg/m^2; Rizzo, personal communication). The observed concentrations fall at the low end of the range of chlorophyll concentrations reported for intertidal mud flats in brackish and saline water. Data for the mesohaline stations were comparable to data reported for similar subtidal habitats (Rizzo, 1977).

The tidal marsh communities observed in all three rivers were typical of streams of similar geomorphometry and salinity regime. None of the marshes had changed since marsh inventories were made a decade ago (Silberhorn, 1974; Moore, 1977, Silberhorn, unpublished survey).

The portions of the Poquoson and Warwick Rivers receiving alum discharges pass through marshes classified as brackish water mixed type 12. In the Warwick close to Route 60, the marsh vegetation grades into swamp/bottomland hardwood forest consisting of black gum, red maple, and sweet gum. These tree-dominated wetlands were judged to be only marginally tidal. Along the upper reach of Broad Creek, there are approximately 70 acres of predominantly type 12 tidal marsh.

In the Poquoson River, 26 taxa were collected at 10 stations. The most abundant taxa were amphipods, followed by polychaetes and oligochaetes. Faunal diversity was high with five amphipod, eight polychaete and two oligochaete species present. The fauna from the Poquoson River was composed almost entirely of marine species; only 5 of 26 taxa were of freshwater origin. The salinities at all stations were high enough to reduce the occurrence of freshwater species.

In the Warwick River, 13 benthic taxa were collected at 11 stations. The most abundant taxa were harpacticoid copepods, oligochaetes, and cladocerans. The species were freshwater forms with limited or no salt tolerance. In the reach of the Warwick River studied, the salinity at all stations was 0 °/oo.

In Broad Creek, 17 benthic taxa were collected at 15 stations. The fauna from Broad Creek was composed of salt-tolerant freshwater species and estuarine endemic species of marine origin. The most abundant taxa were oligochaete worms, followed by polychaete worms. The distribution of the fauna suggests that Stations 1, 2 and 3 are never exposed to salt water or exposed only for short intervals. From Station 4 to 10, an area where salinities are thought to fluctuate widely, the fauna included a mixture of freshwater and marine species, with oligochaetes numerically dominant. Stations 11 to 15 were characterized solely by estuarine species, suggesting that the salinity never drops below 5-8 °/oo in this reach of the creek.

A characteristic of fauna that inhabits transitional and fluctuating low salinity habitats is that they are very eurytopic and tolerant of extreme environmental conditions. These species may individually exhibit extremely high abundances when conditions favor. Freshwater and marine species which are more sensitive to fluctuations in their environment are excluded from these habitats.

The number and relative abundances of taxa were low at upstream stations in all three creeks, and with the exception of the Warwick River, increased as one progressed downstream. Given the nature of the habitats under consideration, the changes in number of taxa and relative abundance could result either from a deleterious effect of alum sludge or from the salinity distribution. In order to assess these alternative possibilities, the number of taxa and total abundance at each station in all three rivers were plotted against the Al:Si ratio at the sediment surface at each station and the salinity at the station (Fig. 3 and 4).

The number of species was low at all stations at which the salinity was below 15 °/oo, regardless of the Al:Si ratio. While no stations with Al:Si ratios greater than 0.6 had more than 3 species, several stations with Al:Si ratios less than 0.6 had 4 or less species present (Fig 3). The number of individuals was also generally low at salinities below 15 °/oo; a few stations in fresh or nearly fresh water had extremely high numbers of individuals, always of a single species (Fig 4). At several of these stations we observed high organic loading which favored a particular species; in some such cases, the fauna was reduced to that single species. This situation never occurred at stations with a high Al:Si ratio, but these stations were generally different in geomorphometry.

While species diversity and infaunal abundances were generally low, they were well within ranges reported for other low salinity fluctuation environments (Diaz, 1977; Tenore, 1972; Jordan, et al., 1976). While the evidence is not conclusive given the paucity of stations at which

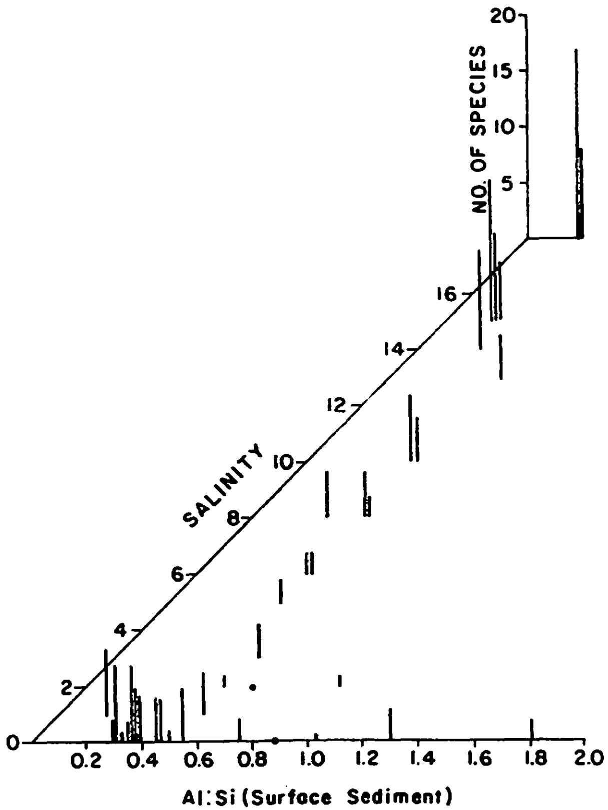
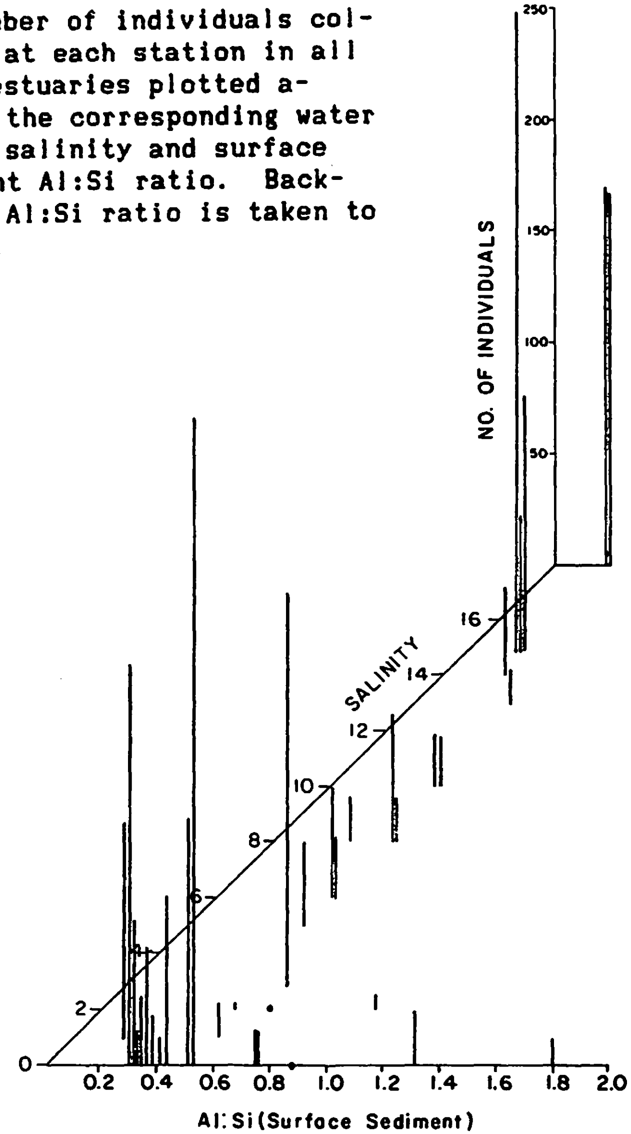


Figure 3 The number of species collected at each station in all three estuaries plotted against the corresponding water column salinity and surface sediment Al:Si ratio. Background Al:Si ratio is taken to be 0.2.

Figure 4 The number of individuals collected at each station in all three estuaries plotted against the corresponding water column salinity and surface sediment Al:Si ratio. Background Al:Si ratio is taken to be 0.2.



the Al:Si ratio at the sediment surface exceeded 0.5, there is little or no basis for alleging a severe negative impact of aluminum enrichment on the benthic invertebrate species diversity or abundance. In naturally physically stressed environments such as freshwater transition zones, detection of effects of additional stresses becomes nearly impossible (Roberts et al. 1975).

There was no evidence of an adverse effect from the alum sludge discharges except with regard to the primary producers. In this case, effects observed are attributed to increased suspended solids loads and light availability, and hence ultimately on the ability of the primary producers to form new biomass, rather than to any toxic effect. The effect on light availability probably exists nearly continuously in both the Warwick River and Broad Creek, and immediately following discharges in the Poquoson River. Marsh grass and benthic invertebrate communities show no evidence of any impact from alum sludge deposited on them.

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LITERATURE CITED

Blair, R.E., Jr., Doe, P.W. and Malmrose, P.E., "Water treatment plant waste disposal study for City of Norfolk, Virginia." 23 pp., 50th Annual Meeting of the Virginia Section of AWWA, Norfolk, Va., 21 October 1983.

Burnison, B.K., "Modified dimethyl sulfoxide (DMSO) extraction for chlorophyll analysis of phytoplankton," Canadian J. Fish. Aquat. Sci. Vol. 37, 729-733, 1980.

Burrows, W.D., "Aquatic Aluminum: Chemistry, toxicology, and environmental prevalence," CRC Critical Rev. Environ. Contr. Vol. 7, 167-216, 1977.

Diaz, R.J., The effects of pollution on benthic communities of the tidal James River, Virginia, PhD Dissertation, Univ. Virginia, Charlottesville, VA, 149 pp., 1977.

Diaz, R.J., and Roberts, M.H., Jr., "Present and historical environmental survey of Broad Creek, Norfolk, VA, with special reference to biotic communities and the effects of alum discharge," SRAMSOE No. 275, 46 pp., Virginia Institute of Marine Science, Gloucester Pt., VA, 1985.

Diaz, R.J., Roberts, M.H., Jr., Silberhorn, G.M. and Anderson, G.F., "Present and historical environmental survey of the Poquoson River, York County, Virginia and the Warwick River, Newport News, Virginia with special reference to biotic communities and the effects of alum discharge," SRAMSOE No. 276, 109 pp., Virginia Institute of Marine Science, Gloucester Pt., VA, 1985.

Flemer, D.A., "Primary production in the Chesapeake Bay," Chesapeake Sci., Vol. 11, 117-129, 1970.

Gallagher, J.L. and Daiber, F.C., "Primary production of edaphic algal communities in a Delaware salt marsh," Limnol. Oceanogr., Vol. 19, 390-395, 1974.

Jordan, R.A., Carpenter, R.K., Goodwin, P.A., Becher, C.G., Ho, M.S., Grant, G.C., Bryan, B.B., Merriner J.V. and Estes, A.D., "Ecological studies of the tidal segment of the James River encompassing Hogg Point," Spec. Sci. Rep. No. 78, 321 pp., Virginia Institute of Marine Science, Gloucester Point, VA, 1976.

Moore, K.M., "City of Newport News and Fort Eustis Tidal Marsh Inventory," SRAMSOE No. 137, 59 pp., Virginia Institute of Marine Science, Gloucester Pt., VA, 1977.

Rizzo, W.M., "The effects of chronic oil pollution on salt marsh periphyton," MS Thesis, College of William and Mary, Williamsburg, VA. 87 pp., 1977.

Roberts, M.H., Jr. and Diaz, R.J., "Assessing the effects of alum sludge discharges into coastal streams," Proceedings AWWA, (in press), 1986.

Roberts, M.H., Jr., Boesch, D.F. and Bender, M.E., "The Chesapeake Bay: A study of present and future water quality and its ecological effects. Vol. II. Analysis and Projection of Ecological Conditions," Final Report to the National Commission on Water Quality, 199 pp., 1975.

Silberhorn, G.M., "York County and Town of Poquoson Tidal Marsh Inventory," SRAMSOE No. 53. 67 pp., Virginia Institute of Marine Science, Gloucester Pt., VA, 1974 (reprinted 1981).

Strickland, J.D.H., "Measuring the production of marine phytoplankton," Fish. Res. Board, Can., Bull. No. 122, 172 pp., 1960.

Strickland, J.D.H. and Parsons, T.R., "A Practical Handbook of Seawater Analysis," Fish. Res. Board Can., Bull. No. 167, 310 pp., 1972.

Stross, R.G. and Stottlemyer, J.R., "Primary production in the Patuxent River," Chesapeake Sci., Vol. 6, 125-140, 1965.

Tenore, K.R., "Macrobenthos of the Pamlico River Estuary, North Carolina," Ecol. Monogr., Vol. 42, 51-59, 1972.