THE ONGOING AQUATIC MONITORING PROGRAM

FOR THE GUNSTON COVE AREA

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by

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INTRODUCTION

This section reports the results of the on-going aquatic monitoring program for Gunston Cove conducted by the Department of Biology at George Mason University and supported by the Department of Public Works of Fairfax County, Virginia. This study is a continuation of work originated in 1984 at the request of the County's Environmental Quality Advisory Committee and the Department of Public Works. The original study design utilized 12 stations in Gunston Cove, the Potomac mainstem, and Dogue Creek. Due to budget limitations and data indicating that spatial heterogeneity is not severe, the study has evolved such that only two sites are sampled, but the sampling frequency has been maintained at semimonthly during the growing season. This sampling regime provides reliable data given the temporal variability of biological communities and is a better match to other biological sampling programs on the tidal Potomac including those conducted by the Maryland Department of Natural Resources and the District of Columbia.

The 1984 report entitled "An Ecological Study of Gunston Cove - 1984" (Kelso et al. 1985) contained a thorough discussion of the history and geography of the cove. The reader is referred to that document for further details.

This work's primary objective is to determine the status of biological communities and the physico-chemical environment in the Gunston Cove area of the tidal Potomac River for evaluation of long-term trends. This will facilitate the formulation of well-grounded management strategies for maintenance and improvement of water quality and biotic resources in the tidal Potomac. Important byproducts of this effort are the opportunities for faculty research and student training which are integral to the educational programs at GMU.

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METHODS

A. Profiles and Plankton: Sampling Day

Sampling was conducted on a semimonthly basis at stations representing both Gunston Cove and the Potomac mainstem (Figure 1). A change in station coverage was implemented in July when Station 10 in Pohick Bay was dropped for budgetary reasons. The two remaining sample sites were located at the center of Gunston Cove (Station 7) and in the Potomac channel off the Belvoir Peninsula just north of the mouth of Gunston Cove (Station 9). Dates for sampling as well as weather conditions on sampling dates and immediately preceding days are shown in Table 1.

Sampling was initiated at 8-9 am on each visit. While this results in differences in tide stage on sampling dates, the two stations at which sampling is conducted are not expected to show substantial variation as a function of tide stage. Four types of measurements or samples were obtained at each station : (1) depth profiles of temperature, conductivity, and dissolved oxygen measured directly in the field; (2) water samples for determination of pH, total alkalinity, chlorophyll a, photosynthetic rate, and phytoplankton species composition and abundance; (3) water samples for determination of nutrients, BOD, alkalinity, suspended solids, chloride, and pH by NMC Laboratory; (4) net sampling of zooplankton and ichthyoplankton.

Profiles of temperature, conductivity, and dissolved oxygen were conducted at each station using YSI Model 58 dissolved oxygen-temperature meter and YSI Model 33 salinity-conductivity-temperature meter. Measurements were taken at 0.3 m, 1.0 m, 1.5 m, and 2.0 m in the cove. In the river measurements were made at depths reached by playing out rope to nominal depths of 0.3 m, 2 m, 4 m, 6 m, 8 m, 10 m, and 12 m. Despite being strongly weighted the line was often deflected by the tidal currents so that the actual depths of measurement were shallower. Meters were checked for calibration before and often during sampling.

A 2-liter depth-composited sample was constructed from equal volumes of water collected at each of three depths (0.3 m, middepth, and 0.3 m off bottom) using a submersible bilge pump. A 100-mL aliquot of this sample was preserved immediately with acid Lugol's iodine for later identification and enumeration. Another aliquot was used to measure field pH using Hach phenol red and thymol blue test kits. The remainder of the sample was placed in an insulated cooler filled with river water to maintain *in situ* temperature until return to the lab. A 1-liter sample was collected from 0.3 m using the submersible bilge pump and placed in the insulated cooler for lab analysis of surface chlorophyll a. A 4-liter sample was collected monthly from surface (0.3 m) and bottom (0.3 m off bottom) at each site using the submersible pump for determination of nutrients and other parameters by NMC Laboratory.

Microzooplankton was collected by pumping 32 liters from each of three depths (0.3 m, middepth, and 0.3 m off the bottom) through a 44 µm mesh sieve. The sieve consisted of a 12-inch piece of 6-inch diameter PVC pipe with a piece of 0.44 µm nitex net glued to one end. The 0.44 µm cloth was backed by a larger mesh cloth to protect it. The pumped water was passed through this sieve from each depth and then the collected macrozooplakton was backflushed into

the sample bottle. The resulting sample was preserved with formalin containing a small amount of rose bengal to a concentration of 5-10%.

Macrozooplankton were collected by towing a 202 µm net for 1 minute at each of three depths (near surface, middepth, and near bottom). Ichthyoplankton were sampled by towing a 333 µm net for 2 minute at each of the same depths. Each net was about 2 meters long with a 0.3 m (macrozooplankton) or 0.5 m (ichthyoplankton) opening into which a General Oceanics flowmeter was fitted. The depths were established by playing out rope equivalent to about twice the desired depth. Samples which had obviously scraped bottom were discarded and tow was repeated. Flowmeter readings taken before and after towing allowed precise determination of the distance towed which when multiplied by the area of the opening produced the volume of water filtered. Macrozooplanton and ichthyoplankton were preserved immediately with formalin to a concentration of 5-10%. Rose bengal formalin was used for macrozooplankton, but not for ichthyoplankton. Macrozooplankton were collected on each sampling trip; ichthyoplankton collections ended after July because larval fish were normally not found after this time.

Samples were delivered to NMC Laboratory by 1 pm on sampling day and returned to GMU by 2 pm. At GMU 10-15 mL aliquots of both depth-integrated and surface samples were filtered through 0.45 µm membrane filters (Gelman GN-6) at a vacuum of less than 10 lbs/in^2. During the final phases of filtration, 0.1 mL of $MgCO_3$ suspension (1 g/100 mL water) was added to the filter to prevent premature acidification. Filters were stored in 20 mL plastic scintillation vials in the lab freezer for later analysis. Seston dry weight and seston organic weight were measured by filtering 200-400 mL of depth-integrated sample through a pretared glass fiber filter (Whatman 984AH).

Photosynthetic rate was determined on the sample date by adding 100 µL of ^{14}C-labeled sodium bicarbonate (20 µCi/mL) to 50 mL of water from the depth-integrated sample. The 50 mL aliquot was split into two 20 mL glass scintillation vials that were placed at two light levels and incubated at river ambient temperature in a controlled temperature water bath. A total of four light levels, provided by a 1000 watt high pressure sodium bulb (Ceramalux), were used corresponding to roughly 1200, 600, 100, and 50 $\mu moles/m^2/sec$ of photons. (Full sun in summer is about 2000 $\mu moles/m^2/sec$). Following a 1 hr incubation, 15-mL of vial contents were filtered through a 0.45 µm membrane filter (Gelman GN-6). Filters were frozen for later analysis.

pH and alkalinity were determined on 100 mL aliquots of the depth-integrated sample. pH was measured with a Hach EC-30 lab pH meter calibrated to 7 and 10. Alkalinity was determined by titration with 0.02 N H_2SO_4 to a pH of 4.6 (Standard Methods 1980). Acid titrant was calibrated with standard $NaCO_3$.

Sampling day activities were normally completed by 5:30 pm.

B. Profiles and Plankton: Followup Analyses

Chlorophyll samples were extracted in a ground glass tissue grinder to which 4 mL dimethyl sulfoxide (DMSO) was added. The filter disintegrated in the DMSO and was ground for about 1 minute by rotating the grinder under moderate hand pressure. The ground suspension was transferred back to its scintillation vial by rinsing with 90% acetone. Ground samples were stored in the refrigerator overnight. Samples were removed from the refrigerator and centrifuged for 5 minute to remove residual particulates.

Chlorophyll concentration in the extracts were determined fluorometrically using a Turner Desings Model 10 field fluorometer set up as specified by the manufacturer for chlorophyll analysis. The instrument was calibrated using standards obtained from Turner Designs. Fluorescence was determined before and after acidification with 2 drops of 10% HCl. Chlorophyll a was calculated from the following equation which corrects for pheophytin interference:

Chlorophyll a (ug/L) = $F_s R_s (R_b - R_a)/(R_s - 1)$

where F_s=concentration per unit fluorescence for pure chlorophyll
R_s=fluorescence before acid /fluorescence after acid for pure chlorophyll
R_b=fluorescence of sample before acid
R_a=fluorescence of sample after acid

All chlorophyll analyses were completed with one month of sample collection.

To determine radiocarbon uptake, frozen filters were first placed in concentrated HCl fumes for 10 minutes to drive off residual inorganic carbon. Then, each filter was placed in a scintillation vial and scintillation cocktail was added. Vials were counted for 10 minutes each in a Packard Tricarb 2100TR liquid scintillation counter and corrected for efficiency by the external standard ratio method. Photosynthetic rate was determined from the following equation:

$$PhotosyntheticRate(mgC/L/hr) = \frac{(DPM)(ALK)(CF)(1.06)}{(DPMwat)(TIME)}$$

where DPM=^{14}C activity on filter (algae), (DPM/L)
ALK=Total alkalinity, (mg/L as $CaCO_3$)
CF=conversion factor from total alkalinity to dissolved inorganic carbon (Wetzel and Likens 1991)
DPMwat=^{14}C activity in incubation water (DPM/L)
1.06=isotopic discrimination factor
TIME=incubation time, (hr)

Phytoplankton species composition and abundance was determined using the inverted microscope-settling chamber technique (Lund et al. 1958). Ten milliliters of well-mixed algal sample were added to a settling chamber and allowed to stand for several hours. The chamber

was then placed on an inverted microscope and random fields were enumerated. At least two hundred cells were identified to species and enumerated. Counts were converted to number per mL by dividing number counted by the volume counted.

Microzooplankton and macrozooplankton samples were rinsed by sieving a well-mixed subsample of known volume and resuspending it in tap water. This allowed subsample volume to be adjusted to obtain an appropriate number of organisms for counting and for formalin preservative to be purged to avoid fume inhalation during counting. A one mL subsample was placed in a Sedgewick-Rafter counting cell and whole slides were analyzed until at least 200 animals had been identified and enumerated. A minimum of two slides was examined for each sample. References for identification were: Ward and Whipple (1959), Pennak (1978), and Rutner-Kolisko (1974). Zooplankton counts were converted to number per liter with the following formula:

$$Zooplankton = \frac{(N)(V_s)}{(V_c)(V_f)}$$

where N=number of individuals counted
V_s=volume of reconstituted sample, (mL)
V_c=volume of reconstituted sample counted sample counted, (mL)
V_f=volume of water sieved, (L), normally 96 L

Ichthyoplankton samples were sieved through a 333 um sieve to remove formalin and reconstituted in ethanol. Larval fish were picked from the reconstituted sample with the aid of a stereo dissecting microscope. Identification of ichthyoplankton was made to family and further to genus and species where possible. If the number of animals in the sample exceeded several hundred, then the sample was split with a plankton splitter and resulting counts were multiplied by the subsampling factor. The works of Hogue et al. (1976), Jones et al (1978), Lippson and Moran (1974), and Mansueti and Hardy (1967) were used for identification. The number of ichthyoplankton in each sample was expressed as number per 10 m3 using the following formula:

$$Ichthyoplankton = \frac{(N)(10)}{V}$$

where N=number of ichthyoplankton in the sample
V=volume of water filtered, (m^3)

C. Adult and Juvenile Finfish

Fishes were sampled by trawling at Stations 7, 9, and 10 (Figure 1). A try-net bottom trawl with a 15-foot horizontal opening, a 3/4 inch square body mesh and a 1/4 inch square cod

end mesh was used. The otter boards were 12 inches by 24 inches. Towing speed was 2-3 miles per hour and tow length was 5 minutes. In general, the trawl was towed across the axis of the cove at Stations 7 and 10 and parallel to the channel at Station 9, but most tows curved up to 90^{o} from the initial heading and many turned enough to head in the opposite direction. The direction of tow should not be crucial. Dates of sampling and weather conditions are found in Table 1.

Shoreline fishes were sampled by seining at 3 stations: 4, 6, and 11 (Figure 1). The seine was 45-50 feet long, 4 feet high and made of knotted nylon with a 1/4 inch square mesh. The seining procedure was standardized as much as possible. The net was stretched out perpendicular to the shore with the shore end in water no more than a few inches deep. The net was then pulled parallel to the shore for a distance of 100 feet by a worker at each end moving at a slow walk. At the end of the prescribed distance the offshore end of the net was swung in an arc to the shore and the net pulled up on the beach to trap the fish. Dates for seine sampling were the same as those for trawl sampling.

After the net (trawl or seine) was hauled in, the fishes were measured for standard length to the nearest 0.5 cm. Standard length is the distance from the front tip of the head to the end of the vertebral column and base of the caudal fin. This is evident in a crease perpendicular to the axis of the body when the caudal fin is pulled to the side.

If the identification of the fish was not certain in the field, the specimen was preserved in 10% formalin and identified later in the lab. Identification was based on characters in dichotomous keys found in several books and articles, including Jenkins and Burkhead (1994), Hildebrand and Schroeder (1928), Loos et al. (1972), Dahlberg (1975), Scott and Crossman (1973), Bigelow and Schroeder (1953), and Eddy and Underhill (1978).

D. Macrobenthos

Macrobenthos was sampled at Stations 7 and 9 on October 27. A ponar grab was used to collect three replicate samples at Station 9 and an Ekman grab was used to collect for triplicate sampling of sediments at Station 7. Contents of the grab were sieved through a 0.5 mm stainless steel sieve in the field and the resulting animals and detritus were preserved in 5-10% formalin with rose bengal for later analysis. In the lab the formalin was rinsed from the samples and the entire sample was picked. Macroinvertebrates were identified and enumerated in each replicate. Keys for identification included Pennack (1978), Thorp and Covich (1991), and Merritt and Cummins (1984).

RESULTS

A. Climate and Hydrological Parameters

Air temperatures were near normal for most of the year (Table 2). The exceptions were June, which was 1.6^{o}C below normal, and September, which was 2.3^{o}C above normal. Maximum temperatures above 90^{o}F were observed on 32 days, evenly distributed among July, August, and September. The distribution of precipitation in 1998 was very unusual. The usual pattern in the Washington, D.C. area is for roughly equal amounts of precipitation (about 7-10 cm) to be observed each month. However, in 1998 over 70 cm of rain fell in the first six months of the year, while only 18.8 cm were recorded from July through December. The driest months were August and October when only 1.5 cm (0.6 in) were observed.

Stream flow followed a typical pattern of highest flows in spring with a general decline throughout the summer and in to the fall. This pattern was enhanced by the sharp difference in spring-early summer vs. late summer-fall precipitation. Potomac River flow from March through early July was generally above average while flows later in the year were below average (Figure 2). Flows were generally above 20,000 cfs in the spring, but never exceeded 10,000 cfs after late June. Mean flows in August and September were less than half the long-term average (1930-58). Accotink Creek exhibited a typical pattern of rapid response to rainfall events with sharp peaks, but a decline to seasonal base flow within a few days (Figure 2). Seasonal base flow was about 20 cfs in March and early April, declining slightly to 10 cfs by late May, and then to less than 1 cfs by early September. Mean flows for July-September were 25-50% of the long-term mean.

B. Physico-chemical Parameters: Embayment and River Stations

Water temperatures increased steadily from about 10^{o}C in late March to nearly 25^{o}C in late May across the study area (Figure 3). Temperatures remained between 24 and 29^{o}C over the entire study area from late May through early October. During October water temperature declined sharply to about 10^{o}C in November and December. Conductivity was relatively low in the spring and early summer with values typically 100-300 uS/cm in the cove and river (Figure 3). Slightly higher values were found in Pohick Bay. During August conductivity began a steady increase throughout the study area culminating in values above 600 uS/cm by December.

Dissolved oxygen was highest during the cooler months and during late summer when values above 10 mg/L were typical (Figure 4). For most of the year values were near saturation (80-120%). The exception was from mid July through September when dissolved oxygen was highly supersaturated (>140%) in the cove resulting most probably from photosynthetic activity by phytoplankton. The same pattern was observed in the river to a more modest extent.

pH was typically 7-8.5 in the study area (Figure 5). In the cove values above 9 were found in late summer and fall. pH values in the river varied over a narrower range and never exceeded 9. Total alkalinity was generally in the range 40-70 mg/L as $CaCO_3$ in the cove and somewhat higher in the river (Figure 6, 7). Values below this range were observed in late June, late September, and early October. Values above this range were noted in November and

December. Chloride demonstrated a strong upward trend during the second half of 1998 (Figure 7). Values below 30 mg/L were typical the first half of the year followed by a steady increase to nearly 100 mg/L by December.

Light transparency as revealed by Secchi disk readings (Figure 8) was quite low in March, but increased markedly by early April in the cove. This was followed by a period of rather constant readings through late September in the range 40-60 cm. Transparency was generally higher in the river with readings typically 55 to 75 throughout the summer. The one exception to this pattern was late July when Secchi depth reached 79 cm in the cove and 86 cm in the river. Transparency as measured by extinction coefficient demonstrated some similar patterns. Low transparency in March was followed by period of relatively constant light extinction through early August. A drastic decrease in light penetration in early August was followed by a steady increase in penetration through December.

Ammonia nitrogen was highest in Pohick Bay, intermediate in Gunston Cove and lowest in the Potomac mainstem (Figure 9). Ammonia nitrogen was generally above 2 mg/L in Pohick Bay, 0-1 mg/L in Gunston Cove and lower in the river. The method used in 1998 had a detection limit of 0.10 mg/L; several cove readings and almost all mainstem samples were reported as below this value. Un-ionized ammonia nitrogen was less than 0.1 mg/L for all samples with detectable ammonia nitrogen readings (Figure 9). Values were similar in the cove and Pohick Bay.

Nitrate nitrogen remained below 1 mg/L throughout the study region through mid-July (Figure 10). In the late summer and fall values rose steadily reaching about 2 mg/L in December. Values in the river mainstem were consistently higher by about 0.5 mg/L than those in Gunston Cove. Nitrite nitrogen was highest in Pohick Bay, followed by the cove and then the river mainstem (Figure 10). Values in the cove were generally 0.1-0.2 mg/L whereas in the river values were consistently less than 0.1 mg/L. Organic nitrogen was not available for many samples since this is derived from total kjeldahl nitrogen and ammonia nitrogen and numerous ammonia nitrogen values were below detection limits (Figure 11). Values were generally in the range 0.5-1.5 mg/L in the cove.

Almost all measurements of soluble reactive phosphorus (SRP) were below the detection limit of 0.05 mg/L. This is not surprising given past results in which SRP consistently fell in the range 0.01-0.05 mg/L at all sites. Total phosphorus was generally elevated in summer relative to spring and fall (Figure 11). An exception was observed in March which had the highest values of the year in the cove and river. Values averaged about 0.06 mg/L in spring and fall and 0.10 mg/L in midsummer. There was not a consistent difference between cove and river.

N:P ratio showed a tendency to increase through the year (Figure 12). This trend was most consistent in the river with a gradual climb from less than 10 in the spring to nearly 100 by fall. In the cove the pattern was similar with more variation.

Biochemical oxygen demand (BOD) exhibited both seasonal and spatial patterns (Figure 12). The seasonal pattern resulted from increasing levels during spring reaching a peak in both areas in late August. A steady decline was found through the remainder of the year. The spatial

pattern was consistently higher BOD in the cove by about 2-3 mg/L so that the maximum in the cove was 8 mg/L and in the river 5 mg/L.

Total suspended solids (TSS) was generally 10-30 mg/L at all sites (Figure 13). Very little difference was observed among sites. TSS was slightly higher in March. Volatile suspended solids followed clear seasonal and spatial patterns (Figure 13). After the high values in March VSS declined and then gradually increased through the summer and early fall reach maxima in both river and cove in September before declining through December. Cove values were consistently greater than observed in the river with a maximum of 16 mg/L in the cove and 8 mg/L in the river.

C. Phytoplankton

Chlorophyll levels increased markedly between late March and early April (Figure 14). Then they remained relatively constant through July. In August and September chlorophyll reached a maximum and then dropped off for the remainder of the year. Maximum values observed in the cove were about 140 µg/L whereas 75 µg/L was the top in the river. A rather marked decline was observed in late June at all sites. Pohick Bay levels were similar to those observed in the cove.

Seasonal patterns in photosynthetic rates were similar, but not identical to those in chlorophyll (Figure 15). Photosynthetic rate increased gradually from March through mid-July and then increased dramatically during August and early September. Values declined in late September. Photosynthetic rate per unit chlorophyll demonstrates that the major cause of the jump in August and early September was a clear increase in photosynthetic rate per unit chlorophyll and not increased chlorophyll. These readings corresponded to a change in the volume of ^{14}C used for photosynthetic rate measurement.

Phytoplankton cell density (number of cells per mL) showed a pattern of gradual increase from March through early June (Figure 16). A decline was observed in late June followed by a rapid increase through early September. Phytoplankton density peaked at almost 7 million cells/mL in the cove and about 1.5 million cells/mL in the river. Phytoplankton biovolume (μm^3/mL), which incorporates both abundance and size of individual cells, showed a somewhat different seasonal pattern (Figure 16). In the cove values showed a less consistent spring increase to a peak in early June. A marked decline in late June was followed by a rebound in early July and a gradual rise through early September. The early June and early September peaks were similar in magnitude as measured by biovolume though the densities were quite different. In the river biovolume did not exhibit the early June peak, but did show a late summer maximum in early August. However, the highest value of the year was actually observed in November.

Phytoplankton densities in both river and cove were overwhelmingly dominated by the small-celled cyanobacteria for the majority of the year (Figure 17). The only time that this was not the case was in spring in the cove and spring and early summer in the river. Dominant taxa in terms of cell density varied seasonally and spatially. In June *Chroococcus* and *Oscillatoria* were the dominants in the cove (Figure 18). In early July *Merismopedia* and *Microcystis incerta* were

most common. *Microcystis aeruginosa*, *Aphanocapsa*, and *Merismopedia* dominated for the remainder of the summer and fall. *Microcystis aeruginosa* reached 1 million cells/mL, declined in late August, but rebounded in early September to about 2 million cells/mL. In the river *Aphanocapsa* was dominant for most of the summer (Figure 18). *Microcystis aeruginosa* was dominant in early September attaining a maximum of 400,000 cells/mL.

Phytoplankton biovolume was more evenly distributed among major taxa than was cell density (Figure 19). In the cove diatoms were most important in spring and early summer. Cyanobacteria became more important in late July and continued to dominate biovolume through September. Green algae was important at some times, but never dominant. In the river diatoms dominanted the entire year with the possible exception of early September when cyanobacteria were codominant and late September when cyanobacteria and greens were codominant.

In the cove *Melosira* was the most important diatom the entire year (Figure 20). The centric diatoms *Coscinodiscus* and *Cyclotella* were briefly abundant, but never dominant. The green alga *Actinastrum*, the cryptophyte *Cryptomonas*, and the euglenoid *Euglena* were the most abundant taxa in the other groups. In the river *Melosira* was again dominant for the entire year except in early April when *Cyclotella* was dominant. The large November peak in biovolume in the river was attributable to *Melosira*.

In terms of cyanobacteria in the cove, *Oscillatoria* was dominant in spring and codominant most of the summer with *Microcystis* (Figure 21). *Anabaena* and *Chroococcus* were important at times during the summer. In the river *Oscillatoria* was the main summer dominant with a substantial contribution from *Microcystis* in early September.

D. Zooplankton

Rotifers increased markedly during April in the cove reaching over 2000/L in early May (Figure 22). A decline in late May was followed by another increase in early June to nearly 3000/L. A second decline was observed in early July followed by a return to high levels through early October. Spring dominants were *Polyarthra* in early May, *Keratella* in early June, *Brachionus* in late July and August as well as in October. During September a diverse rotifer assemblage of *Brachionus, Filinia, Keratella,* and *Polyarthra* was found.

In the river rotifers increased more slowly (Figure 22). An early June maximum was followed by a decline in late June and then a buildup to over 2000/L by early October. Dominance patterns were a little different with *Brachionus* dominant in early June and joined by *Keratella* in July. In August and September a diverse assemblage including Conochilidae, *Keratella,* and *Polyarthra* shared dominance.

Bosmina exhibited very different temporal patterns in the two areas (Figure 23). In the cove there was a distinct increase in the population over the spring and early summer months reaching a peak of 200/L in late June. A precipitous decline to low levels occurred by early July. In the river *Bosmina* took much longer to get started, but was more persistent. The maximum was observed in early August at 160/L, but remained above 50/L through November.

In the cove *Diaphanosoma* exhibited two population maxima, one in early June and the other in late August (Figure 23). The early summer peak was nearly 35,000/m^3, while the late August peak was lower at about 12,000/m^3. In the river *Diaphanosoma* showed one peak in late July at about 10,000/m^3. While much less abundant, *Daphnia* was present in appreciable numbers during spring and early summer peaking at about 600/m^3 in late May in the cove and mid July in the river.

Ceriodaphnia and *Moina* were both quite scarce in 1998 (Figure 24). *Ceriodaphnia* did not exceed 200/L in the cove and 400/L in the river. *Moina* was less than 200/L at both sites. *Leptodora* found only on a few days and peaked at less than 80/L in the cove (Figure 24). *Leptodora* was somwhat more common in the river attaining 400/l in early August.

Copepod nauplii were most common in the cove in June and early September at about 200/L (Figure 25). In the river values peaked at 500/L in early July. The calanoid copepod *Eurytemora* peaked briefly in the cove in late May at nearly 25,000/m^3 and again in late August at 7500/m^3 (Figure 25). In the river moderate levels of about 4000/m^3 in the summer gave way to a strong fall and winter buildup to nearly 30,000/m^3 in December. *Diaptomus*, another calanoid, exhibited two brief peaks: one in late May at 1400/m^3 and another in late August at about 600/m^3 (Figure 26). *Diaptomus* was rare in the river. Other calanoids attained brief peaks in both river and cove of several thousand per m^3 (Figure 26). Cyclopoids were very abundant in the river in mid-July and September reaching nearly 20,000/m^3 (Figure 26). In the cove cyclopoids were less abundant reaching a maximum of 5000/m^3 in late August.

E. Ichthyoplankton

Collections of larval fishes were begun on March 26 at three stations (Stations 7, 9, and 10) and continued twice each month through July. The fish taxa that were collected and their abundance are shown in Table 4. Larvae of at least seven species were taken, and probably at least one more which was not distinguishable from one of the previous species. The river herrings, blueback herring and alewife, were once again dominant, accounting for 74.1% of the total. The two species are not usually definitely distinguishable from each other, so their numbers are combined. White perch were second in abundance at 14.2% of the total. Gizzard shad were third with 11.0% of the total. The other species represented less than 1% of the total, even when combined.

The mean numbers of river herring, gizzard shad, white perch and yellow perch larvae per 10m^3 on each collection date for all stations combined are shown in Figure 27. The river herring (*Alosa* sp.), gizzard shad, and white perch all appeared on April 9. The river herring density remained low until May 21, when they reached peak densities of 115 larvae/10m^3. They remained abundant through June 4, after which they evidently became able to evade the ichthyoplankton net. Gizzard shad densities rose slightly to 13 larvae/10m^3 on May 7, then fell to low catch numbers. White perch densities were highest on May 21, but remained high through June 4.

The densities of the three most numerous taxa groups were all greatest at Station 9 in the river. The densities at Station 7 were less than half as dense, and those at Station 10 were even

lower, except for white perch, which were slightly more dense at Station 10 than they were at Station 7.

F. Adult and juvenile fishes

Trawls

Trawls began on March 27 and continued through December 4 for a total of 16 sampling days at three stations (Stations 7, 9, and 10). The total numbers of each species collected are shown in Table 5. A grand total of 3016 individuals of 23 species were caught in 48 trawls. White perch remained the most abundant species (74.6% of the total), followed by spottail shiner (7.2%), bay anchovy (4.1%), channel catfish (3.3%), tessellated darter (2.4%), blueback herring (2.3%), pumpkinseed (1.8%), brown bullhead (1.2%), alewife (0.6%), and gizzard shad (0.6). These ten species accounted for 98.1% of the total.

The numbers of individuals of each species that were collected on each sampling date are shown in Table 6. As in most previous years, the abundance of white perch dominate the seasonal changes of the other species (Figure 28). White perch were numerous in the trawls from June 19 until late August or even early October. As usual, bay anchovy were present in numbers only during the early fall and yellow perch only during the spring, but many other species show little seasonal differences in abundance.

The numbers of individuals of each species that were collected at each station are shown in Table 7. Eighteen species were taken at Stations 7 and 10, but only ten were caught at Station 9. White perch were dominant in numbers at all three stations, but especially so at Station 7, where they were 85.3% of the total catch. At Station 10 they were 67% of the total, and at Station 9 they were 57.8% of the total. A similar pattern of distribution is seen when the percentages of white perch caught at the three stations are compared. Station 7 produced 53.6% of all white perch, Station 10 37.3% of the total, and Station 9 only 9.1%. The catch of non-white perch species was highest at Station 10 (413 individuals, almost half of which were spottail shiner), followed by Station 7 (208 individuals, almost half of which were bay anchovy and spottail shiner), and Station 9 (149 individuals, two-thirds of which were channel catfish). The mean catch per trawl was 88.3 at Station 7, 22.1 at Station 9, and 78.1 at Station 10 (Figure 28 bottom). Almost all of the herrings (clupeids) and minnows (cyprinids) and sunfishes (centrarchids) were collected within Gunston Cove at Stations 7 or 10. On the other hand, almost all of the channel catfishes and hogchokers were caught in the river at Station 9.

The mean numbers of individuals per trawl in each month for selected abundant species are shown in Figure 28 (top). The mean numbers of individuals per trawl at each station of the six selected species are shown in Figure 28 (bottom).

Seines

Collections of fishes were made with seines at three sites in Gunston Cove (Stations 4, 6, and 11. Collections were begun on March 27 and continued through December. Representatives

of 27 species were collected by 48 seine hauls. The total numbers of individuals of each species that were caught are presented in Table 8. The most abundant species was once again banded killifish (28.2% of the total), followed by spottail shiner (23.2%), white perch (20.0%), inland silverside (7.8%), and eastern mosquito fishes (5.4%). These five species accounted for 84.6% of the total.

The numbers of individuals of each species caught on each collection date are shown in Table 9. The abundance of the three most numerous species was highest during the summer, which was the pattern of almost all species. Banded killifish increased in early May and declined after early August, spottail shiner increased in mid to late June and declined in early August, and white perch increased in mid to late June and declined in mid to late August.

The numbers of individuals of each species caught at each station are shown in Table 10. The numbers of species caught at Stations 4, 6 and 11 were 22, 19, and 15, respectively. The mean catch per seine was highest at Station 4 (165.4 individuals), second at Station 6 (115.0 individuals), and lowest at Station 11 (54.4 individuals). Of the three dominant species, both spottail shiner and white perch followed a similar catch pattern, but banded killifish were most abundant at Station 6, intermediate in abundance at Station 4 and least abundant at Station 11. On the other hand, alewife, gizzard shad, bay anchovy, and striped bass were most numerous at Station 11.

The mean numbers of individuals per seine in each month for selected abundant species are shown in figure 29 (top). The mean numbers of individuals per seine at each station of the same six abundant species are shown in Figure 29 (bottom).

G. Macrobenthos

Oligochaetes were found in roughly equal abundances of about $3500/m^2$ in the river and cove (Figure 30). Chironomids were the second most abundant group in the cove with about $700/m^2$. Other groups found in the cove were spheriid clams and small numbers of chaoborid (phantom midge) larvae and amphipods. Some caddisfly cases, but no living caddisflies were found in the cove. The river hosted a wider range of other taxa. Amphipods were the most abundant group at over $9000/m^2$. Flatworms were quite abundant ($1651/m^2$) as were chironomids ($700/m^2$). A variety of other groups were also observed in the river including isopods, the asiatic clam *Corbicula*, spheriid clams, gastropods (snails), caddisflies, riffle beetles, and fly larvae.

DISCUSSION

A. Climatic and Hydrological Factors

The year 1998 was characterized by a very wet first half and a very dry second half. This was probably the most distinct seasonal shift in rainfall pattern experienced since this study began. Stream and river flows reflected this abrupt shift in precipitation. River and creek flows and subsequent flushing were high in the spring, but declined to low values in the summer. In the river spring flows were similar to a high flow year (1996) whereas summer flows were similar to a low flow year (1997). Temperatures showed a near normal seasonal pattern. August was slightly warmer than July; the opposite is usually the case. And warm temperatures carried into September to a greater degree than normal. As of February 1998, sunshine data were no longer collected at National Airport. We were unaware of this until the writing of this report. We have now initiated collection of our own solar radiation data as of July 1999.

B. Physico-chemical Parameters: Embayment and River Stations

As in previous years dissolved oxygen (Figure 31) was normally near saturation in the cove (Station 7 data only). However, supersaturated oxygen was observed more frequently in 1998 than in previous years with about 40% of all readings above 120% saturation. The incidence of subsaturated readings likewise declined. Possible explanations for this phenomenon include enhanced photosynthetic activity and/or sampling later in the day. The first explanation seems most likely as sampling time has changed little. Another possible explanation is the fact that values from Station 10 were used in previous analyses, whereas these were not used for 1998 since they were available for only a portion of the year. A similar pattern was also observed in the river where no change in stations was made this year.

pH values in the cove (GMU data) were centered on 8-9 in 1998 compared with 7-8.5 historically (Figure 32). pH reported by LPL peaked in the 9-9.5 range which was higher than normally observed in that data set (Figure 33). These results also suggest higher than normal photosynthetic activity. In the river a similar pattern was observed with the majority of values in the 8-8.5 range, similar to 1997, but generally higher than in previous years. LPL river data were also shifted slightly to higher values in 1998.

Ammonia nitrogen levels were generally lower than observed in past years with almost 90% of all readings being less than 1.0 mg/L (Figure 34). This probably reflected mostly the dropping of Station 10 since readings at that site were typically above 1.0 mg/L and those at Station 7 were typically less. Flushing by low ammonia stream and river flow could also be a factor. As in past years the river exhibited very few values above 1.0 mg/L in ammonia nitrogen. Un-ionized ammonia was generally very low compared with recent years partially, but not completely, due to the dropping of Station 10.

Nitrate nitrogen in the cove showed a greater incidence of values below 1 mg/L than in past years (Figure 35). In the river this was also true with over half of all readings less than 1 mg/L. This was mainly due to low values observed in the spring when river and creek flows were

high and could be attributable to high rates of flushing by low nitrate runoff. Nitrite values were typical of past years. Organic nitrogen levels were shifted somewhat higher than in recent years, although the very high readings found in the 1980's were not repeated (Figure 36). This was principally due to somewhat higher values in spring and fall rather than in summer. Organic nitrogen levels in the river were typical of past years.

Total phosphorus continued to be generally lower in 1998 than in the 1980's and early 1990's (Figure 37). Almost 80% of cove total phosphorus readings were less than 0.1 mg/L in 1998 as compared with about half in the earlier periods. A similar pattern was found in the river. Total phosphorus did not display a strong seasonal pattern in 1998 as it had in many previous years. Trends in SRP could not be identified since almost all data was below the detection limit of 0.05 mg/L.

As in previous years N:P ratio was generally greater than 20 indicating a phosphorus limited system (Figure 38). Only about 15% of readings were less than 20 in the cove whereas this was true for about 35% of river values. The seasonal pattern of N:P was different than observed in previous years. In 1998 minimum N:P occurred in March and then values gradually increased. In most previous years N:P gradually declined through spring and summer reaching a minimum in August of September. This phenomenon was associated with a gradual decline in N values as the summer progressed which was not observed in 1998 perhaps due to the high sustained spring/early summer flows. These high flows diluted N in the spring; when flows abated in the summer N concentrations increased.

In 1998 BOD showed a fairly typical seasonal pattern in the cove with higher values in the summer (Figure 39). BOD continues to be lower than in past years with over 80% of BOD values in the range 2-8 mg/L and very few readings above 8 mg/L. The river showed a similar pattern with a high incidence of even lower values. As in 1997 TSS showed little seasonal pattern, but VSS was strongly seasonal with highest values in August and September.

C. Phytoplankton

Chlorophyll a levels were shifted higher in 1998 as compared with 1996 and 1997 in both river and cove (Figure 40). Maximum values in the cove in 1998 were nearly 140 µg/L compared with about 90 µg/L in 1997. In the river a maximum of 70 µg/L was found in 1998 compared with 50 µg/L in 1997. Chlorophyll followed a fairly typical seasonal pattern with a maximum in early September. Unusually strong spring and early summer growth was interrupted in late June by a marked decline. This was observed in the aftermath of high flows in both creek and river and was probably due to flushing of algae from the system.

As in 1997 phytoplankton cell density continued to be high in 1998 as compared with most previous years (Figure 41). This was particularly true in late summer and fall. This effect was largely due to increases in very small cyanobacteria in the cove. One possible explanation is that the average cell size has decreased and therefore more cells are observed even though the total amount of chlorophyll remains unchanged. This is consistent with the observation that nutrient concentrations have decreased; lower nutrient levels favour smaller algal cells. Other

possibilities included lower chlorophyll content per cell and changes in the lower size cutoff for counting cells.

As in previous years cyanobacteria dominated cell density data. *Microcystis* was much more prevalent in 1998 than in most recent years. *Oscillatoria* and *Merismopedia* were less dominant than in recent years. *Aphanocapsa* was more important in the river than in 1997.

Diatoms dominated cove biovolume in the spring and remained important throughout the year. As in most years *Melosira* was the dominant diatom in 1998. It was found in robust numbers throughout the year and showed a distinct drop in biovolume on June 18 simultaneous with the chlorophyll dip mentioned earlier. Cyanobacteria assumed dominance in late summer and early fall in the cove with *Microcystis aeruginosa* and *Oscillatoria* making up most of the biovolume. In 1997 *Microcystis* was unimportant. In the river diatoms were even more important with *Melosira* again dominating. *Oscillatoria* was the most important cyanobacterium in the river. In 1997 it shared dominance with *Anabaena*.

Summer chlorophyll levels in the cove in 1998 were generally higher than those observed in 1996 and 1997, but not enough so to alter the general downward trend in cove levels which has been occurring since 1988 (Figure 42). Likewise in the river, observations in 1998 were consistent with a continuation of the slow decline in chlorophyll values since a high in 1991.

D. Zooplankton

Total microzooplankton increased from less than 100/L in March to more than 2000/L in June and remained above 1000/L for the rest of the year. The high levels in fall contrast with most previous years when zooplankton dropped off markedly in fall. Perhaps the low flows and low flushing in fall allowed the populations to sustain themselves in spite of a decreased growth rate. As in the past years rotifers were by far the most common microzooplankters. While *Brachionus* was common in 1998 it shared dominance with *Keratella* and *Filinia* more frequently than in 1997. In the river *Polyarthra* was dominant in late summer.

The small cladoceran *Bosmina* had about the same maximum abundance in 1998 as in 1997 in the cove. However, in the river it was less abundant in 1998 than in 1997 with maximum abundances of 200/L in 1998 as compared with 500/L in 1997. Peak numbers also occurred at a later time in 1998. High spring flows may have inhibited and delayed the growth of the *Bosmina* population. *Diaphanosoma* reached much higher levels in the cove in 1998, but was abundant over a more restricted time than in 1997. Maximum densities of 34,000/m^3 in 1998 were more similar to maxima of 30,000/m^3 in 1996 and 45,000/m^3 in 1995.

The *Daphnia* maximum was lower in 1998 than in 1997 but it was present at elevated values for a longer time. *Ceriodaphnia* was present at much lower levels in 1998 and *Moina* was virtually absent. *Leptodora* was much scarcer in 1998 than in recent years especially in the cove.

Copepod nauplii were generally somewhat greater in the cove in 1998 than in 1997. Typical early summer values were 200/L in 1998 as compared with 100/L in 1997. River values

were similar between the two years. *Eurytemora* showed two large peaks in 1998 reaching 24,000/m^3 in late May and 8000/m^3 in late August. In 1997 two peaks were also observed in the cove, but they were more closely spaced during the summer and were smaller in magnitude. A steady increase in *Eurytemora* in the river in 1998 was very similar to one observed in 1997 except that the 1997 increase attained lower levels and dropped in December whereas the 1998 increase continued perhaps due to the continued low flows.

Diaptomus was substantially less common in 1998 than in 1997. Other calanoids showed some periods of high relatively high abundance. Cyclopoid copepods were much more common in the river in 1998 than in 1997. The period of maximum occurrence was also shifted later in the year.

E. Ichthyoplankton

The mean monthly density of all clupeid (river herring and gizzard shad) larvae are plotted in Figure 44 for both 1998 (top graph) and for data from 1984-1990 (bottom graph). The monthly pattern for 1998 is very similar to the 1984-1990 collections, but the densities are much lower than the early years of this study. The density of clupeid larvae was about the same as 1997 and 1992, but much lower than the catches of 1984-1989 and 1991, 1993, 1994 and 1995. However, the densities of river herring (*Alosa*) larvae in 1998 are similar to those of previous years from 1992, 1995, and 1997. The density of *Alosa* larvae in 1996 was about half that of these 4 years.

The mean monthly density of fish larvae of the genus *Morone* (white perch and striped bass) are shown in Figure 45 for both 1998 (top) and for 1984-1990 (bottom). All or almost all of these larvae are white perch larvae. The densities in 1998 are slightly higher than those of 1991-1994 and 1997, but lower than those of 1984-1990, 1995, and 1996.

The pattern of highest total larval densities at Station 9 followed in sequence by Station 7 and Station 10 is the same as that of 1997.

F. Fish

Trawls

The mean catch per trawl for all species combined in 1998 was 62.8 individuals (Table 11). This is higher than that of 1996 (32.4 fish), but slightly lower than several recent years (1997--70.8, 1995--73.3, 1994--82.1) and much lower than the catches of 1991-1993 (119.8 to 159.2). Most of this variation is set by the abundance of white perch.

As usual, most of the white perch that were caught are newly transformed young-of-the-year.

The mean catches per trawl for all species combined at all stations are shown in Figure 48 for each month.The number of stations and the number of trawls per month and per year were not constant. The 1998 catch rate is similar to that of 1997 and of the long term average. The

seasonal shift in peak catches noted in recent years continued. In the early years of this study, the peak catches were made in mid-summer, but in recent years they have been made during late summer or even early fall.

The mean catch per trawl for white perch at all stations are shown in Figure 49 (top) for each month. The 1998 catch was similar to those of 1997 and 1995. They were greater than those of 1996, 1990, and 1984-1989. They were less than those of 1991-1994.

The mean catch per trawl for bay anchovy at all stations is shown in Figure 49 (bottom) for each month. The catches in 1998 were greater than those of 1996, 1994, and 1990, similar to those of 1997, 1995, 1993, and 1992 and lower than those of 1991 and 1984-1989.

The mean catch per trawl for blueback herring at all stations is shown in Figure 50 (top) for each month. The catches of 1998 were similar to those of 1992-1997, but less than those of 1991 and earlier years.

The mean catch per trawl for alewife at all stations is shown in Figure 50 (bottom) for each month. The pattern of interannual variation was similar to that of blueback herring.

The mean catch per trawl for gizzard shad at all stations is shown in Figure 51 (top) for each month. The catch was similar to those of 1992-1996. This was less than the catches of 1997 and 1991 and much less than the mean of 1984-1989.

The mean catch per trawl of brown bullhead at all stations is shown in Figure 51 (bottom) for each month. The catch was similar to those of 1997-1993. However, it was much less than the 1984-1989 and 1990-1995 means.

The mean catch per trawl of channel cat at all stations was similar to those of 1997-1990.

The mean catch per trawl of spottail shiner at all stations was also similar to those of 1997-1990.

Thus, the overall catch per trawl of 1998 continued at about the same level as the intermediate years of 1994, 1995, and 1997, but lower than those of 1991-1993 and higher than 1996. Since white perch dominated the abundance of all species combined, their pattern of interannual variation set the pattern for all species combined. Bay anchovy, blueback herring, alewife, and gizzard shad catch remained about the same as the years since 1991. That of brown bullhead was similar to the years since 1992 and that of channel cat was similar to the years since 1990. However, the mean catch per trawl of most of these species was higher in the 1984-1989 period than it was in 1998.

Seines

The total mean catch per seine in 1998 was 111.6 individuals, which continues the slight rise from 109.0 in 1997 and 106.5 in 1996 (Table 12). The mean catch of white perch rose to 22.4

individuals, compared to 14.3 in 1997 and 29.9 in 1996. Banded killifish mean catch per seine was 31.5 fish, down from 1997's 37.5, but higher than 1996's 18.7. The mean catch of spottail shiner was much higher in 1998 at 25.9 individuals per seine. In 1997 the mean catch was 5.0, and in 1996 it was 12.2.

The mean catch per seine at Station 4 continued to rise from 106.1 fishes in 1996 to 116.5 in 1997 to 165.4 in 1998. The mean catch at Station 6 (115 individuals/seine) remained about the same as 1997 (126.4) and 1996 (109.3), and the catch at Station 11 (54.4) was similar to 1997 (45.3), but almost half that of 1996 (91.2).

The populations of fishes along the shore were abundant in 1998. White perch and banded killifish continued to numerically dominate the shoreline shallows in 1998. Spottail shiner increased substantially and shared dominance in 1998. Station 4 continued to yield large populations of juvenile fishes, as did Station 6. The shore fish community at Station 11 was much less abundant than the other two stations, but seemed healthy nonetheless. Alewife, gizzard shad, bay anchovy, and striped bass were more numerous there than they were at the other two stations.

G. Macrobenthos

As in previous years oligochaetes were the most numerous macrobenthic organisms in the cove. As usual only a few other taxa were found in the cove. Chironomids were the second most abundant taxon as has been the case in previous years. Sphaeriids were unusually abundant in 1998 as compared with previous years. *Chaoborus* and amphipods were found in small numbers in one sample.

In the river amphipods were dominant for the first time. The numbers found in 1998 represent one of the highest densities found in the study since its inception. Flatworms were also present in unusually high numbers in the river in 1998. The presence of caddisflies was also unusual. Oligochaetes and chironomids were similar in abundance to recent years as were *Corbicula*, sphaeriids, isopods, and other insects. The occurence of caddisflies and the increase in amphipods and flatworms suggests improving conditions for benthos which could be related to improved habitat or water quality, increased food supplies, or decreased predation. If these trends continue, causes can and should be investigated further.

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