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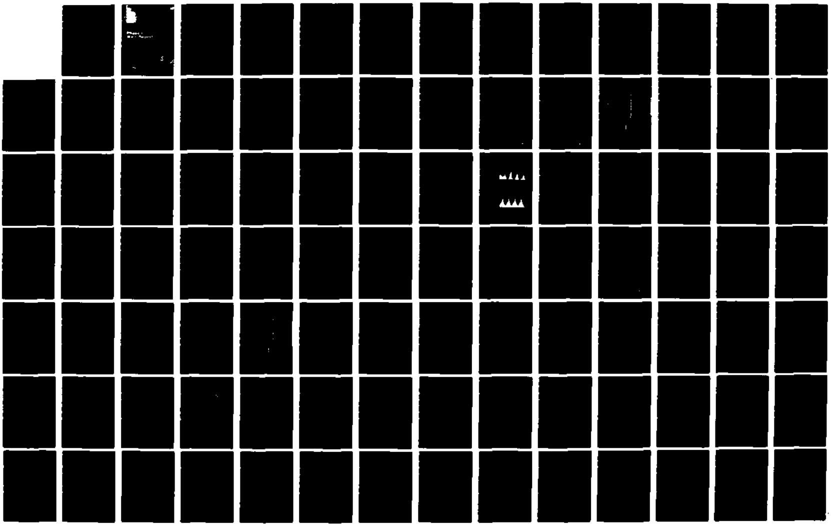

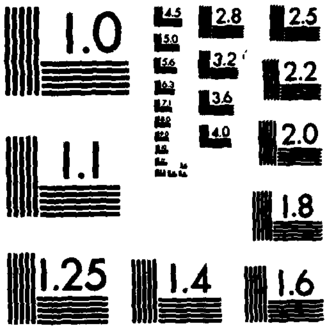
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Chesapeake Bay Low Freshwater Inflow Study

Phase II
Main Report

Prepared for
U.S. Army Engineer District Baltimore
by Western Eco-Systems Technology, Inc.

May 1982

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A123 260

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
CHESAPEAKE BAY LOW FRESHWATER INFLOW STUDY
BIOTA ASSESSMENT
Phase II
Main Report

5. TYPE OF REPORT & PERIOD COVERED
FINAL

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Gail B. Mackiernan
G. Bradford Shea
David F. Bleil

8. CONTRACT OR GRANT NUMBER(s)
DACW31-79-C-0056

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Western Eco-Systems Technology, Inc.
204 215th St. S.E.
Bothell, Washington 98011

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Engineer District Baltimore
P.O. Box 1715
Baltimore, MD 21203

12. REPORT DATE
May 1982

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Phase I of this report consists of a 2-volume report plus one appendix containing species tolerance and habitat information.
Phase II consists of a one-volume report and a supplementary MAP FOLIO.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Chesapeake Bay, Biology, Salinity, Habitat, Estuary

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An assessment of the effects of low freshwater inflow conditions on the biota of Chesapeake Bay was conducted through use of data output from the U.S. Army Corps of Engineers' Chesapeake Bay Hydraulic Model. Phase I of the biota assessment focussed on methodology development and establishment of a baseline for determination of freshwater inflow-induced change. Physical and chemical information, along with salinity tolerance and other habitat related information was collected for a group of over 50 study organisms.
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20. **ABSTRACT** (continued)

In Phase II of the assessment, four sets of hydraulic model test conditions (scenarios) were used which simulated effects of drought and effects of future consumptive water use as deviations from present average flow conditions. Changes in habitat for the selected study organisms were predicted and mapped based on salinity and other variables. Changes in habitat, which were used to delineate the amount of impact from reduced freshwater inflow, were found to include increases and decreases depending on the species, its lifecycle, tolerances, and interactions with other organisms. The magnitude of habitat change was found to generally increase as salinity changes increased.

CHESAPEAKE BAY LOW FRESHWATER INFLOW STUDY

BIOTA ASSESSMENT

PHASE II: FINAL REPORT

May 1982

by: Gail B. Mackiernan
David F. Bleil
G. Bradford Shea

Project Director and Editor: G. Bradford Shea
Map Atlas by: Jocelyn Shea and Judith McFarland

WESTERN ECO-SYSTEMS TECHNOLOGY, INC.
204 215th Street, S.E.
Bothell, Washington 98011

submitted to:
U.S. Army Corps of Engineers
Baltimore District
Chesapeake Bay Study Branch

This document is the result of studies by Western Ecosystems Technology, Inc. and represents the judgements and conclusions of the authors. It does not necessarily reflect the opinions of the U.S. Army Corps of Engineers.

ACKNOWLEDGEMENTS

Many people have aided in the development and success of this project by providing labor, ideas, suggestions, and criticism. Other members of WESTECH's staff made the production of the report and atlas possible. Sarah Pelot and Sandra Cohen assisted Joellyn Shea ar Judy McFarland in preparation of the Map Atlas accompanying this report. Mirga Massey provided typing support and Allison Gerst typed the final copy. Judy McFarland and Joellyn Shea prepared the report graphics.

The authors wish to thank the Baltimore District Corps of Engineers for their continued support throughout the process, particularly Ted Robinson and Steve Stegner of the Chesapeake Bay Study Branch. We also wish to thank the WES staff at the Kent Island Hydraulic Model, particularly Dave Richards for helping us wade through and make sense of an enormous data base.

We wish to thank also our anchor team, Alice J. Lippson, Robert Otto, Anthony Provenzano, Louis Sage and J. Court Stevenson for their support, review and suggestions. We also wish to thank the numerous bay scientists and agency personnel who helped with many aspects of the project. Thanks also to the personnel at the U.S. Naval Academy in Annapolis for support in conducting our Final Conference during September 1981.

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ABSTRACT

An assessment of the effects of low freshwater inflow conditions on the biota of Chesapeake Bay was conducted through use of data output from the U.S. Army Corps of Engineers' Chesapeake Bay Hydraulic Model. Four sets of test conditions (scenarios) were used which simulated effects of drought and effects of future consumptive water withdrawal and use as deviations from present average flow conditions. Changes in habitat of over 50 biological organisms were predicted and mapped based on salinity and other variables. Changes in habitat, which were used to delineate the amount of impact from low flow, were found to include increases and decreases depending on the species its lifecycle, tolerances, and interactions with other organisms. The magnitude of habitat change was found to generally increase as salinity changes increased.

EXECUTIVE SUMMARY

This report and accompanying map atlas are the principal products of the second phase of the Biota Assessment portion of the Low Freshwater Inflow Study. It utilizes the methodologies and information synthesized during Phase I, and applies those methods and information to predict biological consequences resulting from changes in freshwater inflow to Chesapeake Bay. The effort was part of the overall Chesapeake Bay Study, originally authorized by Congress in 1965.

Four sets of data from the U.S. Army Corps of Engineers Hydraulic Model of Chesapeake Bay were used as separate sets of inflow conditions, designated scenarios. These represented 1) base (or present) average inflow conditions, 2) drought conditions as simulated to correspond to an actual drought during the 1960's, 3) future average inflow conditions projected from increased water consumption in the year 2020 and 4) future average inflow conditions reduced by drought (again 1960's drought).

These data served as input to the biota assessment and were used to generate sets of salinity maps of Chesapeake Bay for each season and for depths appropriate to various biological organisms. The salinity maps depicted seasonal salinity lines of equal concentration, termed isohalines, at differences of one part per thousand from the mouth of the bay to the head of the tide in each tributary.

From methodology developed in Phase I, four major parameters were found to available in a standard baywide form which could be used to define potential habitat of a given organism; salinity, depth, substrate and dependence on other species. These four factors were used to determine habitat under each of the flow scenarios for over fifty species of organisms through means of overlay mapping. This resulted in production of a set of maps for each scenario which could be used for comparison of direct flow effects baywide or in any given area.

From the map sets, ratios indicating the degree of habitat change were determined by planimetry. These ratios, termed impact ratios, constitute the direct effects of low flow conditions resulting from each scenario. Indirect or secondary effects were studied in several ways including potential effects from short term extremes in salinity (deviation from seasonal averages) and effects on other organisms in the food web through trophic or habitat related interactions.

From the tables of impact ratios and tables and charts of species trophic interactions, quantitative and qualitative effects of low flow on each study species are discussed. For analytical purposes, impact ratios have been grouped into categories indicating the degree of change and whether the change is positive (increase in habitat) or negative (decrease in habitat).

The results showed considerable variation in the degree and even direction of habitat change. Many species or species lifestages showed increases in habitat, although decreases were distinctly dominant (roughly 2:1). The amount of change increased in the order of scenarios given by future average (least); base drought; future drought (most); however, in determining actual effect on the species, one must note that the future average does constitute a permanent event while drought events are temporary.

All organism groups were somewhat sensitive to inflow changes with rooted aquatic plants in freshwater areas being particularly sensitive as well as sessile benthic (bottom dwelling) organisms (including shellfish) and nursery and early stages of fish. The degree to which these habitat changes influence species productivity, abundance and economic return can only be determined qualitatively at the present time and these questions should serve as a focus of future research.

I. PURPOSE AND SCOPE

This report is the product of the second and final phase of the Biota Assessment portion of the Chesapeake Bay Low Flow Study. It is intended to build on the Phase I report furnished to the Corps in three volumes in August 1980. The results of both phases of the Biota Assessment are intended to mesh with other components of the Chesapeake Bay Low Flow Study (a portion of the Chesapeake Bay Study) which is being conducted by the U.S. Army Corps of Engineers. Upon completion, this report and its accompanying atlas will form input into other Corps activities involving evaluation of biological and physical management of the bay, as well as social and economic effects under low-flow conditions.

A. CHESAPEAKE BAY STUDY AND LOW FLOW STUDY COMPONENT

In 1965, Congress adopted Section 312 of the River and Harbor Act which authorized the Secretary of the Army, acting through the Chief of Engineers to:

> "...make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin..."

This investigation became known as the Chesapeake Bay Study. It was to include such subject areas as:

- navigation
- fisheries
- flood control
- noxious weed control
- water pollution
- water quality control
- beach erosion
- recreation

In addition, to carry out the purposes of Section 312, the Secretary acting through the Chief of Engineers, was authorized to construct a hydraulic model of the Chesapeake Bay Basin and an associated technical center.

The Chesapeake Bay Study began in 1967 directed toward the overall goals of determining the most beneficial uses of the water related resources of the Basin. The three objectives of the study are to:

- Assess the existing physical, chemical, biological, economic and environmental conditions of Chesapeake Bay and its water-related resources.
- Project the future water resources needs of Chesapeake Bay to the year 2020.
- Formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

An inventory of Chesapeake Bay Resources comprised the first stage of the study, resulting in a seven volume Existing Conditions Report, published in 1973. This report provided an overview of Chesapeake Bay resources and documented information directed toward satisfying the first of the three goals. The second goal spurred the compilation of the second major study document, the twelve volume Chesapeake Bay Future Conditions Report which documents future water and water resources needs of the Bay region. A special study was also undertaken as a result of Tropical Storm Agnes which disrupted many of the Bay's physical and biological processes in the early 1970's. That report has been published as Impact of Tropical Storm Agnes on Chesapeake Bay.

As a major tool to aid in the assessment of changes or impacts on the Chesapeake Bay, the Corps of Engineers constructed a 14 acre hydraulic model of the Bay on Kent Island, Maryland. Construction of the model began in 1973 and was completed in 1976. Following initial calibration, adjustment and verification, the model has been used to provide data on salinities, velocities, tidal elevations and currents under various situations of interest for a wide variety of government and public agencies. The model also was used to provide input conditions to the present study as described in detail in Section I-B.

The Chesapeake Bay Low Flow Study is a component of the overall Chesapeake Bay Study. The Low Flow Study has focused on effects of drought or water withdrawals on the entire Chesapeake Bay (Figure I-1). This emphasis on low flows has resulted from recogni-

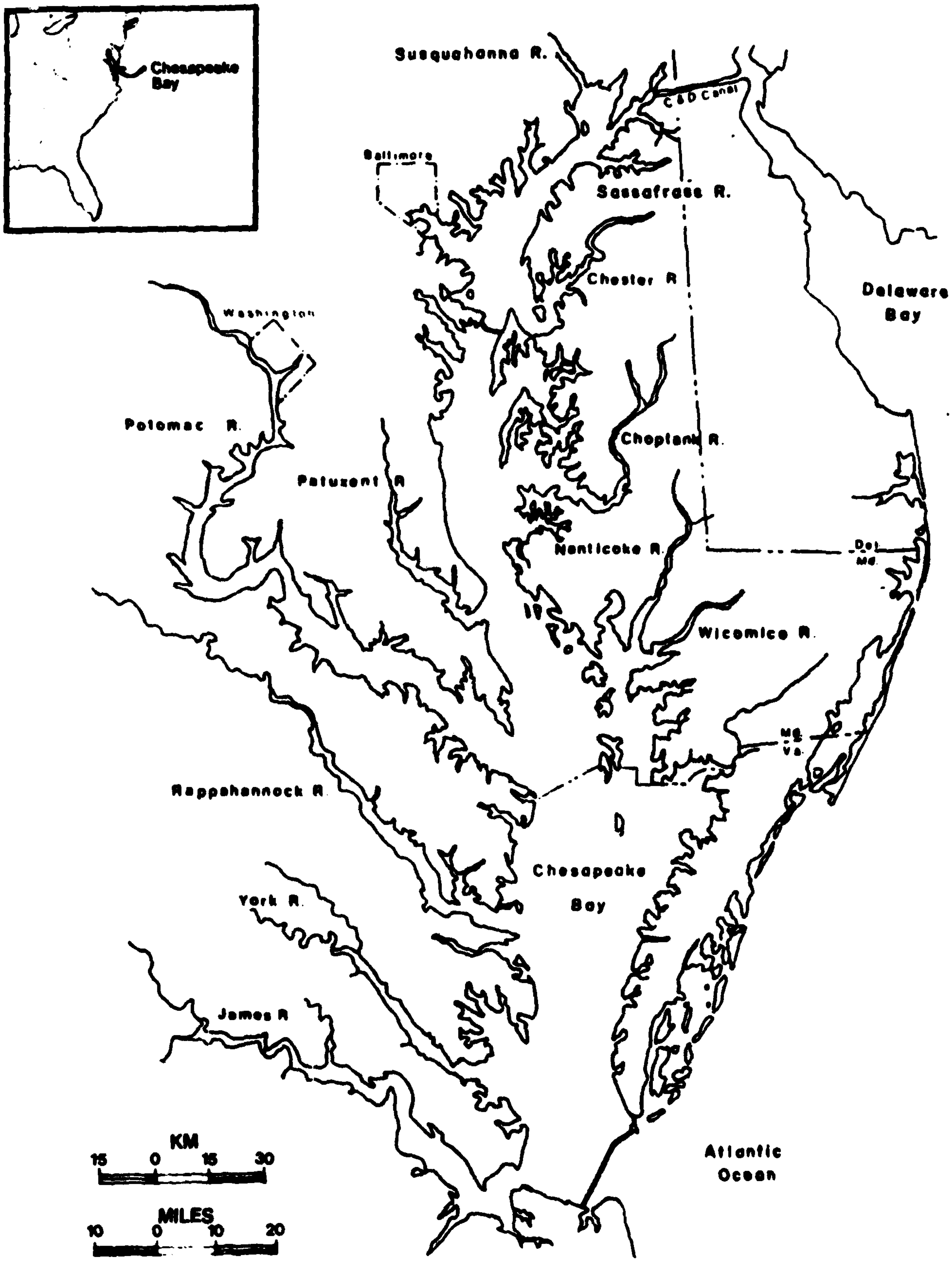


Figure I-1. Chesapeake Bay Area

tion that past drought events have produced noticeable changes in the physical, chemical and biological conditions in the Bay. The potential of recurrence of drought events and the predicted increases for consumptive water losses in the bay area (due to expanding water use by increased population) are the factors targeted in the Low Flow Study.

The environmental, social, and economic effects accompanying changes induced by low flows to Chesapeake Bay are being studied by the Corps of Engineers. One of the areas of major concern in this effort is the direct effect of lower inflow to the biotic communities of Chesapeake Bay. To address this issue, the Corps contracted with Western Eco-Systems Technology, Inc. (WESTECH), to perform a Biota Assessment Component of the Low Flow Study. This report represents the second and final phase of that assessment.

B. BIOTA ASSESSMENT

The Biota Assessment was designed to achieve two main objectives:

- To define quantitatively (whenever possible), the biological relationships which govern the health and productivity of the Chesapeake Bay.
- To identify the effects of particular low flow conditions on biological organisms and relationships.

The program to accomplish this was set up in two phases, the first phase directed toward developing and understanding of potential low flow effects and developing a methodology for dealing with them, and the second phase directed at applying the methodology and information base toward analyzing particular low flow conditions. These conditions were predicted through use of the Corps of Engineers hydraulic model mentioned above.

1. Phase I

Phase I of the Biota Assessment focused initially on establishing baseline conditions to serve as a reference point for comparisons with flow-induced changes. Establishment of these baseline conditions involved consideration of:

- stable, average flow conditions
- patterns of physical and chemical parameters (particularly salinity)
- key biological species or species groups
- distribution, range and abundances of key species
- salinity tolerance of key species
- biological productivity and diversity
- interrelationships between organisms (competition, predation, etc.)

and other parameters. Most of these parameters were found to fluctuate widely and it became clear that no set of conditions existed which could be uniformly identified as defining a healthy and productive bay against which changes can be measured. Therefore, a period of average inflow was defined (water year 1960-1961) to represent "normal" bay conditions. An extensive literature search was also carried out to document physical and chemical conditions, organism tolerances and distribution, however, these by necessity extended over a much longer period than the water year defined for the average inflow baseline.

The study area for the Biota Assessment is defined as the Chesapeake Bay and its tributaries from the bay mouth to the head of tide (Figure I-2). The first phase studies resulted in a selection of over 50 study species which utilize the study area and which are important ecosystem components. Many of these organisms were selected for their sensitivity to change of environmental factors, primarily those related to flow and salinity. For these species, tolerance data and species interactions were identified and synthesized.

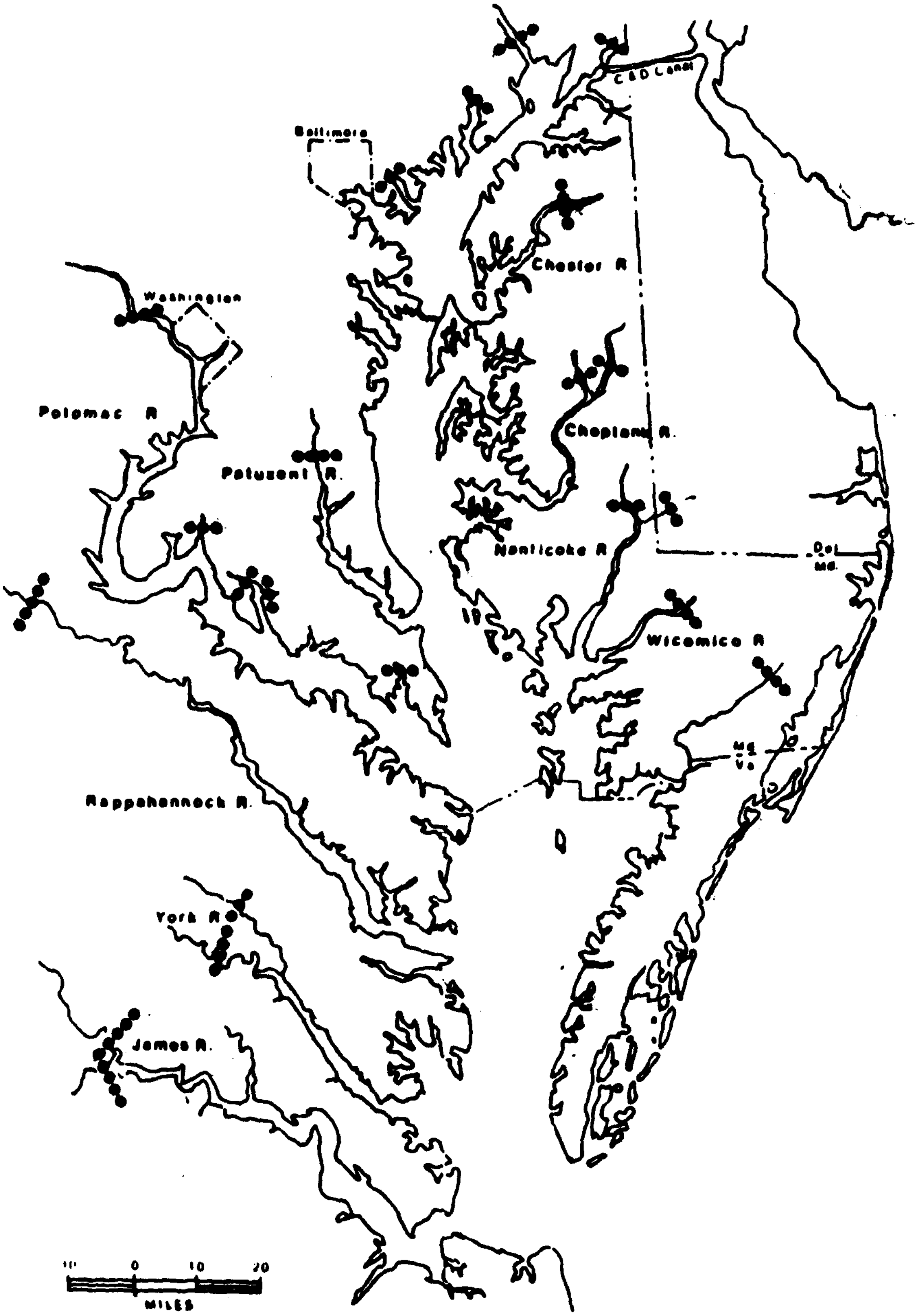


Figure I-2. Head of the Tide in Chesapeake Bay Tributaries (Source: Md. Geological Survey, 1970)

In conjunction with the identification of factors which influence the study species, a search was carried out for those parameters which can be consistently defined across the study area. The list of these proved to be small, however, it did contain many of the most important influences on organism distribution. The parameters are:

- salinity
- depth
- substrate
- biological communities (e.g. submerged aquatic vegetation)

Water quality data, water velocities and other parameters proved unavailable in a synoptic, baywide usable format.

Using the parameters above, coupled with organism tolerances and interactions, distributions of potential organisms habitat were mapped for the 57 study species under average inflow conditions (WY 1960-1961). These distributions were confirmed by checks against existing studies and historical records. The maps were created at 1:250,000 scale and then combined in an atlas published with the Phase I report at a reduced scale of 1:500,000.

The methodology developed during Phase I to assess flow-related changes was based on the mapping techniques developed above. "Potential habitat" was defined for the purposes of this study to be those areas defined by salinity, depth, substrate or biological communities which were usable for the organism in question based on its tolerances and requirements. Changes in these habitat parameters alter the distribution of potential habitat and hence constitute habitat change or impact. A comparison of the habitat area available under altered conditions with that of baseline conditions is defined as an "impact ratio". These impact ratios are the methodological tools which are used in Phase II to define quantitative primary effects of flow changes. Secondary effects are identified through changes of other parameters or of species interactions. Methodologies evolved in Phase I for defining these interactions included a Conceptual Model of trophic relationships in the bay (Figure I-3). Secondary effects were found to be non-quantifiable in many cases, although their importance cannot be dismissed.

The products of Phase I were a three volume report and a map atlas. The report and atlas included:

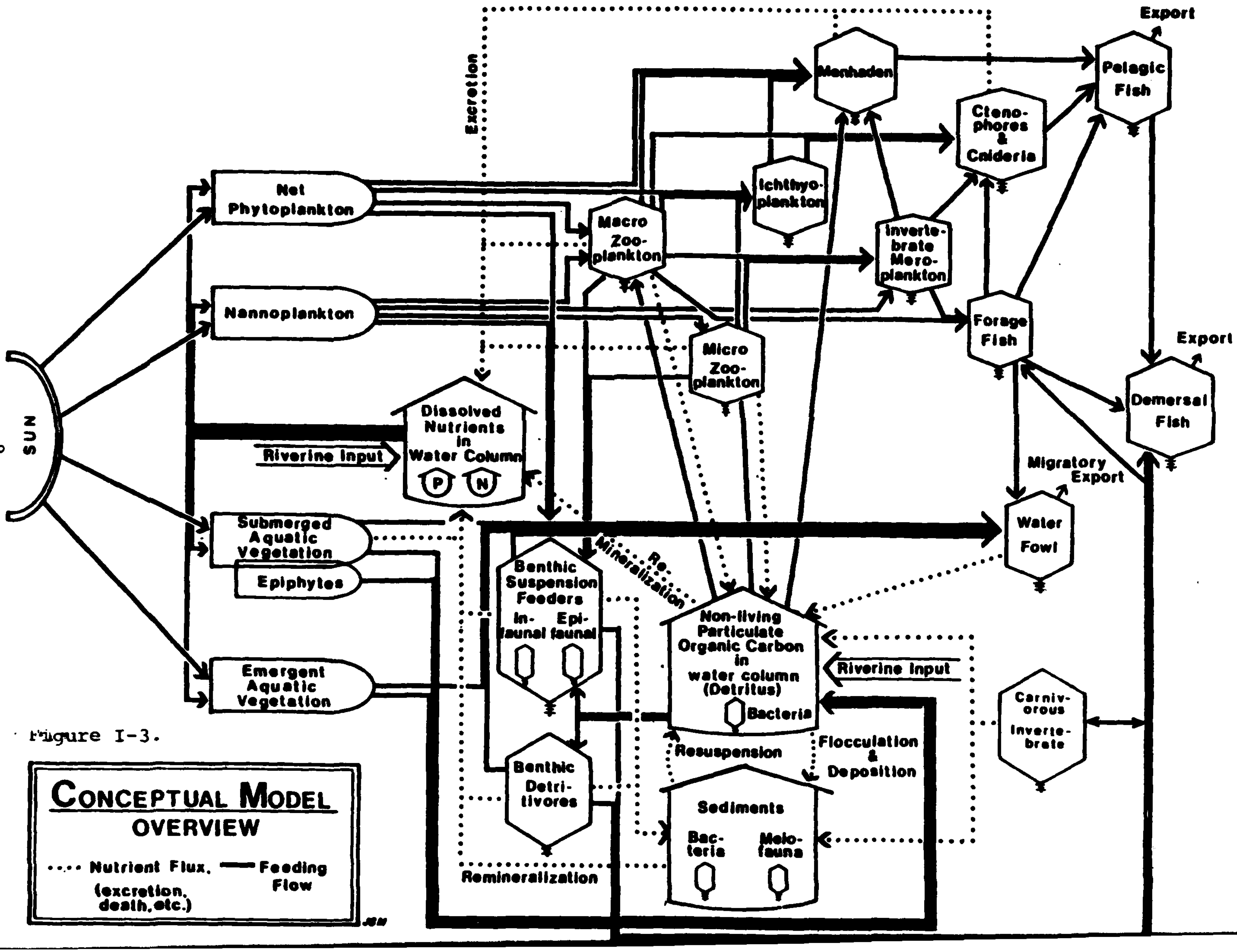
- a detailed review of the literature
- selection criteria and list of study species
- detailed analysis of physical, chemical and biological baseline conditions
- discussion of species interactions and trophic modeling
- a synopsis of tolerances and requirements for each of the study species
- a map atlas of potential and actual species distributions during a historic average inflow year

The report was furnished to the Corps of Engineers in final form in August, 1980.

2. Phase II - Scenarios - Low Flow Impact Assessment

In preparation for Phase II of the Biota Assessment, the Chesapeake Bay Study Branch of the Corps of Engineers conducted several flow tests using the Chesapeake Bay Hydraulic Model. Variable amounts of freshwater enter the model from 21 inflow points (Figure I-4). The flow regimes were selected to represent particular conditions of interest to the goals of the Low Flow Study and include:

- Base Average - present average salinity conditions
- Base Drought - 1963-1966 drought salinities
- Future Average - 2020-present average salinity conditions as modified by consumptive losses
- Future Drought - 1963-1966 drought salinities as modified by the effects of consumptive losses (2020)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Net Phytoplankton
Nannoplankton
Submerged Aquatic Vegetation
Epiphytes
Emergent Aquatic Vegetation
Riverine Input
Dissolved Nutrients in Water Column
P
N
Excretion
Macro Zoo-plankton
Micro Zoo-plankton
Ichthyo-plankton
Menhaden
Inverte-brate Mero-plankton
Cteno-phores & Calderia
Forage Fish
Pelagic Fish
Export
Demersal Fish
Export
Water Fowl
Migratory Export
Re-Mineralization
Benthic Suspension Feeders
In-faunal
Epi-faunal
Non-living Particulate Organic Carbon in water column (Detritus)
Bacteria
Riverine Input
Carniv-orous Inverte-brate
Resuspension
Flocculation & Deposition
Benthic Detri-tivores
Sediments
Bac-teria
Meio-fauna
Remineralization
CONCEPTUAL MODEL
OVERVIEW
Nutrient Flux. (excretion, death, etc.)
Feeding Flow
JSN

Figure I-3.

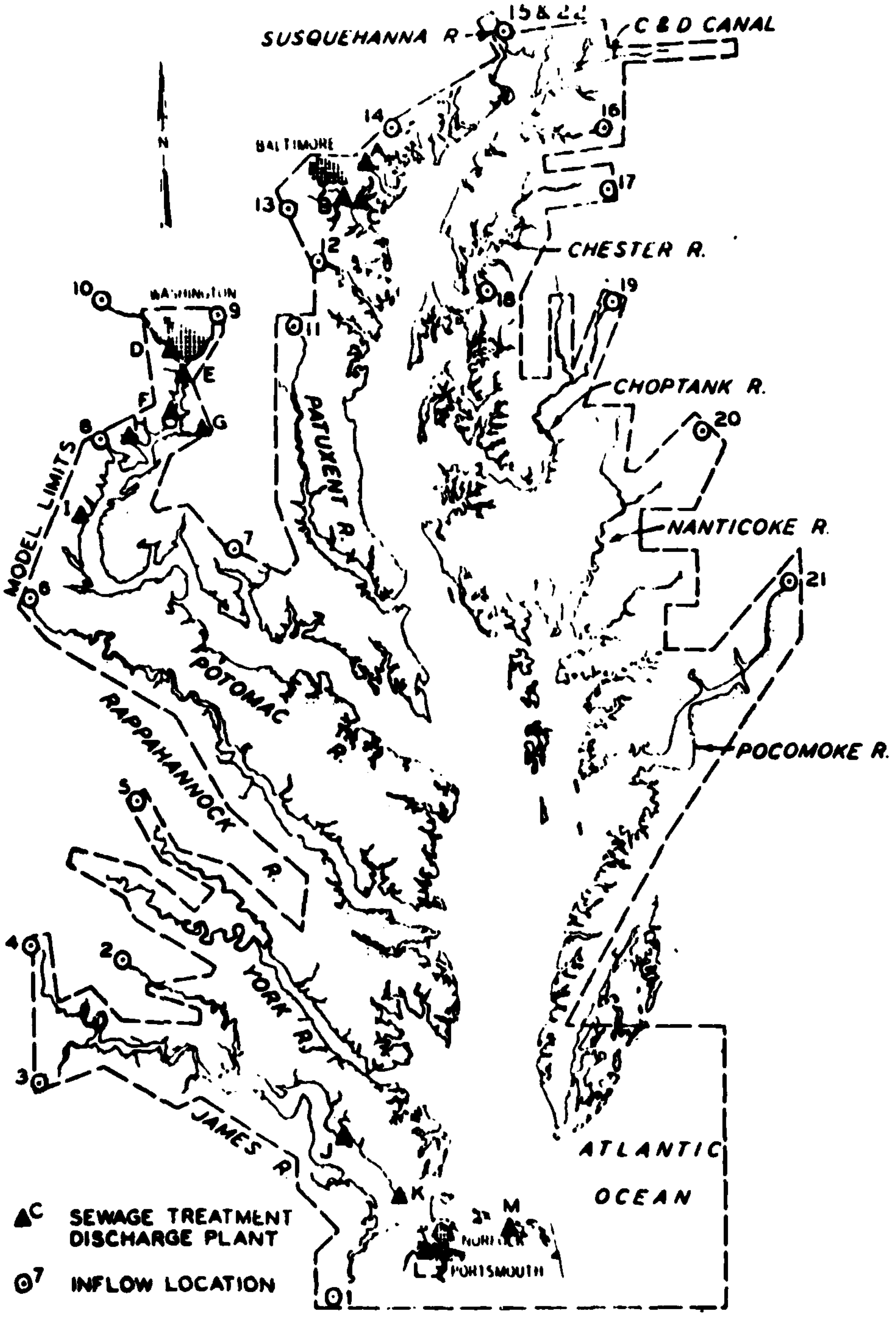


Figure 1-4. Freshwater Inflow Points of the Corps of Engineers Hydraulic Model. (Richards and Gulbrandsen 1981).

The Base Average represents non-drought conditions and has been developed from weighted monthly average tributary flows over the period of record. The Corps of Engineers terms this weighted average a "modal hydrograph." The Base Drought consists basically of a set of flow conditions which reproduce the drought of the mid-1960's. The Future Average scenario represents the Base Average conditions as reduced by predicted consumptive water losses in the year 2020. The Future Drought scenario represents a recurrence of the 1960's drought further reduced by projected consumptive losses for the year 2020. Salinity data was collected at various depths at 203 stations located on transects of the Corps hydraulic model shown on Figure I-5.

During Phase II, the Corps data was converted to values at standard depths by interpolation and mapped as plan-view salinity isohalines for several depths. This mapping was done for each season and for each of the four scenarios described above.

From the isohaline maps and from maps and information of habitat requirements from Phase I, new sets of maps were generated for each of the study species showing habitat distributions for each of the four scenarios above. Comparison of these maps shows changes in the species distributions based on the effects of altered freshwater inflow as predicted by the Corps Hydraulic Model.

Other research has been conducted during this phase to document the effects of altered inflow on trophic relationships and other species interactions, effects of short term salinity fluctuations and other parameter interactions and is included in this report.

The final assessment results of the Phase II Low Flow Biota Assessment are to be:

- o Assessment of potential habitat changes for study species through mapping of available habitat under the four scenarios, and computation of impact ratios based on these areas.

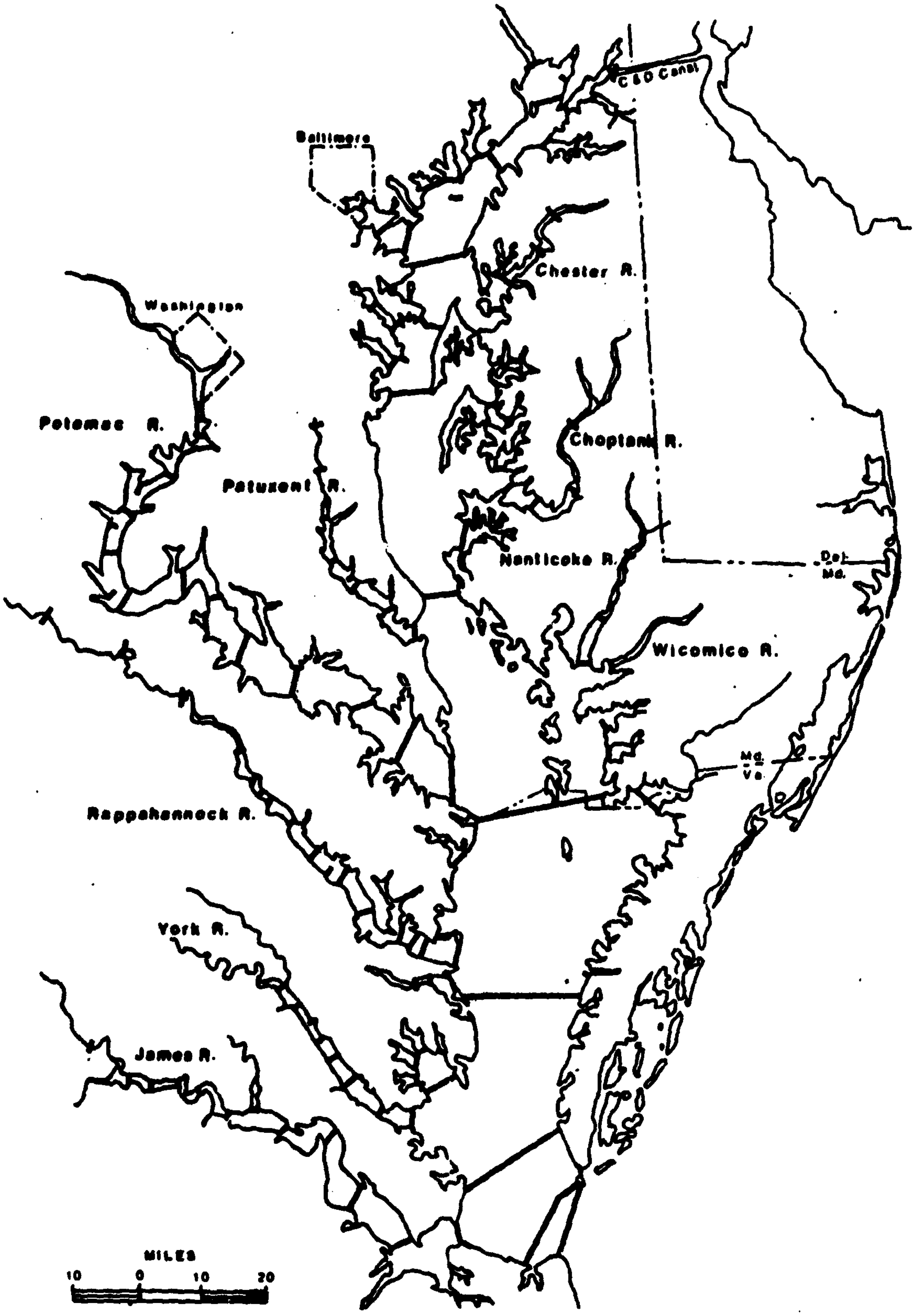


Figure I-5. Major Salinity Transects of the Chesapeake Bay Model (Source: U.S. Army Corps of Engineers, 1979)

- Assessment of potential secondary effects through study species interactions, as well as identification of most sensitive life stages for a number of species.
- Evaluation of "extreme case" effects for some species for which best information is available, using identified short duration extreme events at selected stations.
- Comparison with historical information from previous drought events, where such information is available, to assess recolonization potential, effects of new predators or diseases, food switching, and so forth.

The products of Phase II are this technical report and a map atlas of study species distributions. The species distribution maps will be published for all scenarios for a select list of commercial and recreational species and for all species for the Base Average scenario.

The results of Phase II of the Biota Assessment will be evaluated for the purposes of defining management strategies for Chesapeake Bay. The evaluations will be performed during the winter of 1981-82 by the Corps of Engineers and a select panel of Bay experts termed the "Biota Evaluation Panel" (BEP). This evaluation will serve as one link between the biological evaluations performed in the Biota Assessment and the ultimate recommendations on minimum flows for the Bay with which the Corps of Engineers is charged.

C. REPORT ORGANIZATION

The chapters below detail WESTECH's methodologies and findings during Phase II of the Biota Assessment portion of the Chesapeake Bay Low Flow Study. After a brief recapitulation of key Phase I methodological tools which are applicable to Phase II, Chapter II defines the study methodology and data analysis methods used to convert information from the hydraulic model to predicted biological effects.

Chapter III provides the analyzed data and results. Every attempt is made to place these results in perspective in terms of expected margins of error and the effects of the variable dynamic situations which characterize the estuary. Both direct primary effects of salinity changes and secondary reactions of the biotic community to these changes are covered.

Chapter IV summarizes the results of Phase II from two perspectives. The first perspective is how flow changes will effect species and biota groups. The second perspective compares the overall effects of salinity changes by scenario. The chapter concludes with a review of particular sensitive species or conditions which should be flagged for critical analysis, followed by recommendations for further study.

II. STUDY METHODOLOGY

A. SYNOPSIS OF METHODOLOGY AND PRODUCTS

As outlined in Chapter I, Phase I of the Biota Assessment resulted in the development of certain tools, techniques and products. This development was constrained by limitations of data availability, data consistency and our overall state of knowledge about the immensely complex Chesapeake Bay system. Due to these constraints, the authors discovered that only a few parameters could be effectively used to identify organism habitats on a consistent basis.

Thus, the parameters salinity, depth and substrate (in addition to presence of habitat-modifying organisms such as Zostera) were used to define and map potential habitat of each of the study species. This potential habitat is defined to be the intersection of geographical areas in which each habitat parameter is suitable for the organism and within its tolerance limits. Such an intersection of areas is shown conceptually for two habitat variables in Figure II-1.

It is recognized that potential habitat as identified by these few variables does not completely describe all conditions which may effect the organism, nor does it necessarily reflect the known distribution of organisms. We found, however, that for most organisms, known habitat surveys were patchy and knowledge of organism habitat was seldom consistently available for the entire Chesapeake Bay system. It is therefore not useful as an indicator

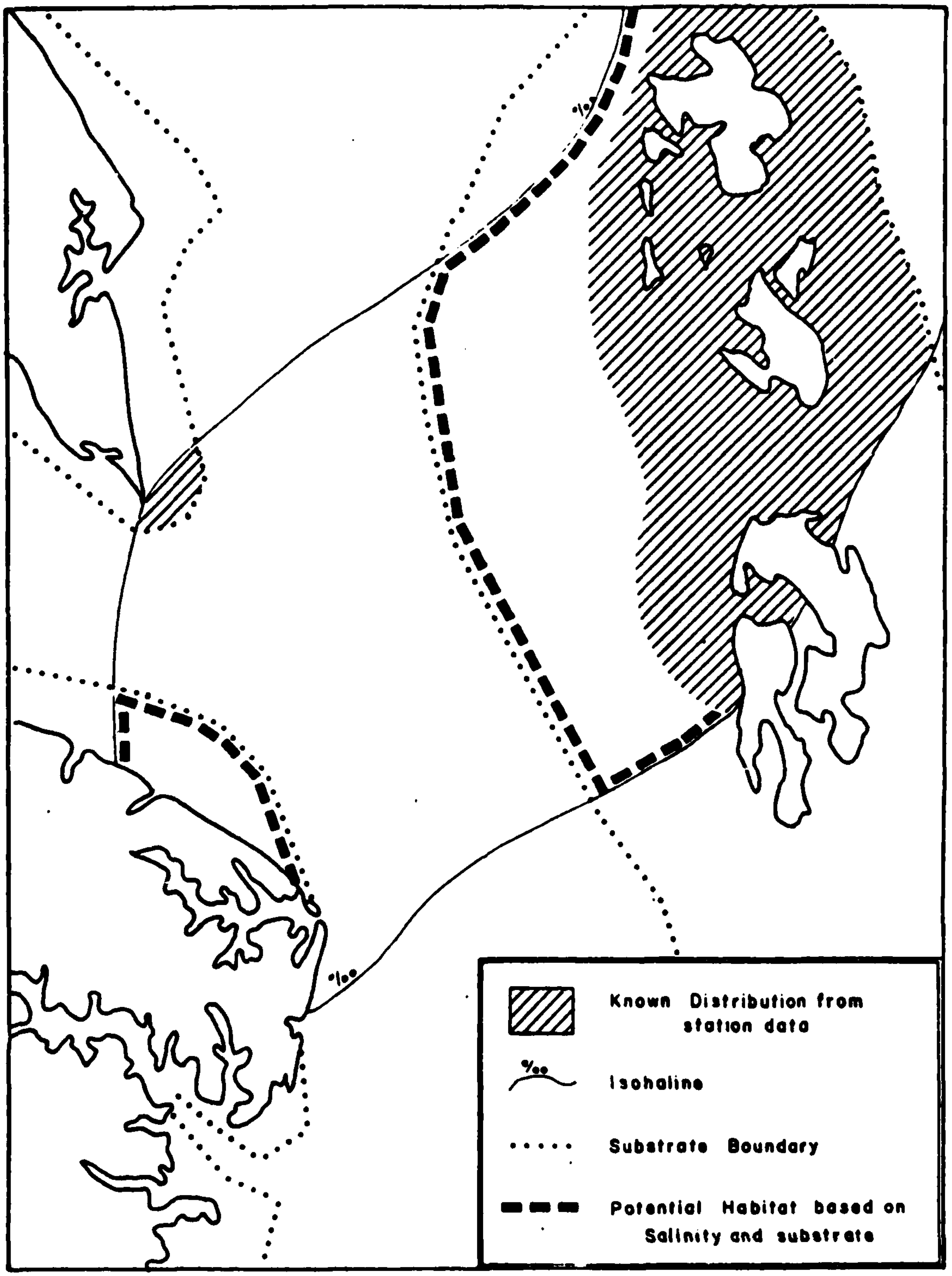


Figure II-1. Known and Potential Habitat of a Hypothetical Benthic Organism Based on Sampling Data (Known Habitat) and Salinity and Substrate (Potential Habitat) of low flow impact. In nearly all cases, however, known habitat closely coincides (lies within) the boundaries defined by potential habitat. Where there were discrepancies, species tolerance data were reexamined during Phase I and the discrepancies were resolved.

Flow variation and consequent salinity changes alter the quantity and distribution of an organism's potential habitat. Due to bay morphology and the interaction of other parameters (substrate, depth, other organisms), the extent of change is not readily predictable. Therefore, the differences were mapped in plan-view, using salinities at the depth most appropriate to the organism in question.

Differences in potential habitat between flow scenarios are expressed in terms of an impact ratio. Each ratio is a comparison of potential habitat under conditions of a reduced flow. compared with conditions during the "base" test which used present average inflow conditions. Thus the impact ratio is defined by:

$$\text{I.R.} = \frac{\text{Potential Habitat - Reduced Flow Scenario}}{\text{Potential Habitat - Base Average Scenario}}$$

Where the Reduced Flow scenario may represent the Base Drought (1963-1966), the Future Average (2020) or the Future Drought (2020) scenario.

It is important to note that the main forcing variable contributing to change in potential habitat is salinity. The effects of the salinity change interact with other variables, which are assumed to undergo no direct change. This is clearly an oversimplification. Flow affects water quality and circulation, changing patterns of water chemistry and dynamics. Study of quantitative effects of flow of these parameters is currently beyond the state-of-the-art, at least in a bay-wide study involving in excess of 50 organisms. Wherever possible, these parameters have been dealt with on a qualitative level.

In order to test this method, a series of maps was prepared using prototype data for water year 1961 (hydraulic model data were not yet available). An examination of average streamflow into Chesapeake Bay (Figure II-3) showed that the 30+ year mean of 75,000 cfs was most nearly approximated by the 1961 water year; however, seasonally, the year was found not to represent average conditions.

In summary, a methodological progression was followed during Phase I to generate a series of products which would enable derivation of impact ratios and calculation of secondary and interactive effects. These products included:

- Base map overlays for substrate, depth and other organisms which modify habitat for other species
- Salinity isohaline maps (1961) in plan-view for each depth and season
- A set of tolerance criteria for each species

Used in conjunction, these products formed a basis for mapping potential habitat under each scenario in Phase II using hydraulic model data. Maps for each parameter were overlayed to identify the intersection area which falls within the species tolerance limits and this area was transferred to a full-scale (1:250,000 scale) species habitat map for each scenario. Impact ratios were then calculated based on changes in area available to the species under each low-flow scenario. Figure II-2 shows the conceptual progression of steps in the study process. These steps begin with Phase I products and employ mapping and calculation of impact ratios to achieve the goals of quantifying low flow impacts in Phase II.

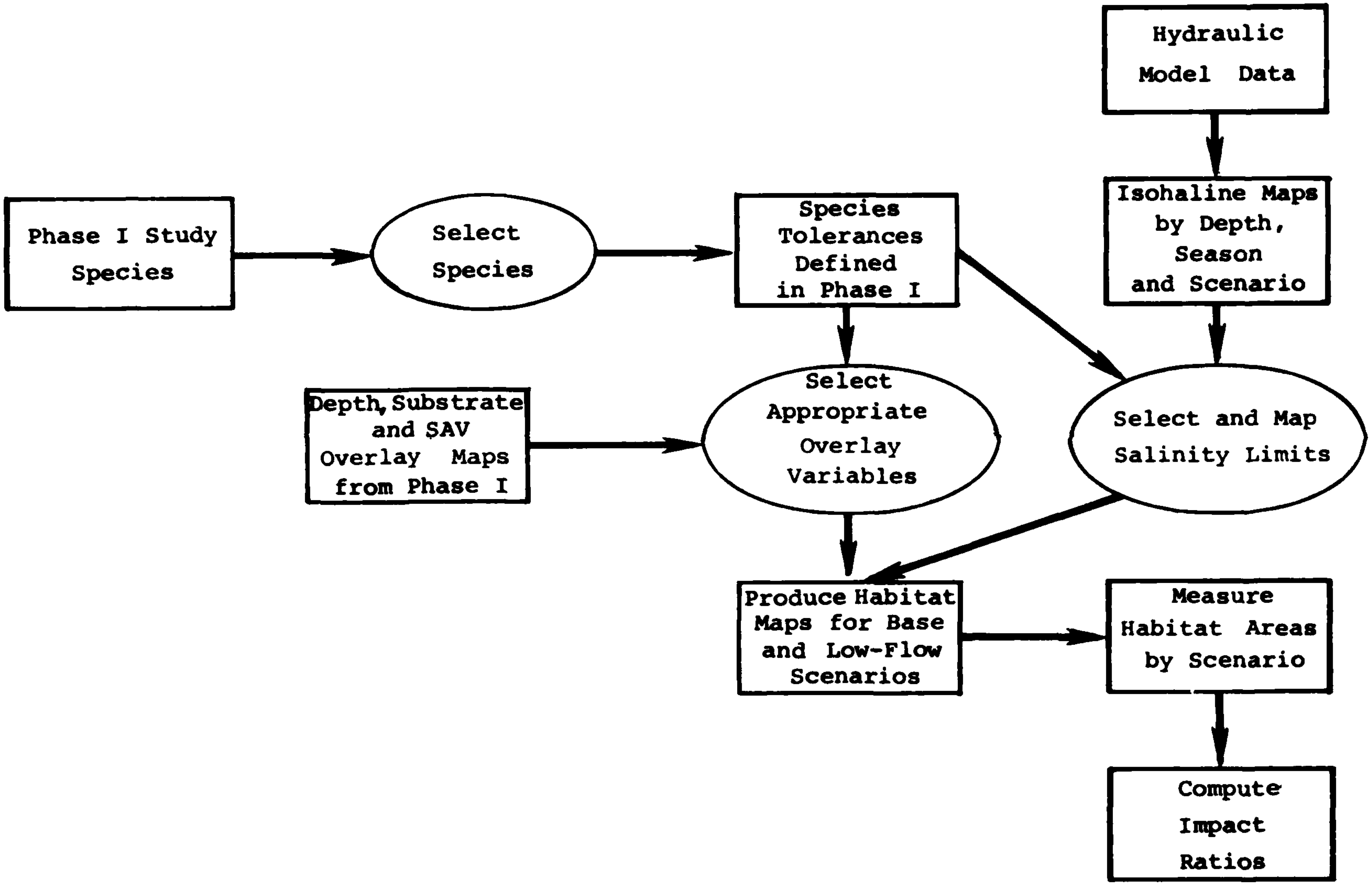


Figure II-2. Steps Involved in the Study Process

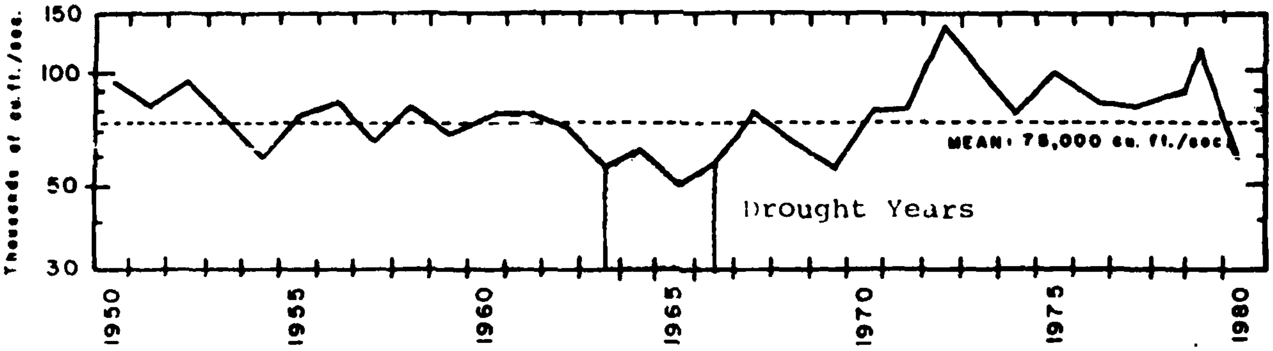
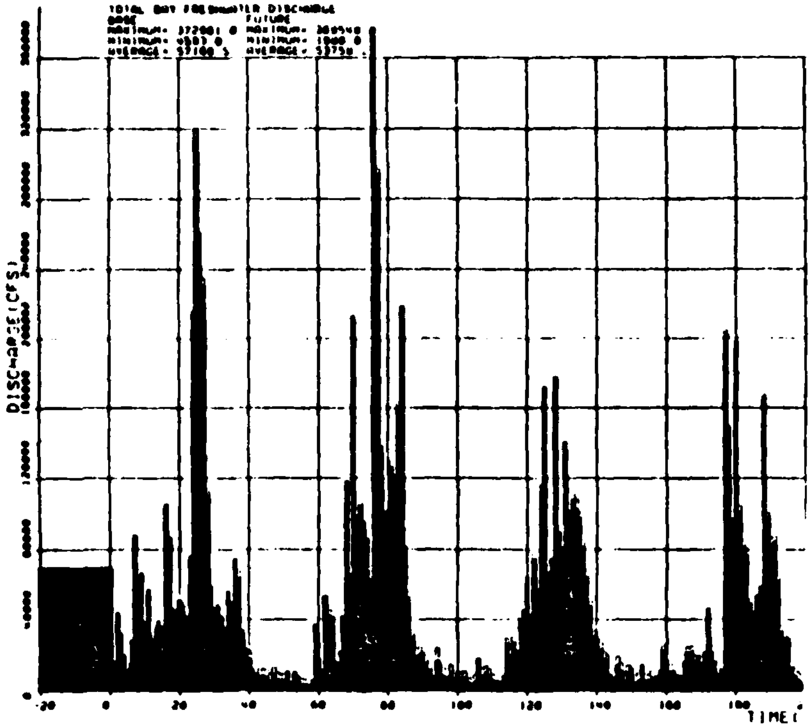
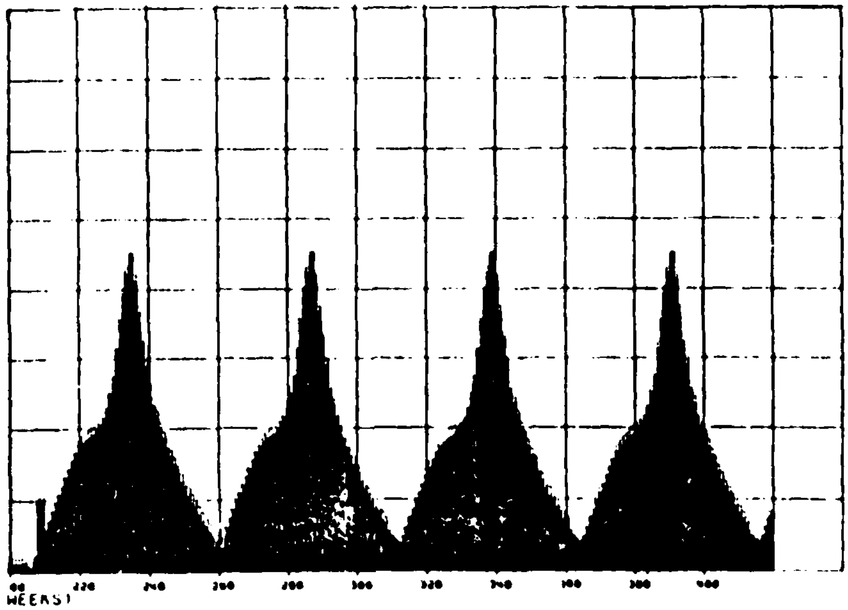


Figure II-3. Average Streamflow into Chesapeake Bay by Calendar Years
(Source: U.S. Dept. of Interior, Geologic Survey, Monthly Streamflow Summary)



Historic Hydrograph (Base Test: Open Bars Future Test: Solid Bars) April 1963 through Sept. 1966



Modal Hydrographs - Four Consecutive Water Years (Base Test: Open Bars Future Test: Solid Bars)

Figure II-4. Comparison of Historic and Modal Hydrographs with Relative Magnitude of Consumptive Losses Shown

B. HYDRAULIC MODEL TEST

The Hydraulic Model was run with four scenarios in two sequences. The first scenario to be run was the historic drought scenario (referred to here as Base Drought) which recreates the fresh water inflow hydrograph of the 1963 to 1966 water years. This was followed by the modal hydrograph (termed Base Average) which was repeated for several scale years in order to permit the Corps of Engineers to determine how rapidly the salinity pattern stabilized. The return to a stable salinity pattern was termed recovery of the Bay from the perturbation of the drought.

The second series of tests was run by reducing all fresh water inflows by the projected amount of water lost from the system due to consumptive uses of water in the year 2020. The inflow hydrograph of the 1963 to 1966 drought, reduced by the projected consumptive losses, was run followed by several repetitions of the modal hydrograph also reduced by the predicted consumptive losses. These tests are labeled "Future Drought" and "Future Average" respectively. As in the first series, the rate of return of the hydraulic model to a stable salinity pattern was measured to determine if the withdrawal of fresh water for human use would affect the rate of return to dynamic normalcy. The full account of the results of the stability return tests is included in the Army Corps of Engineers Report (Richards and Gulbrandsen 1981).

Data from the hydraulic model was collected from 203 stations for both the base and futures tests. Slightly less than half of these stations were located in the main bay and the remainder in the western and eastern shore river systems. The stations are generally arranged along transects which span either the main bay or a river system running east-west in the main bay and across channel at a given river mile in the river systems. The coding system for the stations uses two initial letters designating the bay or river followed by four numbers, the first two designating the transect and the latter two designating the station location along the transect (i.e. CB0405 - Chesapeake Bay, Transect 4, Station 5).

Figure II-5 displays the salinity transects of the Chesapeake Bay Hydraulic Model. Transects are numbered from CB-0 at the mouth to CB-8 at the head of the bay. River transects are denoted by two letters (I.E. PO-Potomac, JG-James, etc.) and are numbered from 1 at the mouth, to the highest transect for the particular river near the fall line.

The spacing of stations along each transect varies according to the topography of the bottom. Along transect CB-2 some stations are as far apart as 15,200 feet, while on transect CB-5 the stations are spaced as close as 1,400 feet apart. On every transect one station was located over the deepest part of the channel.

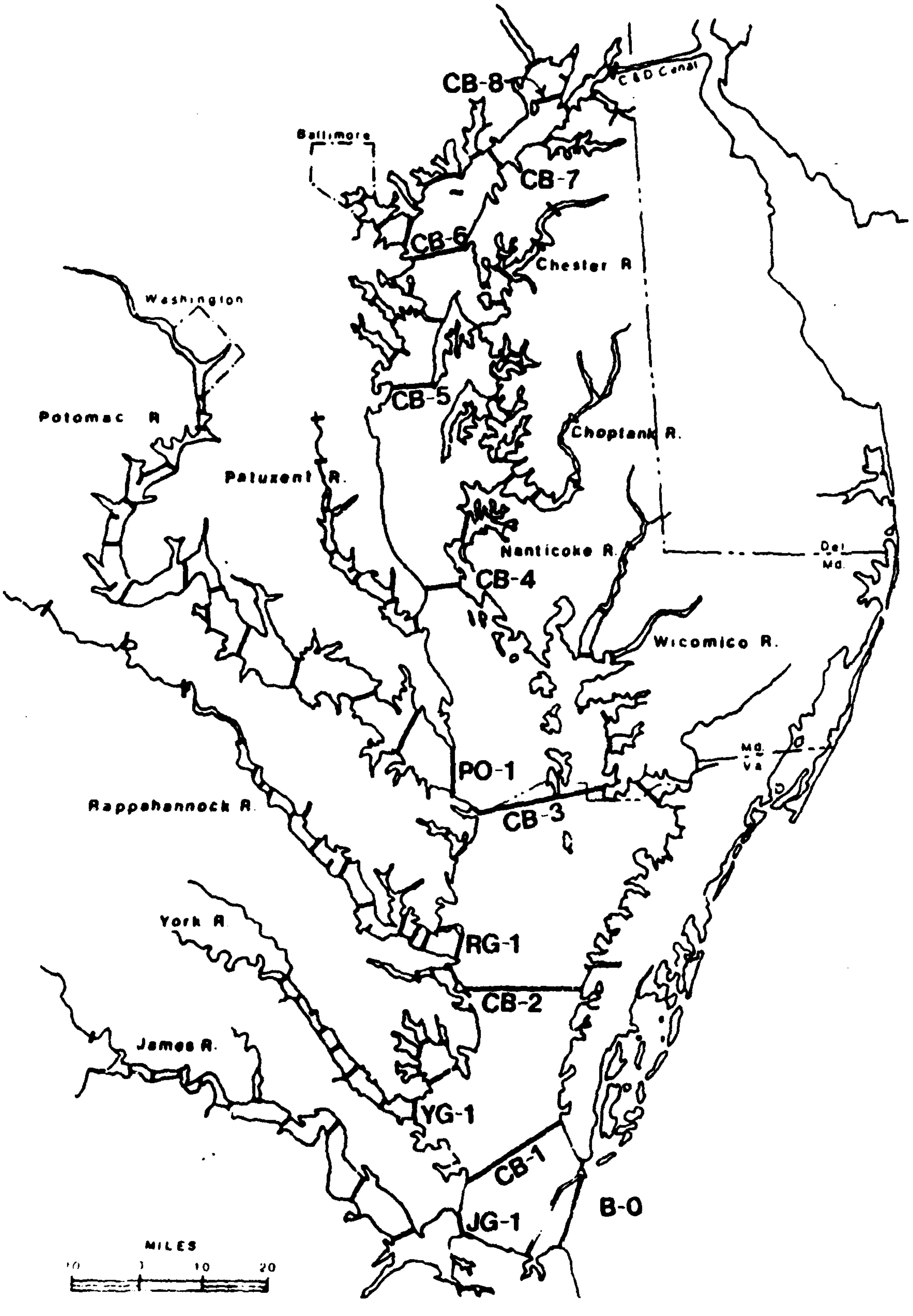


Figure II-5. Major Salinity Transects of the Chesapeake Bay Model (Source: U.S. Army Corps of Engineers, 1979)

C. HYDRAULIC MODEL DATA AND CALIBRATIONS

1.1 Timing and Selection of Seasons

Ninety day periods, which for convenience may be termed "seasons," were identified as corresponding most closely to discrete units of organism life stage. Seasonal averages for salinity and other parameters were found to give a good first order approximation to the conditions under which the organism or lifestage exists. Changes of lifestage and organism migration often require analysis of an organism at more than one season during the year, although in some cases one season suffices to best show the organisms interaction with salinity changes due to the identification of the most sensitive season for the species.

The seasons defined for salinity averaging differ slightly from the calendar seasons. Figure II-6 illustrates the relationship between the redefined seasons and the mean monthly hydrograph from the U.S.Geological Survey (Not the Corps Modal hydrograph, see Figure II-2). The hydrographic seasons used for seasonal averaging of the salinity data are

Winter: December 1 to February 28
Spring: March 1 to May 31
Summer: June 1 to August 31
Fall: September 1 to November 30

Because organisms tend to adapt their biological seasons to the annual changes in the flow response, the deviation from calendar defined seasons will fit the biological time scale a little better. All maps in the Atlas which accompanies this report are labeled by seasons which correspond to these seasons.

It should be noted that all the seasonal average salinities are taken from the high water slack phase of the tide which in itself is the most saline value to which a fixed organism would be subjected. Use of the high slack resulted from both the form of the Hydraulic Model data and the realization that high salinity conditions are most important for evaluating low flow impacts.

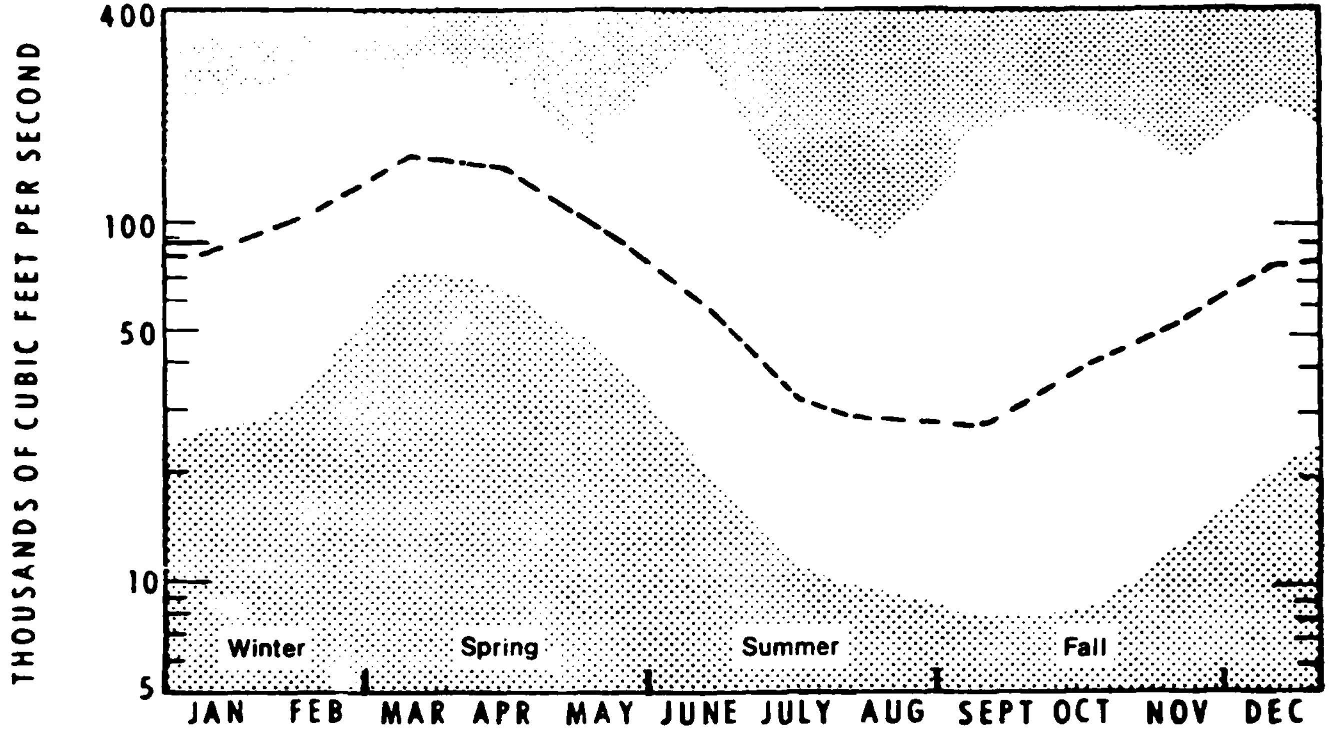


Figure II-6. Monthly Mean Discharge Curve in Chesapeake Bay Showing Biological Seasons.
(Source: U.S. Geological Survey, Monthly Streamflow Summary)
(Unshaded area indicates range of flows for 30 year record)

2. Data Analysis

The processing of the data generated by the Corps of Engineers Hydraulic model was done in several steps. Data generated from the model salinity, tide height and water velocity samplers was written on magnetic tape keyed geographically by station code and keyed by cumulative lunar day and tide stage (high or low slack). The cumulative lunar day was used to drive the tide generator and to control the inflow points to generate the appropriate hydrograph.

a. Seasonal Averages and Data Screening:

The first step in processing the tapes was the conversion of the cumulative lunar day into a calendar day to accommodate alignment with date and season. This was done by the formula:

$$\text{Solar Day} = \frac{\text{Lunar Day} - 149.8}{0.96644}$$

The second step in the processing of the data involved the reduction of the vast quantity of data into usable statistics which were stable and representative. Seasonal averages of the high water slack tide salinities were selected as the most appropriate statistic to use for mapping. Roughly 500,000 salinity data points were read off the source tape and processed to provide seasonal averages by station and by depths.

During the initial processing of the source tape a data screening program was found to be necessary in order to eliminate extraneous symbols, i.e. character data in numeric fields, and to flag gaps in the record or uncharacteristic values (such as salinity reversals with depth). Running averages of salinity were also generated during each season and salinity values deviating in excess of 8 parts per thousand from the running averages were discarded as extraneous values.

A study of the flagged data resulted in a list of problem stations which seemed to contain data errors. In consultation with the Army Corps of Engineers Chesapeake Bay Study Program and with the Waterways Experiment Station, data resulting from malfunctioning samplers was eliminated, recalibrated, or reassigned to correct depths. A corrected set of seasonal averages was then calculated from the refined data and this latter set was used to generate the salinity values used for habitat mapping.

b. Interpolations:

In the Hydraulic Model, salinity samplers were located vertically in the model by fractional distances to the bottom at that station, i.e., surface, 1/4 of depth, 1/2 of depth, 3/4 of depth and bottom. In some places the shallowness of the model precluded sampling all 5 depths. Where this occurred the 1/4 and 3/4 of depth samples were eliminated. This sampling procedure meant that seldom did two stations, even adjacent stations,sample the same depth. It was therefore necessary to convert the salinity data from the depths used by the Corps of Engineers to standard depth planes.

In order to convert salinities at depths sampled by the Hydraulic Model to standard planes, a linear interpolation computer program was developed. The purpose of the program was to develop salinity values for up to 5 interpolated depth planes depending on station depth at a particular location. The interpolated depth planes were selected to be:

Surface (0.5m)	(0 - 1.5 feet)
3.05 meters	(10 feet)
6.10 meters	(20 feet)
9.15 meters	(30 feet)
12.2 meters	(40 feet)

When surface data were not available (surface depths from the data set ranged from 0 - 4 feet), linear extrapolation based on the next two depth values was used to generate surface salinities. If no value of salinity existed at depths less than 5 feet, this extrapolation procedure was found to be highly inaccurate, and these values were generally dropped from the interpolated data set. When checking for extrapolation errors or other errors was completed, the interpolated salinity values were used as the basis for plan-view maps of seasonal salinity averages.

The selection of depth planes resulted in up to five maps of salinity for each season and scenario. The seasonal average salinity value for each station was then entered on the map at the spot corresponding to the location of that station. Salinity values in whole parts per thousand (0/00) were then interpolated by linear measurement between stations and isohalines were constructed by eye through each 0/00 value.

During the preparation of the salinity maps a striking confirmation of the synoptic nature of the model was observed. The pattern of co-tidal lines shown in Figure II-7 was established by Seitz in 1971. Salinity data from the Corps' Hydraulic model was taken in the same way as the same slack salinity runs of the Chesapeake Bay Institute's R.V.Ridgley Warfield. Each transect was sampled sequentially from the mouth of the bay to the head following the high water wave. All the stations on one transect were sampled simultaneously, which meant that samples in the middle of a long transect were at a slightly different stage of the tide than the ends of the transect. Although this tidal difference is slight, the salinity measurements detected it. This co-tidal effect could be responsible for much of the fine-scale detail across the Bay which is observable in some of the plan-view salinity maps.

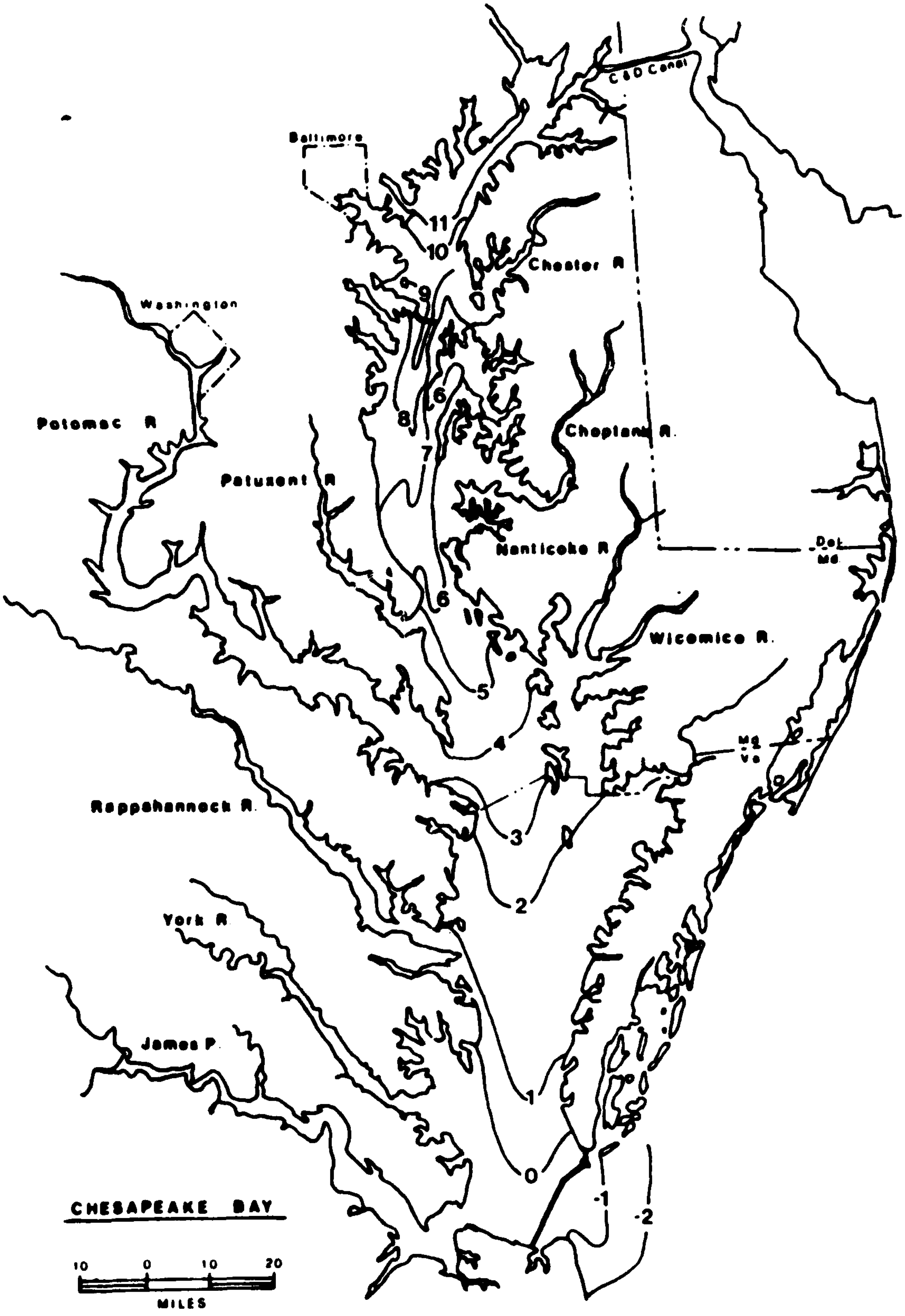


Figure II-7. Co-Tidal Lines (Slack Before Flood in Hours Delay from the Capes)

c. Transect Analysis:

After the plan-view isohaline maps were completed vertical profiles of salinity were constructed along the transects shown in Figure II-8. Cross sectional profiles of salinity were also constructed at each salinity measurement transect from the Corps' Hydraulic Model. Examination of the longitudinal vertical profiles shows the presence of fronts, indicated by the closer than usual spacing of isohalines. The location of these fronts is important because they serve as accumulation sites for organic materials, plankton and fish eggs. Planktivorous fish such as the menhaden often congregate along these fronts because of the concentration of their food supply. The actual position of fronts is closely dependent on the volume of river flow. At the interface, between two different density water layers, waves form and sometimes intrude into the surface layer accelerating mixing processes. Sharp cross estuary currents also form in these frontal zones impacting sedimentation, transport of nutrients and organisms.

d. Analysis of Salinity Extremes:

One matter of concern in the investigation of salinity increases is the effect of short-term pulses of high salinity on sessile or poorly motile species. It is already well known that brief pulses of low salinity water (freshets) effectively limit the upstream penetration of some estuarine organisms such as the oyster drill, Urosalpinx cinerea. The same limiting process could occur in the downstream extension of less salt tolerant vegetation if short duration salinity pulses exceeded the species tolerance.

A computer program was developed by WESTECH to detect and print out the duration and magnitude of short term salinity pulses. From a review of the literature and a selection of sensitive organisms within the list of the study species of the Biota Assessment, it was

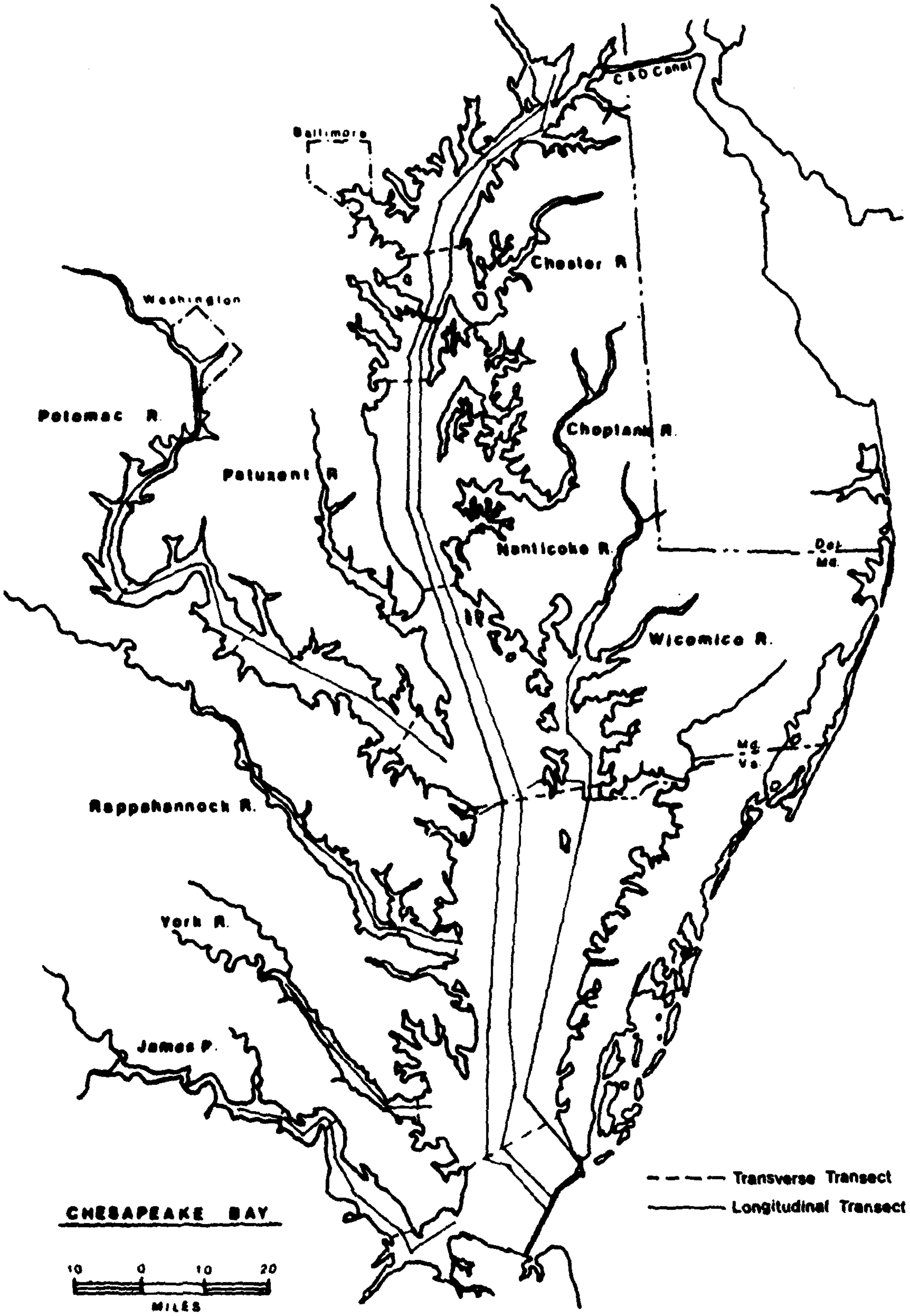


Figure II-8. Cross-Section Plot Locations determined that salinity extremes in the range of 1-2 parts per thousand could be significant. Short duration pulses are experienced on each tidal phase; however, pulses lasting two weeks or more could cause organism mortality either directly through salinity stress or because of secondary effects such as disease, predators, etc.

The salinity extreme program begins with the seasonal averages for each station and depth and then checks for short-term salinity values whose means over two or six-week periods differ significantly from the seasonal averages. The criteria of significance are:

- If 2 week average is more than 2 $^{0}/00$ in excess of seasonal average
- If 2 week average is more than 2 $^{0}/00$ less than seasonal average
- If 6 week average is more than 1 $^{0}/00$ in excess of seasonal average
- If 6 week average is more than 1 $^{0}/00$ less than seasonal average

The number of occurrences of each of these conditions is counted separately and is printed out together with the maximum and minimum values of the 2 week and 6 week averages during the season.

The program has been run for a selected series of stations, each located in the central channel of the bay or major river. Stations were selected so as to be representative of the transect on which they occur. The analysis was carried out for 7 main bay stations, three on the Potomac River and two stations each on the Rappahanock, York, and James Rivers. The results of this analysis will be presented in later chapters.

e. Time-History Plots:

In addition to the salinity tapes, the Corps of Engineers also provided WESTECH with printed salinity time history plots for each station and depth. Visual scanning of these plots was used by WESTECH personnel in cases where the presence or absence of a salinity spike was judged to be significant in the life history of the study species.

The time-history plots were also used to facilitate the early data screening process. Visual inspection often resolved problems of salinity inversion, depth reversal or similar difficulties. Questionable data values could also sometimes be found and eliminated with the aid of visual inspection. An example of a section of a typical time-history plot is shown in Figure II-9.

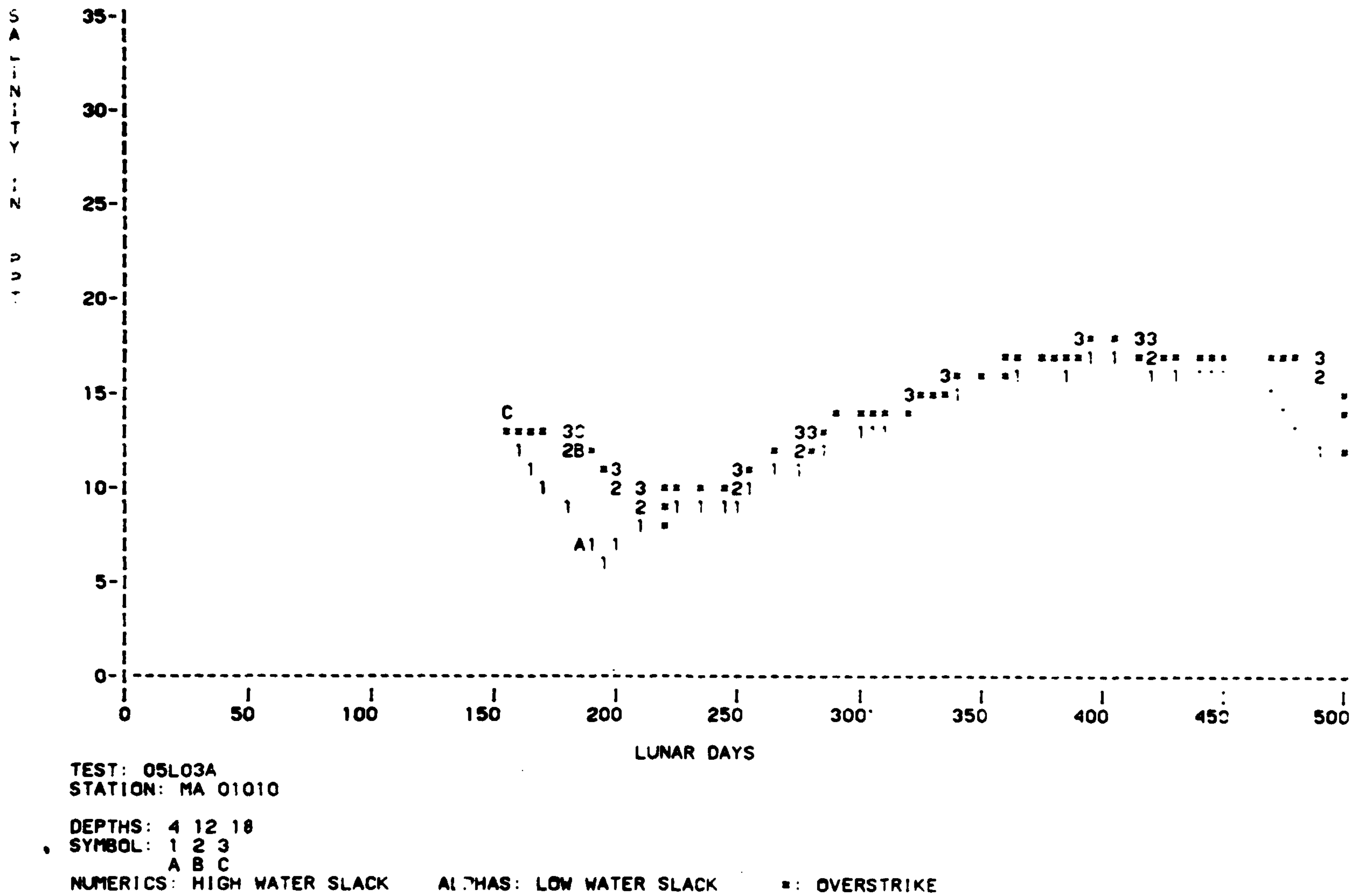


Figure II- 9 . Sample Time-History Plot of Station MA 0101 During Base Test

D. MAPPING

Central to Phase II of the Biota Assessment was the conversion of the geographically point-specific salinity data set to a definition of baywide organism distributions under each of four scenarios. This was accomplished through creation of two series of maps followed by measurement of habitat and habitat change.

1. Isohaline Maps

Beginning with the interpolated salinity data set discussed in the previous section, a series of isopleth style maps was created. The isopleths represent constant salinity with salinity differences between lines of one part per thousand and are termed isohaline contours. Shape of the contours was determined from visual connection of points which represent interpolation between all relevant salinity stations in a given area of the map.

Separate isohaline contour maps were prepared for each depth, season and scenario resulting in a set of approximately 50 maps. Maps at depths below the surface represent only stations with readings at or below that depth. These maps were used with depth contour overlays developed in Phase I to determine areas which were too shallow for plan-view interpolation between adjacent points.

2. Habitat Criteria and Mapping

As discussed previously, salinity, depth and substrate formed the major criteria for mapping potential habitat for organisms. In a few cases, presence or absence of other biological factors was also an important factor. During Phase I, tolerance data for all study species was developed (see Volume III, Chesapeake Bay Low Flow Study: Biota Assessment Final Report, 1980). This tolerance data was condensed to a checklist as shown in Table II-1. The checklist was then used as the guide to potential habitat mapping by overlapping appropriate depth and substrate combinations with the applicable isohaline map or maps. Work maps were generated for each study species showing all four scenarios. In certain cases scenarios were separated and mapped on two or more maps for the same species if the visual information became too complex. This was usually necessary when a species was to be mapped with multiple densities or life-stages. Of the three species of ducks included as Phase I study species, only canvasback was used in the Phase II maps due to data incompatibilities for mallard and black duck.

The habitat mapping portion of the project thus resulted in creation of a set of 1:250,000 scale work maps, one or more for each study species, containing potential habitat under each of the four scenarios. For 15 of these species, the information for each scenario has been transferred to separate 1:500,000 scale mylar base maps. For the remainder of the study species, mylar maps of the Base Average scenario have been prepared. These will be used to evaluate food chain mechanisms and other interactive effects.

3. Habitat Measurement and Calculation of Impact Ratios

From the working habitat maps, habitat areas were measured by polar planimeters using a standard grid as a basis for planimetry of each section of the bay. Measurements for each grid section were recorded on a standardized data form for each scenario. All values were based on averages of several measures and all measurements used were within instrument error. Instruments used were Los Angeles Scientific Instrument Company Polar Planimeters.

Table II-1. Checklist of Study Species Tolerances

Species	Lifestage	Density	Season(s) Mapped	Isohaline Depth (m)	Depth Range (m)	Salinity Range	Sediment Type	Other Organisms
Phytoplankton:								
Tidal Fresh	All	-	Sp,Su	S(surface)	S	0-5	-	-
Oligo-Low Mesohaline	All	-	Sp,Su	S	S	3-10	-	-
Mesohaline	All	-	Sp (Su)	S	S	8-15 (10-34)	-	-
Polyhaline	All	-	Sp,Su	S	S	13-34	-	-
Prorocentrum minimum	All	low 10-1000/m^3	W	6.1	6.1^+	18-34	-	-
		high 1000-10k/m^3	W	6.1	6.1^+	18-34	-	-
		low 500-10k/m^3	Su	S	S	5-18	-	-
		high 10k - 1000k /m^3	Su					
Submerged Aquatic Vegetation:								
Ceratophyllum demersum	All	-	Sp	S	0-3.1	0-7	All	-
Potamogeton pectinatus	All	-	Sp	S	0-3.1	0-12	All	-
Potamogeton pectinatus	All	-	Sp	S	0-3.1	0-12	All	-
Zostera marina	All	-	Sp	S	0-3.1	10-34	All	-
Ruppia maratima	All	-	Su	S	0-3.1	5-34	All	-
Zannichellia palustris	All	-	Sp	S	0-3.1	0-15	All	-
Emergent Aquatic Vegetation:								
Coastal Fresh Marsh	All	-	Su	S	0-1	0-2	All	-
Coastal Brackish Marsh	All	-	Su	S	0-1	2-34	All	-
Brackish Marsh-Irregular flooding	All	-	Su	S	0-1	2-34	All	-
Zooplankton:								
Mnemiopsis leidyi	Adult	1-25/m^3	Su	S	S	5-34	-	Beroe ovata
		25-100/m^3	Su	S	S	5-34	-	-
		0.1-1.0/m^3	W	S	S	11-34	-	-
		1-10/m^3	W	S	S	11-34	-	-

Table II-1. (Cont.)

Species	Lifestage	Density	Season(s) Mapped	Isohaline Depth (m)	Depth Range (m)	Salinity Range	Sediment Type	Other Organisms
Zooplankton: (cont.)								
Chrysaora quinquechirrha	Medusa	0.5-5/m^3	Su	S	S	5-34	-	-
	Polyp	10-50/m^3	Su	3.1	3.1-9.7	5-34	-	-
Brachionis calcyiflorus	Adult	low	Sp	S	S	0.5-5	-	-
		high	Sp	S	S	0.0-0.5	-	-
Acartia clausi	Adult	low	Sp	S	S	5-10+18-34	-	-
		high	Sp	S	S	10-18	-	-
Acartia tonsa	Adult	low	Su	S	S	0.1-1.0 + 26-34	-	-
		high	Su	S	S	0.0-5 + 20-26	-	-
		high (predated)	Su	S	S	5-20	-	Forage Fish
Eurytemora affinis	Adult	low	Sp	S	S	10-12	-	-
		high	Sp	S	S	0-10	-	-
		low	Su	S	S	0-4	-	-
Scottolana canadensis	Adult + Copepodites	low	Su	S	S	0-1.0 + 1.0-5	-	-
		high	Su	S	S	1.0-5		
Bosmina longirostris	Adult	low	Su	S	S	0.5-5	-	-
		high	Su	S	S	0-0.5	-	-
Evadne tergistina	Adult	low	Su	S	S	16-20	-	-
		high	Su	S	S	20-34	-	-
Podon polyphemoides	Adult	low	Sp	S	S	3-8+22-34	-	-
		high	Sp	S	S	8-22	-	-
Benthics:								
Limnodrilus hoffmeisteri	Adult	low	Sp	3.1	3.1-12.2	0.5-1.0	All	-
		high	Sp	3.1	3.1-12.2	0-0.5	All	-
Heteromastus filiformis	Adult	low	Su	3.1	0-10	2-5	All	-
		high	Su	3.1	0-6	5-34	All	-
Pectinaria gouldii	Adult	low	Sp	3.1	0-15	10-15	All	-
		high	Sp	3.1	0-10	15-34	All	-

Table II-1. (Cont.)

Species	Lifestage	Density	Season(s) Mapped	Isohaline Depth (m)	Depth Range (m)	Salinity Range	Sediment Type	Other Organisms
Benthics: (cont.)								
Scolecolepides viridis	Adult	low	Sp	3.1	0-10	0.0-1 +	All	-
						10-15	SM,M	-
		med	Sp	3.1	0-10	1-5	S,MS	-
						5-10		
		high	Sp	3.1	0-10	1-5	S,MS	-
Streblospio benedicti	Adult	low	Su	6.1	1-20	5-34	S	-
		high	Su	6.1	1-20	5-34	MS,SM,M	-
Urosalpinx cinerea	Adult	-	Su	3.1	0-10	12.5-34	H	-
Crassostrea virginica	Adult	-	Su	3.1	0-10	7.5-34	H	MSX,dermo
Macoma balthica	Adult	low	F	3.1	0-12.2	2.5-5	All	-
		high	F	3.1	0-10	5-18	All	-
Mercenaria mercenaria	Adult	low	Su	3.1	1-6.1	12.5-34	SM,M	-
		high	Su	3.1	1-6.1	12.5-34	MS,S	-
Mulinia lateralis	Adult	low	F	3.1	0-12.3	10-15	All	-
		high	F	3.1	0-10	15-34	All	-
Mya arenaria	Adult	rare	Sp	3.1	0-6.1	3.5-5	All	-
		low	Sp	3.1	0-6.1	5-8	All	-
		high	Sp	3.1	0-6.1	8-34	All	-
Rangia cuneata	Adult	low	Su	3.1	1-10	5-10	All	-
		high	Su	3.1	1-10	0.5-5	All	-
Ampelisca abdita	Adult	low	Sp	3.1	3.1-6.1	14-34	All	-
					6.1-12.2	14-34	S	-
		high	Sp	3.1	6.1-12.2	14-34	MS,SM,M	-
Balanus improvisus	Adult	rare	Su	3.1	0-12.2	20-24	H	-
		low	Su	3.1	0-12.2	2-5	H	-
		high	Su	3.1	0-12.2	5-10	H	-
		high (predated)	Su	3.1	0-12.2	10-20	H	-
Callinectes sapidus	Adult & Juv. (male)							
		low	Su	3.1	0-12.2	0.1-15	-	-
		high	Su	3.1	0-12.2	15-20	-	-
		low	W	12.2	13-20	5-25	-	-
		high	W	12.2	20+	5-25	-	-

Table II-1. (Cont.)

Species	Lifestage	Density	Season(s) Mapped	Isohaline Depth (m)	Depth Range (m)	Salinity Range	Sediment Type	Other Organisms
Benthics: (cont.)								
<u>Callinectes sapidus</u>	Adult & Juv.							
	(female)	low	Su	3.1	6.1+	10-34	-	-
		high	Su	3.1	0-6.1	10-34	-	-
		low	W	12.2	10-13	25-34	-	-
		high	W	12.2	13+	25-34	-	-
	spawning	-	Su	S	0	23-34	-	-
<u>Cyathura polita</u>	Adult	low	Su	3.1	0-6.2	0.5-1	All	-
						1-7	M	-
						7-12	All	-
		high	Su	3.1	0-6.2	1-7	S,MS,SM	-
<u>Gammarus daiberi</u>	Adult	low	Su	3.1	0-6.2	0.5-1+	All	-
						5-7		
		high	Su	3.1	0-6.2	1-5	All	-
<u>Leptocheirus plumulosus</u>	Adult	low	Sp	3.1	0-12.3	0.5-15	All	-
		high	Sp	3.1	0-12.3	1-10	All	-
<u>Palaemonetes pugio</u>	Adult & Juv.	low	Su	S	0-3.1	1-5	-	-
		high	Su	S	0-3.1	5-15	-	-
		high (w/ vulgaris)	Su	S	0-3.1	15-20	-	P. vulgaris
Vertebrates:								
<u>Alosa sappidissima</u>	Egg & larvae	-	Sp	S	3.1+	0-3	-	-
	Juv.	-	Su	S	S	0-5	-	-
<u>Alosa pseudoharengus</u>	Egg & larvae	-	Sp	S	0-3.1	0-3	-	-
	Juv.	-	Su	S	S	0-5	-	-
	Adult	-	Su	S	S	0-34	-	-
<u>Brevortia tyrannus</u>	Juv.& larvae	-	W	3.1	1+	0-5	-	-
	Adult	high	Su	S	All	5-18	-	-
		normal	Su	S	All	5-34	-	-
<u>Anchoa mitchelli</u>	Eggs	-	Su	S	S	5-15	-	-
	Larvae	-	Su	S	S	3-7	-	-
	Adult	-	Su	S	S	0-34	-	-
<u>Micropogonias undulatus</u>	Larvae & Juv.	-	W	3.1	1+	0-7	-	-
	Adult	-	Su	3.1	3.1+	10-34	-	-

Table II-1. (Cont.)

Species	Lifestage	Density	Season(s) Mapped	Isohaline Depth (m)	Depth Range (m)	Salinity Range	Sediment Type	Other Organisms
Vertebrates: (cont.)								
Leiostomus xanthurus	Larvae & Juv.	-	W	3.1	1+	0-7	-	-
	Adult	-	Su	3.1	1+	8-34	-	-
Menidia menidia	All	-	Su	S	0-6.2	3-34	-	-
Morone americana	Egg & Larvae	-	Sp	S	0-3.1	0-3	-	-
	Juvenile	-	Su	S	0-3.1	0-5	-	-
	Adult	-	Su	S	S	5-18	-	-
Morone saxatilus	Egg & Larvae	-	Sp	S	S	0-1	-	-
	Juvenile	-	Su	S	S	0-5	-	-
	Adult	-	Su	S	S	5-34	-	-
	Adult	-	W	6.2	6.2+	7-34	-	-
Perca flavescens	Egg & Larvae	-	W	S	S	0-0.5	-	-
	Juv. & Adult	-	Su	S	S	0-12	-	-
Aythya valisineria	Adult	1-10/km^2	W	-	-	-	-	Macoma balthica (SAVs)

Table II-1. (Cont.) Key to Table II-1.

Density: low
high
see map atlas.

Season Mapped:
Sp - Spring
Su - Summer
F - Fall
W - Winter

Isohaline Depth (meters) : S - Surface (0.5m)

Depth Range (meters): S - Surface (0.5m)

Sediment Type:
M - Mud
SM - Sandy Mud
MS - Muddy Sand
S - Sand
H - Hard or Rocky Substrates

Planimetered measurements were aggregated for each scenario and study species. The difference in areas between scenarios was then used to calculate impact ratios for each low flow scenario according to the formula described in Section II-A. These impact ratios have been tabulated and are shown in Chapter III.

E. OTHER ANALYSES

1. Species Interactions

Calculation of impact ratios (IR) gives the response to freshwater inflow reductions of each study species as an isolated entity. In reality, however, these and other organisms are linked to one another by a complex series of trophic, competitive, and other biological interrelationships. Increase in habitat for a major predator or parasite, or reduction in area of an important food source could be expected to exert some degree of secondary effect on study species.

In an effort to predict and assess the impact of such secondary effects, the preliminary step was to identify major interaction pathways between study species (and some additional taxa, when important). Two products were generated to aid in this assessment; trophic diagrams and species interaction matrices.

Trophic Diagrams - a series of conceptualized trophic diagrams were produced to identify important energy/material transport pathways in the Bay's ecosystems. These diagrams are subunits, in greater detail, of the Conceptual Model presented in the Phase I report (Figures II-10 and II-11). Each major trophic and taxonomic subset (e.g. herbivorous zooplankton, benthic detritivores) is

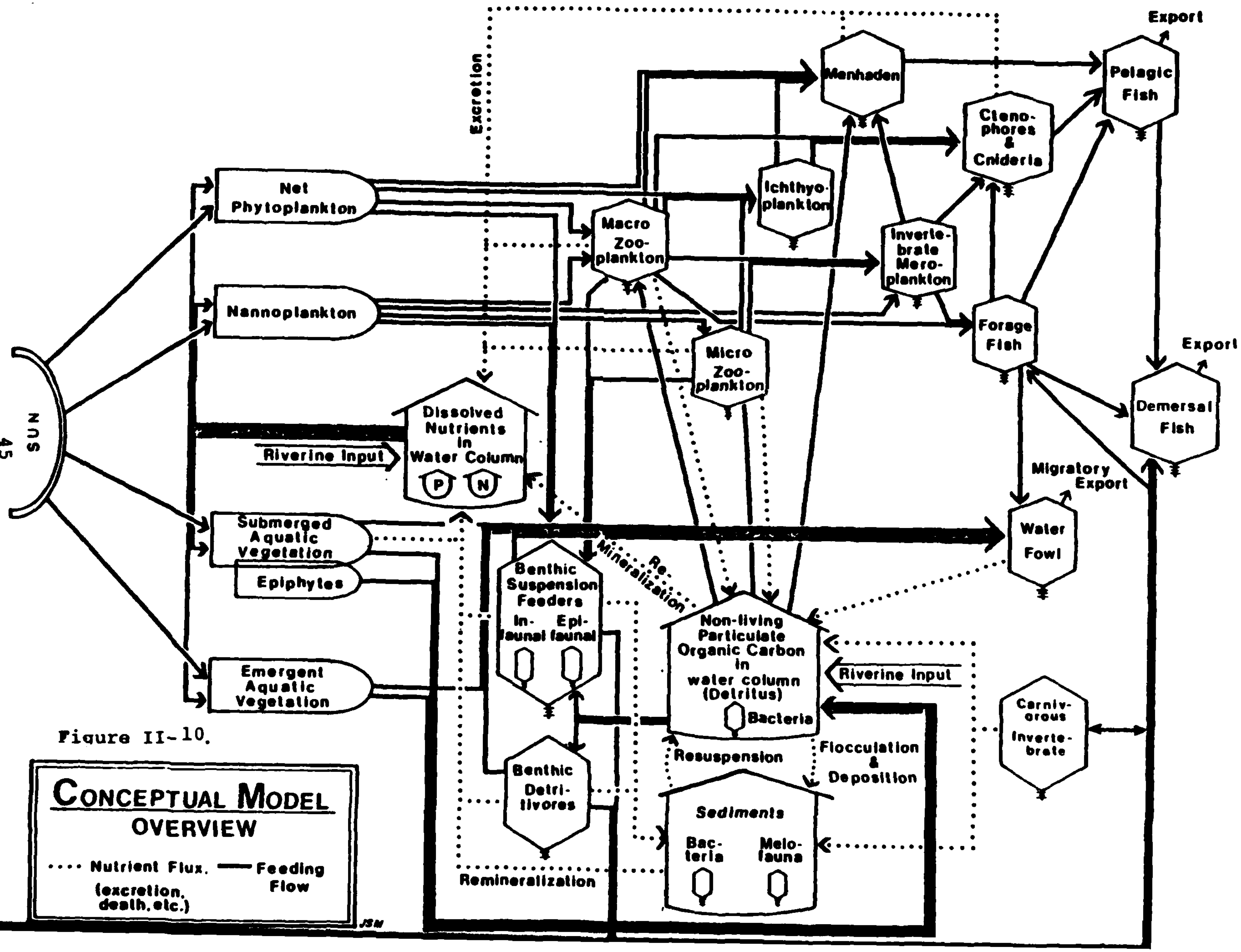

Export
Pelagic Fish
Menhaden
Cteno-phores & Cnideria
Export
Demersal Fish
Ichthyo-plankton
Inverte-brate Mero-plankton
Forage Fish
Excretion
Net Phytoplankton
Macro Zoo-plankton
Nannoplankton
Micro Zoo-plankton
SUN
Dissolved Nutrients in Water Column
P
N
Riverine Input
Migratory Export
Submerged Aquatic Vegetation
Water Fowl
Epiphytes
Re-Mineralization
Benthic Suspension Feeders
In-faunal
Epi-faunal
Non-living Particulate Organic Carbon in water column (Detritus)
Bacteria
Riverine Input
Emergent Aquatic Vegetation
Carniv-orous Inverte-brate
Resuspension
Flocculation & Deposition
Benthic Detri-tivores
Sediments
Bac-teria
Melo-fauna
Remineralization
CONCEPTUAL MODEL
OVERVIEW
Nutrient Flux. (excretion, death, etc.)
Feeding Flow
JSN

Figure II-10.

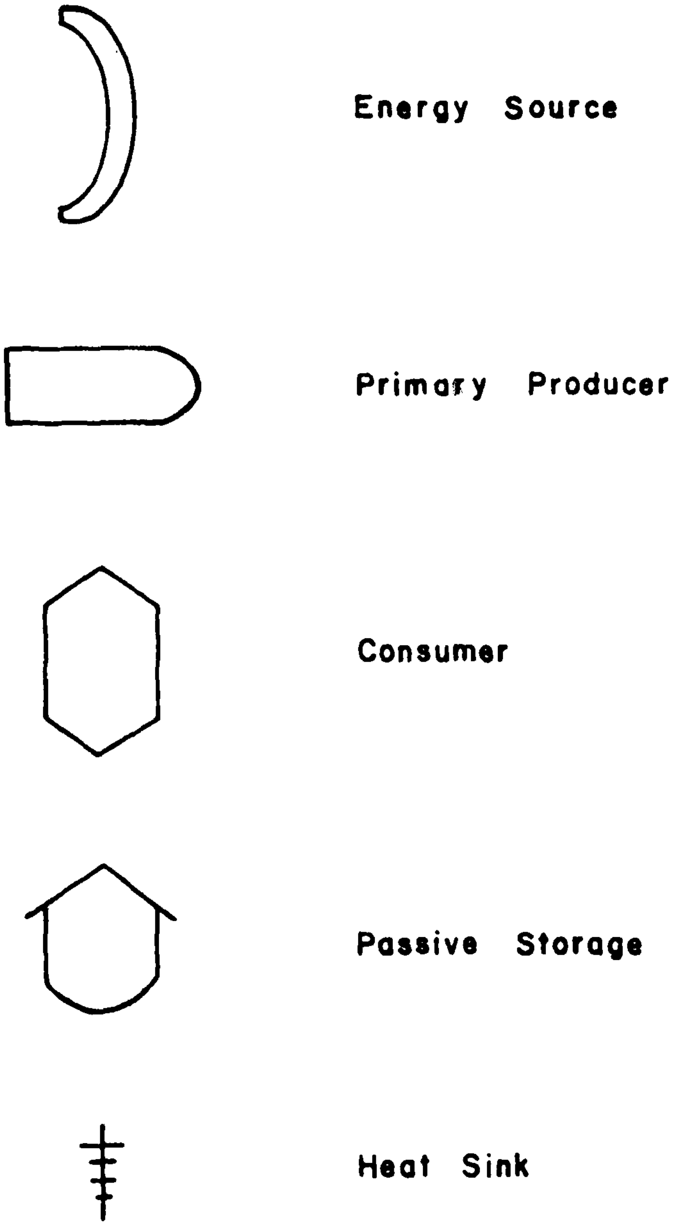


Figure II-11. Key to Symbols Used in the Conceptual Trophic Model (Source: Odum 1972) represented by a trophic diagram; all study species and associations in that set are listed. Where study species occur in subblocks of the diagram they are also listed. For example, Fig. II-12 shows Ctenophores and Cnidaria, with the two study species (Mnemiopsis and Chrysaora) in the center block; subsets with which they interact have study species listed where these occur. Seasonality and salinity range for major components are also included. Trophic diagrams for all ecosystem subsets are presented in Section III-D.

Species interaction matrices - A series of matrices were constructed to show, on a species-by-species basis, major interactions with other ecosystem components. Interactions with study species and with other organisms and/or taxonomic units (when important) are included. The following sets of interactions are included:

Predation - (P) organism in left hand column is a predator on study species.

Prey - (Food) - (F) organism in lefthand column is a prey species or a food source for study species.

Parasite or Disease - (D) organism in left column is a parasite or a disease of the study species.

Competition - (C) organism in lefthand column competes with the study species for food or habitat. This is based on direct evidence (from published reports) or may be inferred from trophic or habitat requirements. In general, if two species rely on the same food for a major portion of their diet ($>$ 25% or so), and that food is limited (or potentially limited under reduced flow regimes), then the two species can be considered competitors. The relationship can work in one direction only, as with an omnivore competing with a species possessing a specialized food requirement.

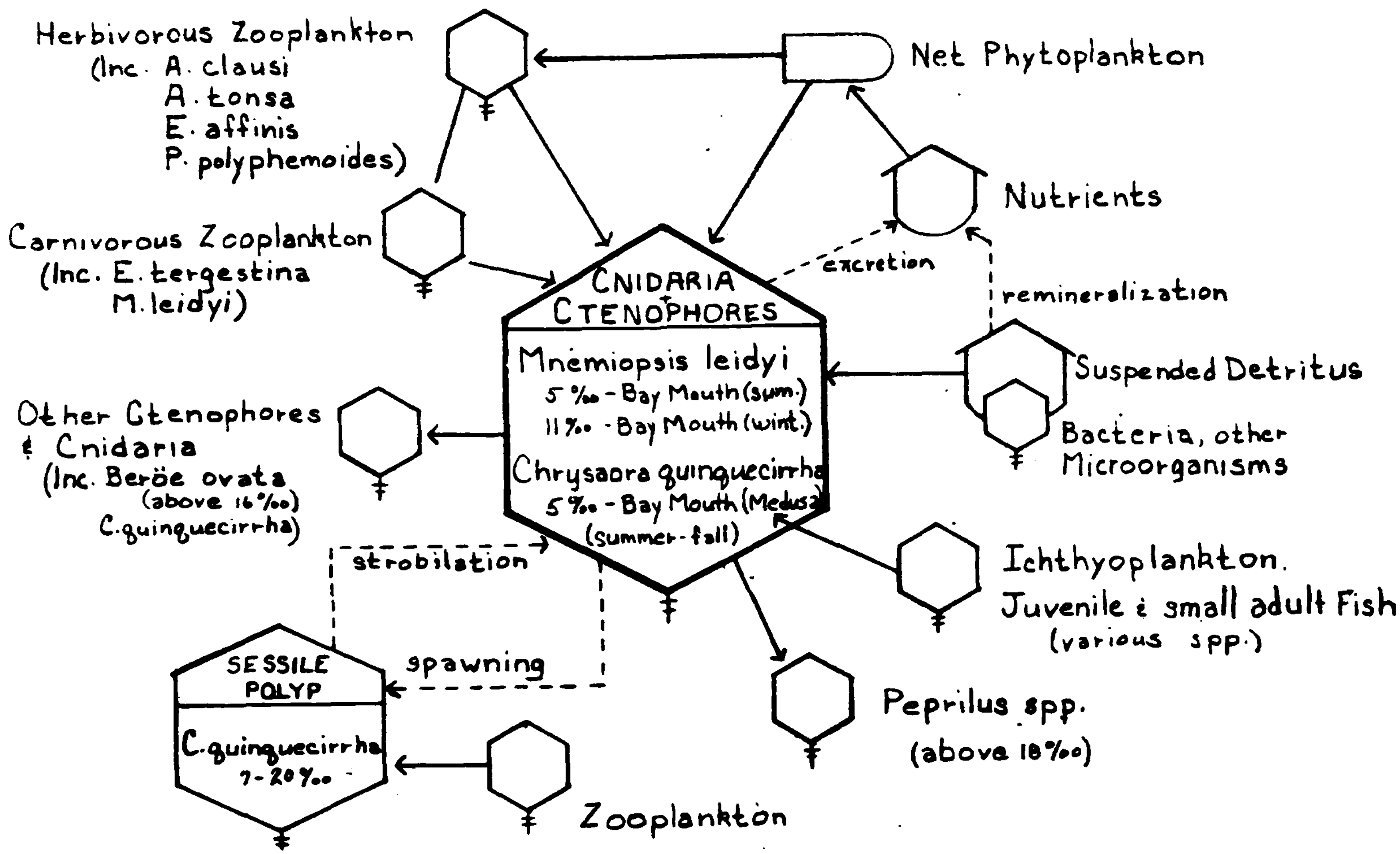


Figure II-12. Sample Sub-Component Trophic Diagram

Habitat provider - (H) species in lefthand column provides a habitat for the study species, or one of its lifestages.

Habitat modifier - (M) species on left modifies habitat for study species. This might be a positive or negative effect (latter exemplified by effect of cow-nosed ray on SAV beds)

Overlap - (0) strongly similar and overlapping habitat, but with little apparent competition;(more complete data might reveal that competition does, however, exist).

* - Asterisks were used to emphasize major interactions between two species in the matrix.

These matrices allow a more detailed examination of species interrelationships, and show more clearly patterns of interactions.

Both trophic diagrams and species interaction matrices were used to identify major species of concern in predicting possible secondary effects. Change in habitat of a major predator, parasite, or competitor will be examined and potential impact discussed in the species accounts presented in Section III-C.

It should be emphasized that such secondary ecosystem effects are, by their nature, more qualitative and speculative than direct impacts based on habitat mapping. The extent and importance of species interactions are not completely known on anything approaching an ecosystem-wide basis. The magnitude of any predicted effect is also somewhat speculative, as the change may in turn be damped or enhanced by simultaneous shifts in other portions of the ecosystem. Nevertheless, an assessment of potential secondary impacts is important in addressing the effects of reduced fresh water inflows to Chesapeake Bay.

2. Tolerance to Extreme Conditions

Effect of short-term extreme salinity values: Potential habitat for the study species was mapped on the basis of seasonal salinity averages, which represent the best approximation of a species' response to the long-term characteristics of its environment. However, salinity changes of greater magnitude - although of relatively short duration - can exert an effect on the distribution of sensitive species. The severity of this impact would reflect; 1) magnitude, seasonality, and duration of the extreme event; 2) sensitivity of the species to such salinity changes; 3) ability of a species to exploit new habitat, or rapidity of its elimination due to unfavorable conditions (by migration or death); 4) recovery period after end of extreme event.

Impact due to extreme salinity events would be primarily associated with the boundary or edge of a species' range. For this reason, selected stations only were examined for extreme values. Salinity changes exceeding ± 2 ^{0}/00 from that station's seasonal average by computer scan of data tapes; extreme events exceeding 14 days duration and events ± 1 ^{0}/00 of 42 days duration were isolated and their frequency noted. These data were compared to known salinity tolerances of a group of study species, and potential impact on these species assessed.

The majority of species inhabiting the estuarine environment are relatively eurytopic as regards environmental variables; however, a number of study species have salinity requirements well enough documented to enable examination of potential short-term effects. Salinity sensitivities of study species and their various lifestages, as well as the season of major concern, were examined. Several taxa were selected for salinity extreme impact assessment. Particular attention was paid to the species' actual response to salinity, both in rapidity of this response, and ability to recover after perturbation. These species can be considered to be examples (or models) of effects of short-term salinity event, as assessment of such effects for all of the 54 study species is beyond the scope of this report (and the existing data). Model species represent several seasons, and a number of types of response. In the majority of cases, extreme events would affect primarily a single life stage, such as spawning, egg or larval survival, or setting of juvenile organisms.

Results of the above assessment are discussed in Section III-B.

3. Velocity Effects

The effects of low freshwater inflows on the tidal velocities were examined because of the dependence of the life stages of some of the study species on estuarine circulation. Velocities were measured in the model by means of miniature Price-type cupped vane meters. These meters measured water velocity over an area equivalent to a 4.0 by 100 foot section of the Chesapeake Bay. The threshold of detection by these mini-meters was 0.3 fps in the Bay (0.178 knots).

Velocity measurements from the Hydraulic Model tests were limited due to difficulty involved in obtaining velocity information during dynamic salinity tests. Only 6 stations supplied consistent velocity information during both spring and summer periods, four of which were on main bay transects with one station on the upper Potomac River and one on the Upper Rappahannock River. Maximum velocities on spring and neap tides were tabulated and analyzed for patterns. Base versus futures velocity test comparisons generally revealed no discernable differences which would be attributed to freshwater inflow suppression.

In June, generally a low inflow period during which drought effects could be expected to be pronounced, spring tide velocities were noted to be generally higher in absolute value during the most severe drought scenario (Future Drought). This may be due to greater relative tidal action during flood tide unimpeded by river flow in the opposite direction.

Since Congress has authorized deepening to 50 feet, channels leading to Baltimore Harbor, all scenarios of the low freshwater inflow test included these 50 foot navigation channels. Since presence of the channels may affect velocities and hence transport of organisms, such effects are discussed here briefly. The effects of increasing the channel depths and cross-sectional area were investigated during the Baltimore Harbor study (Granat & Gulbrandsen 1981) and included minor velocity and salinity effects. However, strong up or down Bay winds occur seasonally and exert a stronger influence on water level and currents than those which occur due to channel deepening. Changes which occur within the range of variation normally encountered by an organisms are not significant as limiting factors.

Of more importance biologically is the change in the net up-Bay flow of water at depth. Within the 50 foot channel bottom tide current velocities increased while surface velocities decreased by approximately the same amount. There is a tendency for the flood velocities to predominate over the ebb at depth and this tendency is increased by the 50 foot channel depth. The trend to increased flood predominance consistantly appears only south of the mouth of the Potomac River. However, the possibility exists that up Bay transport could be enhanced by the 50 foot channel depth baywide.

Small changes in the net up-Bay transport would be more meaningful to some organisms than to others. Sciaenid fish larvae are known to detect and ride the flood then settle to the bottom and sit out the ebb. In this way they reach the upper estuary much faster than they would by merely passive drifting, while expending little effort. Bivalve larvae follow the same pattern. However, phytoplankton such as Prorocentrum appear to drift passively up the Bay with the net flow.

F. INTERACTION WITH THE SCIENTIFIC COMMUNITY

Throughout the Biota Assessment, WESTECH and the Corps have interacted closely with the scientific community of the Chesapeake Bay. Many of the early contacts are described fully in the Phase I report and include visits to scientific institutions, laboratories and libraries, meetings with scientists on an individual and small group basis and phone conversations to keep continually updated to ongoing research activities.

In addition to the above activities, WESTECH has continued during Phase II to maintain an Anchor Team of Bay Scientists to review preliminary results. This Anchor Team has assisted WESTECH staff in presenting a scientific conference on the Biota Assessment. The conference was held on October 29, 1981, at the Naval Academy in Annapolis. Anchor team members present were Alice J. Lippson, Dr. Robert Otto, Dr. Anthony Provenzano, Dr. Louis Sage, and Dr. J. Court Stevenson. At the conference WESTECH staff and representatives from the Corps presented information showing the rationale and basis for the Biota Assessment followed by presentations of preliminary results, including relationships of flow to organism distribution.

The conference was attended by roughly 60 scientists and included representation from the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, National Marine Fisheries Service, U.S. Department of Energy, U.S. Geological Survey, Maryland Department of Natural Resources (Tidewater and Water Supply Divisions), Maryland Department of Health, Virginia State Water Control Board, Pennsylvania Department of Environmental Resources, District of Columbia Environmental Programs Office, University of Maryland, Chesapeake Research

Consortium, Chesapeake Bay Foundation, Virginia Institute of Marine Sciences, Benedict Environmental Research Laboratory, Old Dominion University, Smithsonian Institute - Chesapeake Bay Center for Estuarine Studies as well as representatives from public utilities and several private companies.

Interaction with the scientific community will continue after the completion of this report. The Corps of Engineers and U.S. Fish and Wildlife Service have appointed a Biota Evaluation Panel (BEP) of prestigious scientists to determine the change in species population or biomass associated with each habitat change. The panel will establish salinity-related goals oriented to maintaining a healthy and productive Chesapeake Bay.

III. DATA ANALYSIS AND RESULTS

This chapter will summarize the results of Phase II of the Biota Assessment, beginning with comparison of seasonal salinity patterns in the bay under different scenarios and progressing through mapping and calculation of changes in potential habitat to secondary effects of food chains, species competition, salinity extremes and others. For a pictorial display of detailed changes predicted for organism habitat, the reader should refer to the map atlas which accompanies this report.

A. SEASONAL SALINITIES

Seasonal salinities as described in the section below refer to salinities of summer 1965 through spring 1966 for the Base and Future Drought scenarios. For the Base Average scenario, an average of three modal years was used. For the Future Average scenario, two modal years were used since that test was shorter. The first modal year was excluded in both cases due to some instabilities in salinity structure.

1. Characterization of Baywide Patterns

The low fresh water inflow study produced the largest consistent data set of salinity measurements ever collected for Chesapeake Bay. One half million data points from 206 locations, each having from one to five sampling depths were collected (3 locations were later deleted). The bulk of the salinity observations was taken at high water slack. These observations were reduced to seasonal averages for each year of hydrograph run.

At any selected station salinity variation occurred as a function of hydrographic season. Salinity stratification with depth varied as a function of fresh water inflow. Changes in stratification occurred between neap and spring tides at many locations.

Isohalines are known to be offset in Chesapeake Bay such that higher salinities occur at points on the eastern shore than occur at points on the western shore having the same latitude. This is believed to be due to the twin effects of higher freshwater inflow from the western shore and coriolis force which displaces currents clockwise in the northern hemisphere. As large as it is, the hydraulic model is too small to demonstrate much coriolis effect. It was noted during high inflow periods that the isohalines wer displaced to about the same extent in the model as in the Bay. It appears that fresh water inflow from the western shore is enough to duplicate in the model the effect of both factors in the Bay.

Recovery of the overall salinity pattern from the drought to the modal condition was tracked by examining the time history of salinity at selected stations. This recovery was much more rapid than initially expected. Within the main Bay, salinity patterns returned to predrought configuation within one season.

Figure III-1 taken from the Army Corps data (Richards and Gulbrandsen 1981) gives a good picture of the speed of recovery of main Bay station 1-01. The lower portion of the figure diagrams the inflow hydrograph. The upper portion of the figure shows a jumble of

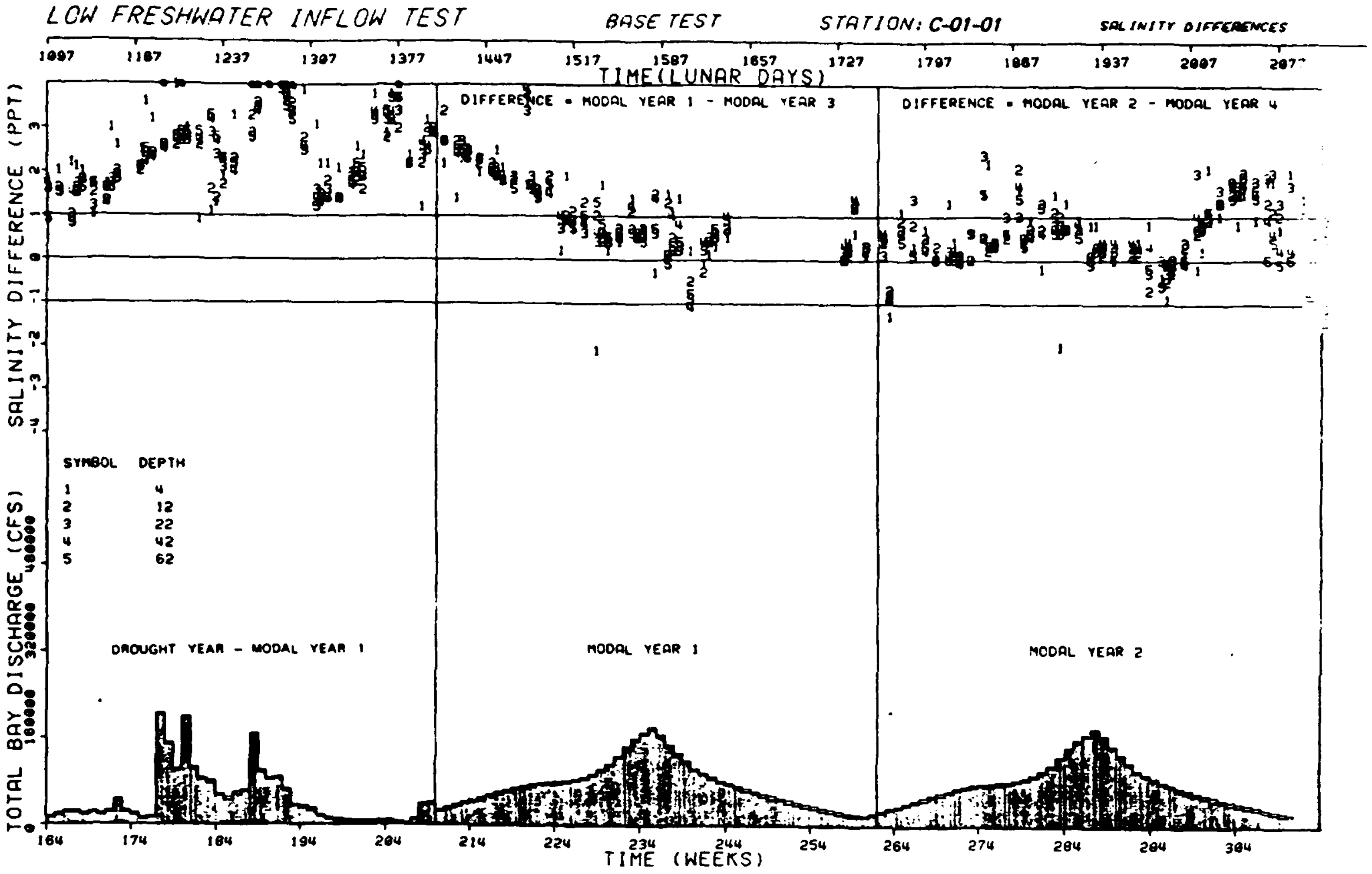


Figure III-1. Dynamic Normalcy Plots, Base Test, Station CB 0101 code. Each integer 1 through 5 represents the difference in a pair of measurements taken at the same depth. During block 1 the differences are between salinity values from the drought hydrograph and the first of the modal years. Nearly all the difference values exceed 1 ppt and several exceed 4 ppt. These values are differences between point measurements not between seasonal averages.

A steep decline in the difference values begins within two weeks of the onset of the modal hydrograph. Within 10 weeks most of the differences are within the band ± 1 ppt. which is defined as salinity normalcy. However, by tracing the surface salinity differences (symbol 1) it can be seen that surface salinities continue to oscillate outside the ± 1 ppt band for at least 2 years at this station. In fact, surface salinity differences continued to oscillate at least ± 2 ppt for the first two modal years at all the Bay and river stations graphed in the Corps report.

However, when compared in the form of seasonal averages the modal hydrograph generated salinities do not differ from each other at any given station. The seasonal averages of the drought year hydrographs do differ from each other and each drought year set of seasonal averages differs from the set of seasonal averages of modal hydrograph generated salinities.

2. Anomalies and Problem Stations

During the preparation of the isohaline maps from the hydraulic model data a few problem areas emerged. The first to be noticed was that areal coverage of the Bay was uneven. In broad shallow regions, there were not enough stations. Places which needed more resolution in order to draw isohalines precisely include Tangier Sound, Pocomoke Sound, Eastern Bay and the Mouth of the Choptank adjacent to Broad Creek.

Several inflow points on minor tributaries were combined into a single port in the hydraulic model. In some cases this left a tributary with no source of fresh water at its head. A seiche would be set up driven by the tide in the main Bay. Under these circumstances salinity measurements up the axis of the tributary reliably produced salinities increasing in an upstream direction. To avoid unrealistic salinity patterns, all upstream salinity stations in tributaries without fresh water inflows were disregarded when drawing the maps. The salinity of the station closest to the mouth of the tributary was used to determine the salinity in that tributary. This phenomenon does happen in rivers with low discharge volumes.

Stations in tributaries which did not fit the salinity gradient established by the neighboring stations would produce an "island" of lower or higher salinity. These stations were considered as anomolous for that particular season and were disregarded when drawing maps.

Occasionally a station was found which was missing large sequences of observations, due to sampler malfunction or failure of an automated inflow valve to cycle properly. Where comparable scenarios existed, essentially other modal hydrographs of the same season, data from the existing time was substituted for the missing time. Where a comparable time block did not exist the seasonal average was omitted for the season in question and values for that station were determined by linear interpolation from adjacent stations.

Sticking valves occurred on only three occasions, all in the futures test and in each case were corrected within one step of the hydrograph.

The Nanticoke, Choptank, York, and Elk rivers each have significant forks which did not have scaled freshwater input into each fork. The sum of the inflow to both forks is introduced by one port into one branch of the river. For mapping purposes the branch without inflow was treated as a mirror image of the branch with the fresh water inflow. Maryland tributaries which did not have fresh water inflows were the Bush,Back, Bohemia,Magothy, South and Saint Mary's. Virginia rivers without fresh water inflow included the Elizabeth, Piankatank, Mobjack Bay tributaries and the Back River. Inflows from thirteen sewage treatment plants were modeled, but the cooling water flows from power plants were not. The sewage treatment plant flows are responsible for an increase in fresh water into the Patuxent during the future tests. This increase is detectable in the salinity stratification during some seasons and is the only example of a consumptive gain in the future conditions. VEPCO Surry power plant takes cooling water from the James River below Hog Island and injects it into the river again upstream of Hog Island. The volume of flow at peak pumping is about 106 cubic meters per second which is enough to produce a detectable local change in the isohaline pattern. This flow was not modeled, however, and the mapping will not exactly recreate conditions in this stretch of the river.

The sixth transect up the main Bay (CB-06) had a substantial loss of data at the 4th station. However, two stations closely spaced on either side did not suffer the same fate and permitted the drawing of isohalines for each season and scenario.

3. Characterization of Scenario Differences

a. Salinity Change:

The response of Chesapeake Bay to reduced fresh water inflow is increased salinity of the Bay. The projected consumptive loss of fresh water is less than the reduction of fresh water inflow due to drought. The increase in salinity of Chesapeake Bay is not as great due to consumptive loss as it is due to drought. Figures III-2 through III-5 graph the salinity values for a transect from the mouth to the head of the Bay. The solid line traces the decrease in surface salinity from 23 $^{0}/00$ at the mouth to 0 $^{0}/00$ at the head. The dotted line shows the decrease in salinity for the same season (spring), during the consumptive water loss scenario.

Spring is the high inflow season and the outflow from the Susquehanna suppresses any detectable surface salinity change down to the mouth of the Choptank River during the consumptive loss (Future Average) scenario. From this point the salinity difference over the Base Average scenario increases steadily until about Newport News where the difference is a maximum. The difference decreases steadily from Newport News toward the mouth of the Bay.

During the Future Drought (drought plus consumptive loss) scenario the salinity differences increase from the head of the Bay to a maximum at about the mouth of Pocomoke Sound and then the difference decreases slightly toward the mouth of the Bay. This one season is illustrative of the pattern of salinity changes observed in the course of the low freshwater inflow test; 1) the drought events are more saline than the projected consumptive loss events, 2) the effects of drought and consumptive loss are additive. The Future Drought is the most saline scenario of the four being considered. 3) The spring is the least saline season and the fall is the most saline season in all the scenarios.

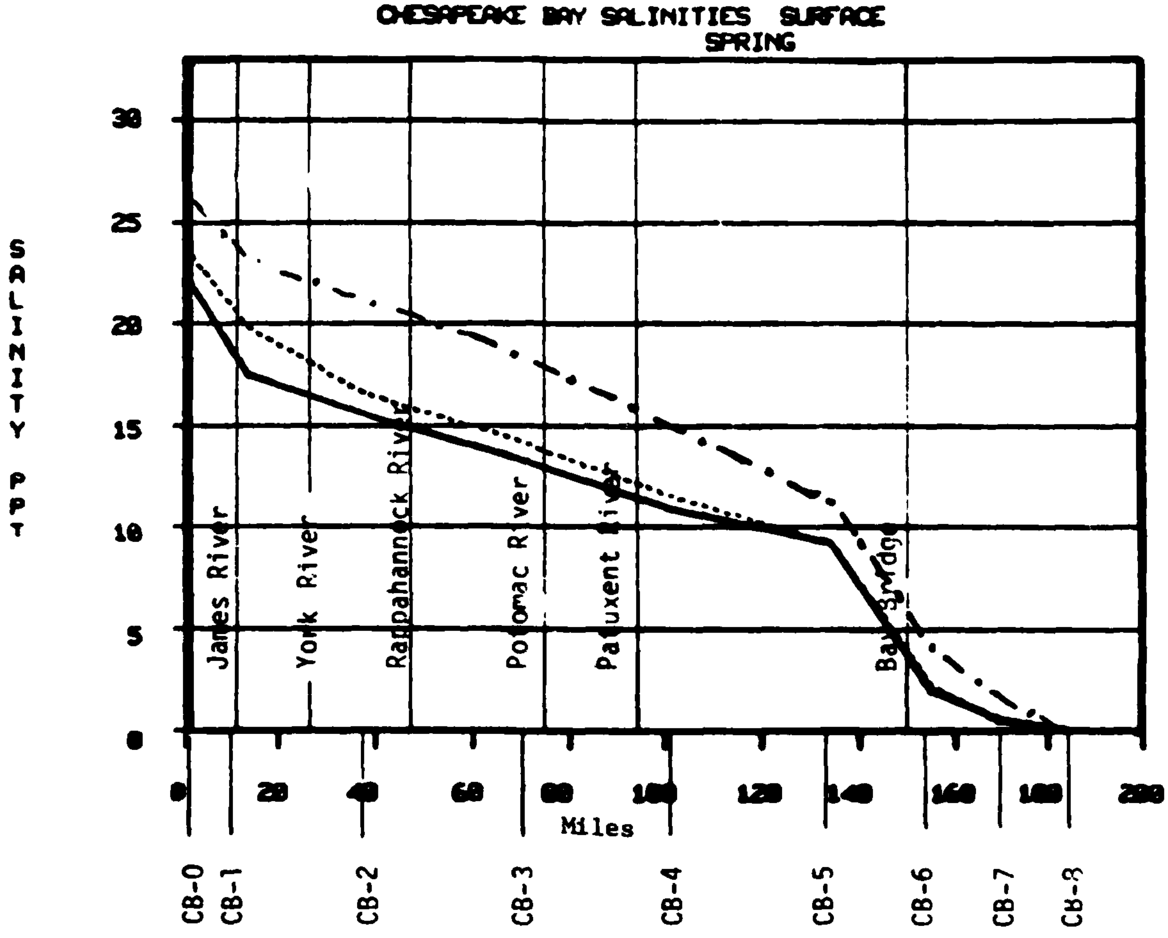


Figure III-2. Salinity Measurements for Spring Base Average (Solid), Future Average (Dotted), and Future Drought (Dot/Dash) Along a Transect from Mouth to Head of Bay. (Source: U.S. Army Corps of Engineers Unpublished Report)

Figures III-3 through III-5 compare the salinities at surface, mid-depth, and bottom with the scenarios of the greatest fresh water inflow extremes Base Average versus Future Drought and the greatest seasonal variation, spring versus fall.

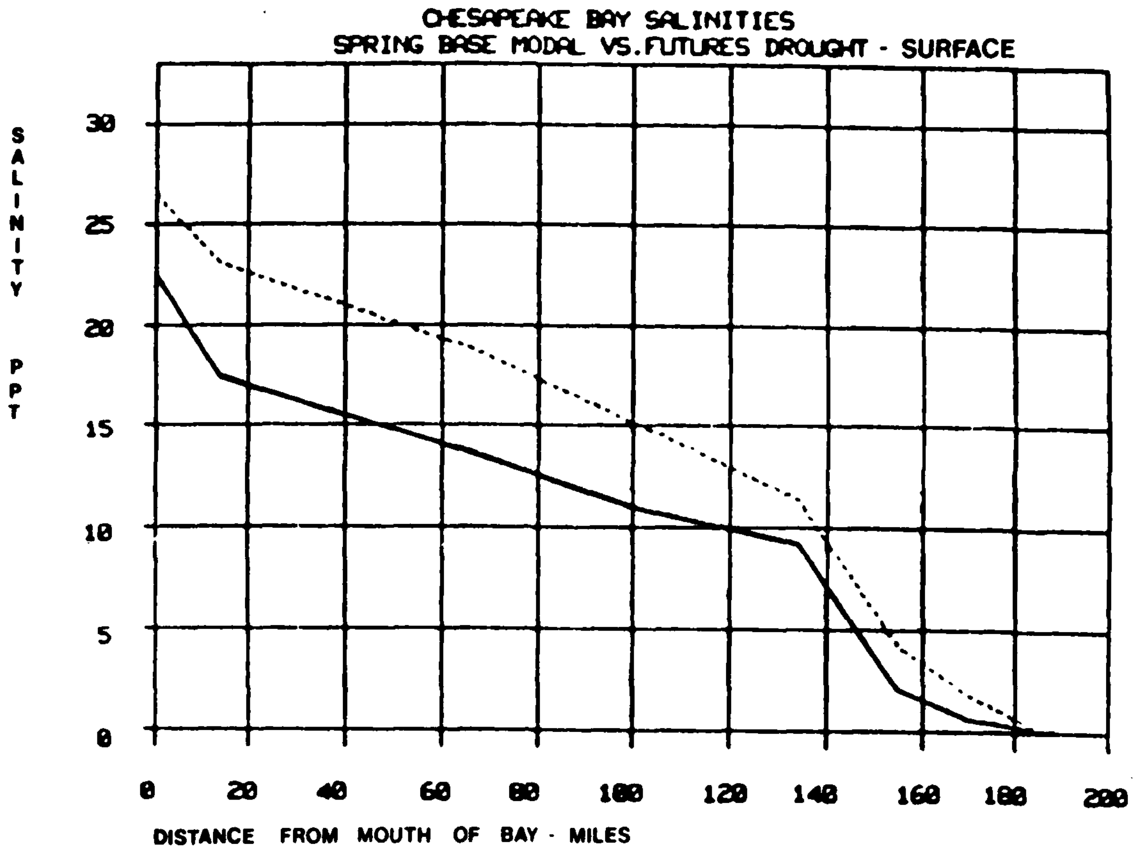
In the spring (Base Average) there are normally two steep gradients of surface salinity, one at the Bay mouth (0 to 15 nautical miles) and the second from 130 to 150 nautical miles. This latter sharp gradient is the turbidity maximum. During the fall there are three steep salinity gradients, the two found in the spring and an additional steep gradient just south of the Susquehanna Flats. In each season the salinity distribution of the Future Drought follows the same pattern as the Base Average but is more saline at each point along the main axis of the Bay.

The effect of freshwater additions from the Potomac River shows in the salinity transect graphs only at mid depth and bottom where the salinity values show a gradual decline from the river mouth southward (100 miles to around 70 miles).

b. Mapping of Change Distribution:

Another way of looking at the relative degree of change is by means of the change in salinity (Δ S) expected at a particular station. Figure III-6 shows the location and relative change in the seasonal average at that point between the Base Average fall scenario and the Future Drought fall scenario. This depicts the greatest scenario change for the most saline season, the extreme case of salinity intrusion into the estuary.

One can observe that the salinity increase is not a simple translation of the isohalines up the estuary but that a greater magnitude of salinity change occurs in the region where the salinity gradient is steepest already. This pattern can be seen in the (1) Upper Bay, (2) Potomac River, (3) Patuxent River, and (4) Rappahannock



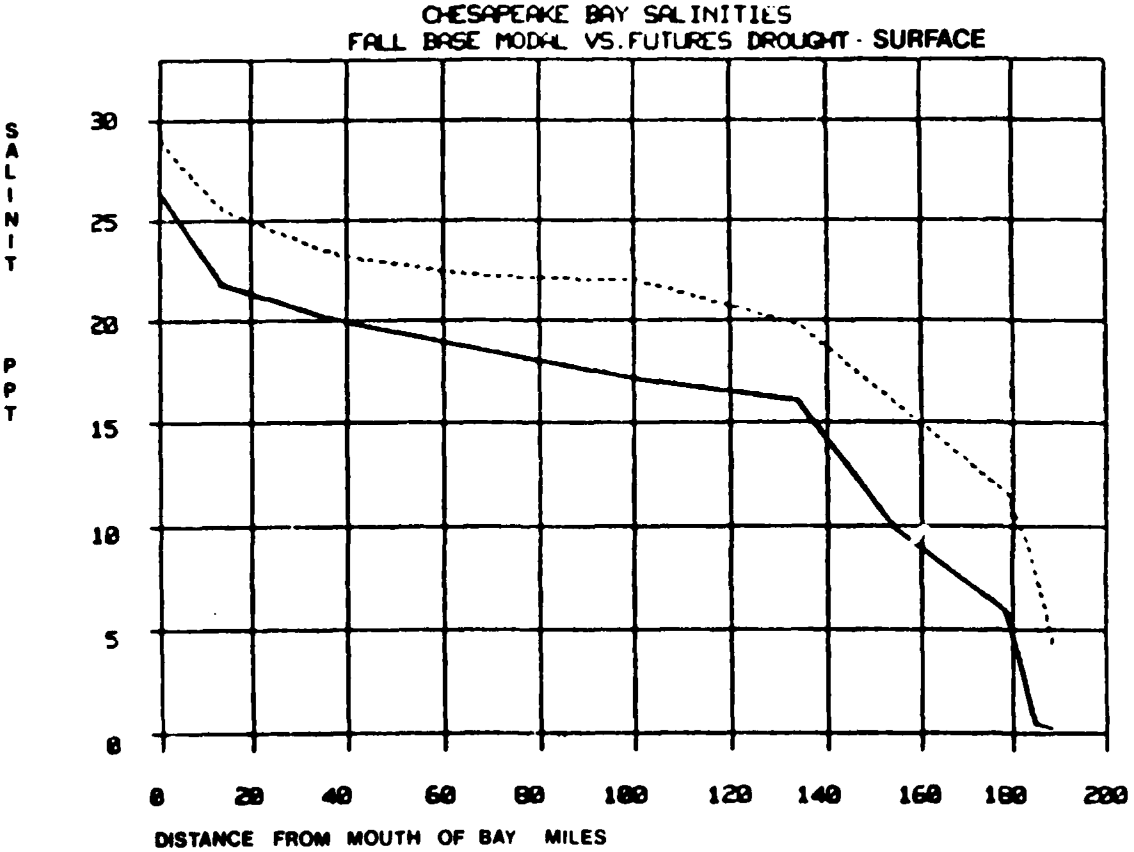
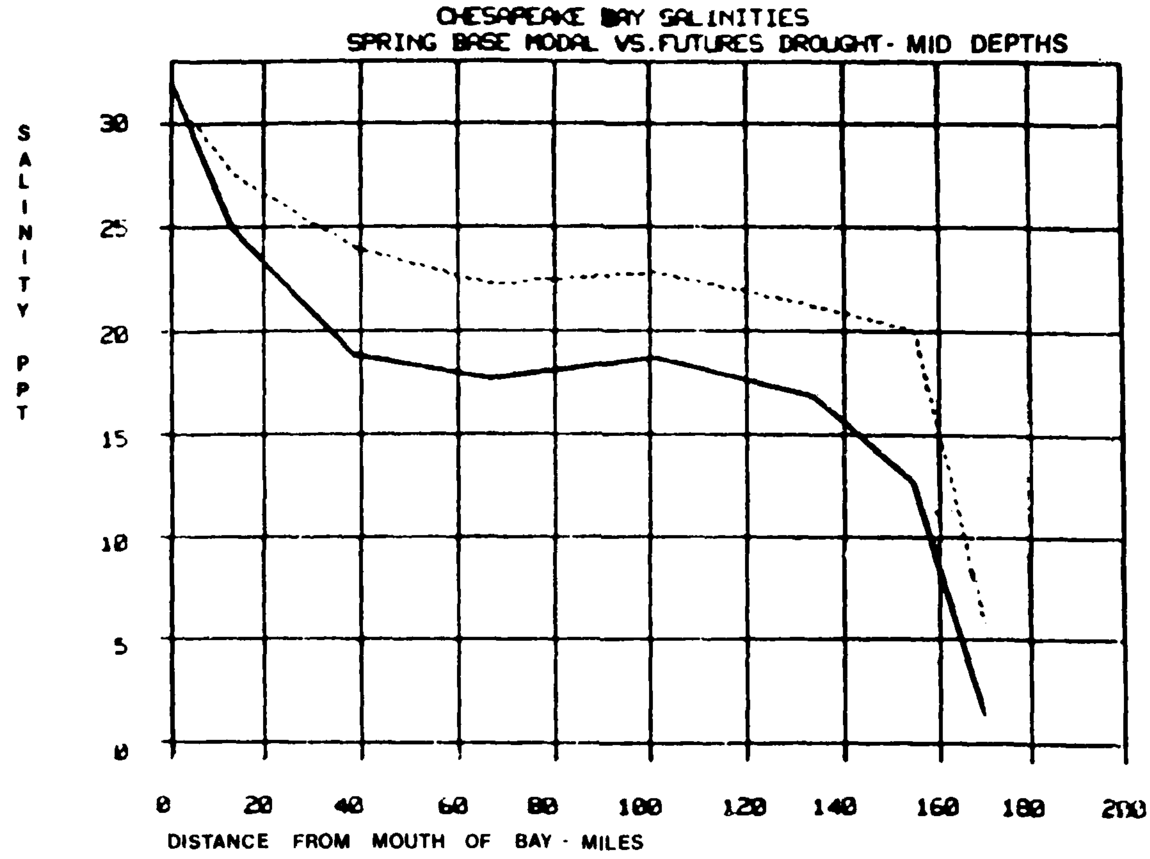


Figure III-3. Salinity Values for Base Average (solid) and Future Drought (dotted) Along a Transect from the Mouth to Head of Chesapeake Bay. (Source: Corps of Engineers Unpbl. Report)



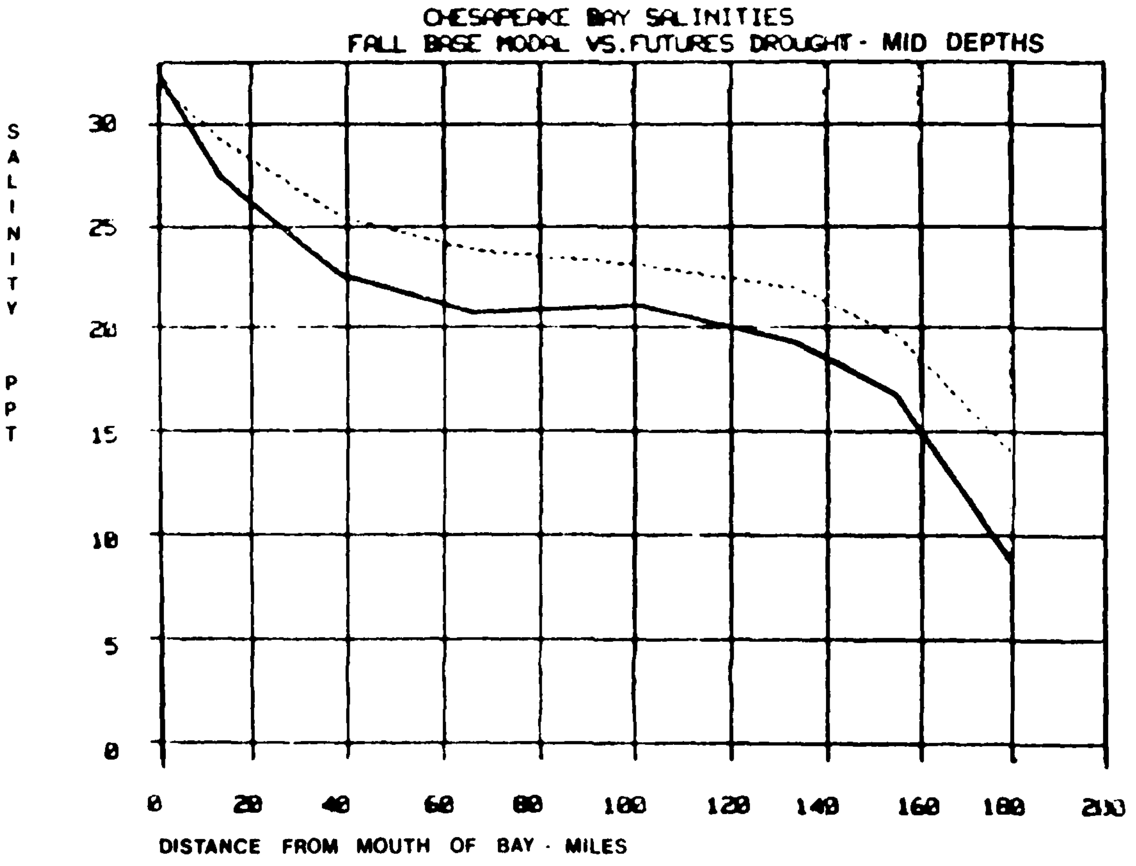


Figure III-4. Salinity Values for Base Average(solid)and Future Drought (dotted) Along a Transect from the Mouth to Head of Chesapeake Bay. (Source: Corps of Engineers Unpbl.Report)

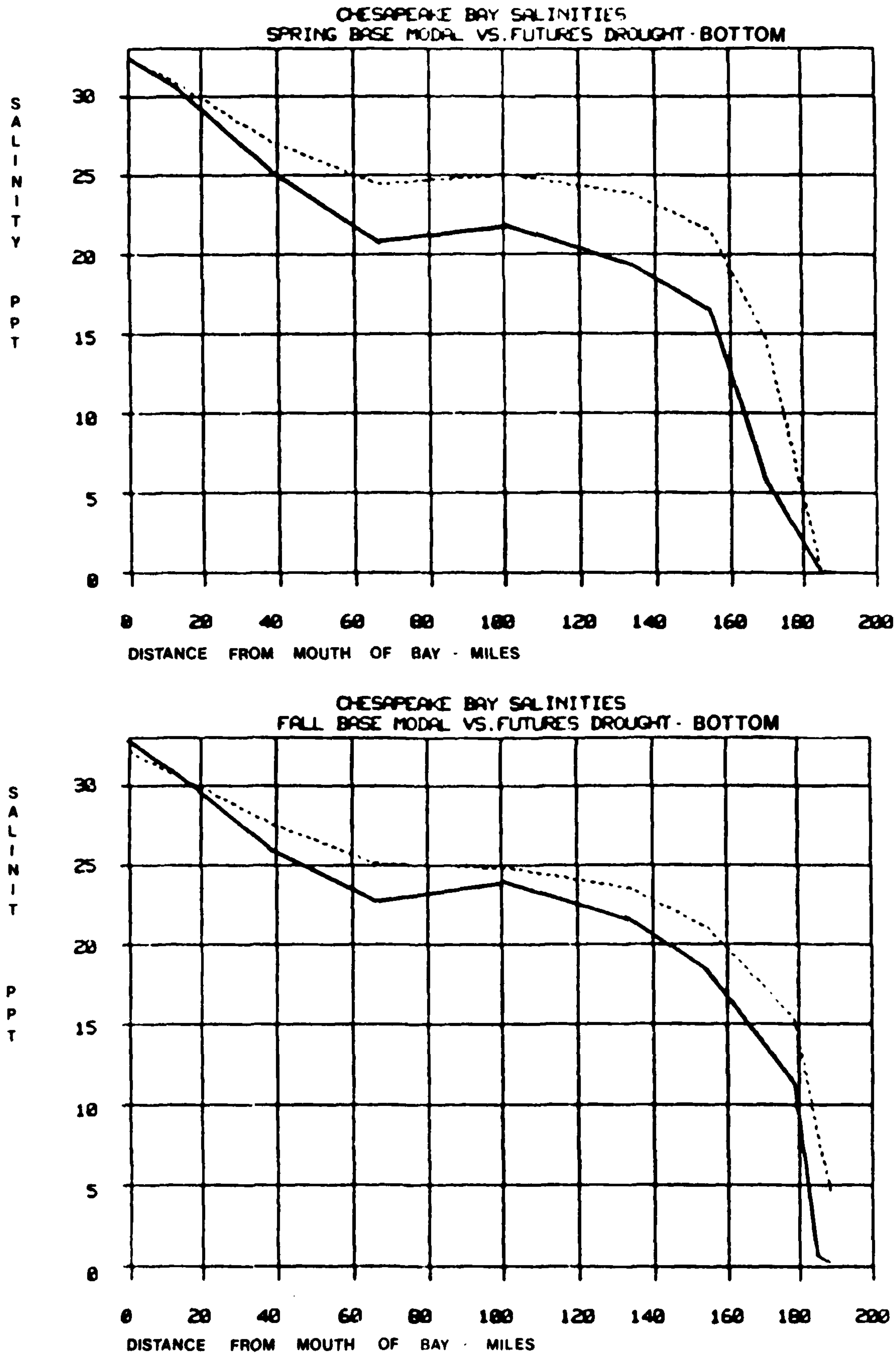


Figure III-5. Salinity Values for Base Average (solid) and Future Drought (dotted) along a Transect from the Mouth to Head of Chesapeake Bay. (Source: Corps of Engineers Unpbl.Report)

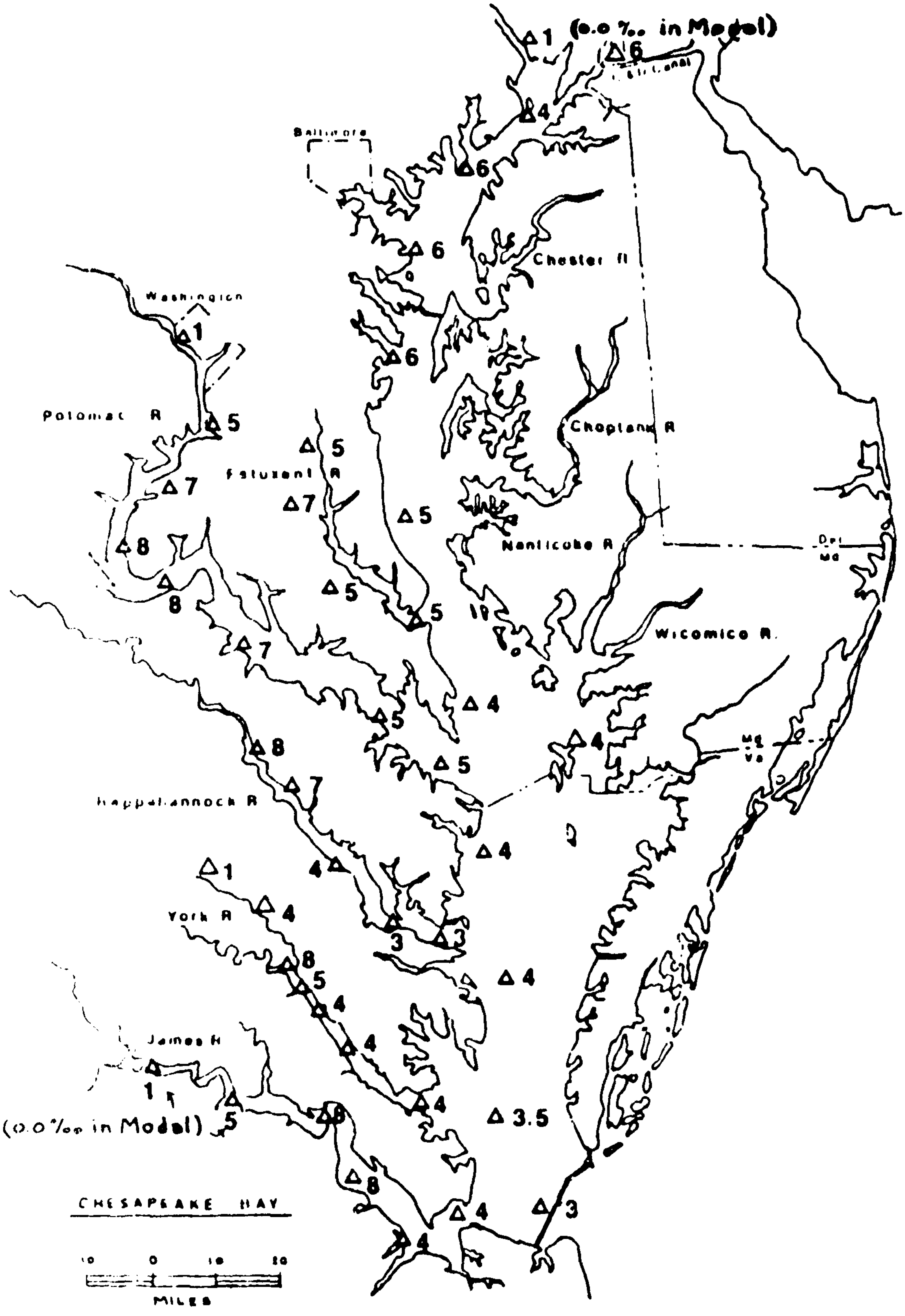


Figure III-6. Observed Surface Salinity Increase (in $^0/00$): Base Average vs. Future Drought (Fall) (Source: Hydraulic Model Data)

River. The pattern indicates that a compression of the density gradient may be occurring in the vicinity of the turbidity maximum which may serve as an upstream limit similar to that normally induced by shallow water or steep temperature gradients.

c. Isohaline Maps:

As previously described in the study methods section the salinity data was mapped on a scale of 1:250,000. These are whole Bay maps and are quite large. Consequently, they will not be published in this report. On the maps of seasonal average salinities isohalines were drawn by interpolation at every full part per thousand. Three examples of small plan-view surface salinity maps are included as Figures III-7 to III-9. Due to the reduced size of these example maps isohalines are drawn only every 5 ppt for sake of clarity. Comparing the Base Average salinity (Fig. III-7) with the consumptive loss scenario (Future Average) one can see that the 1 and 5 ppt isohalines change shape but do not move far up the Bay or the tributaries. However, the center of the 10 ppt isohaline moves from about the mouth of the Potomac to Piney Point and the center of the 15 ppt isohaline moves up the Bay from around Tangier Island to above the mouth of the Potomac to about Point No-Point. This tendency of surface isohalines to translocate further up the estuary in the intermediate regions means that habitat changes will be greater for organisms in the mid estuary than for those organisms restricted to either boundary region.

This translocation of the low mesohaline region can be seen in the Patuxent, Potomac, Rappahannock, York and James Rivers and Pocomoke Sound as well as in the main stem of the Bay.

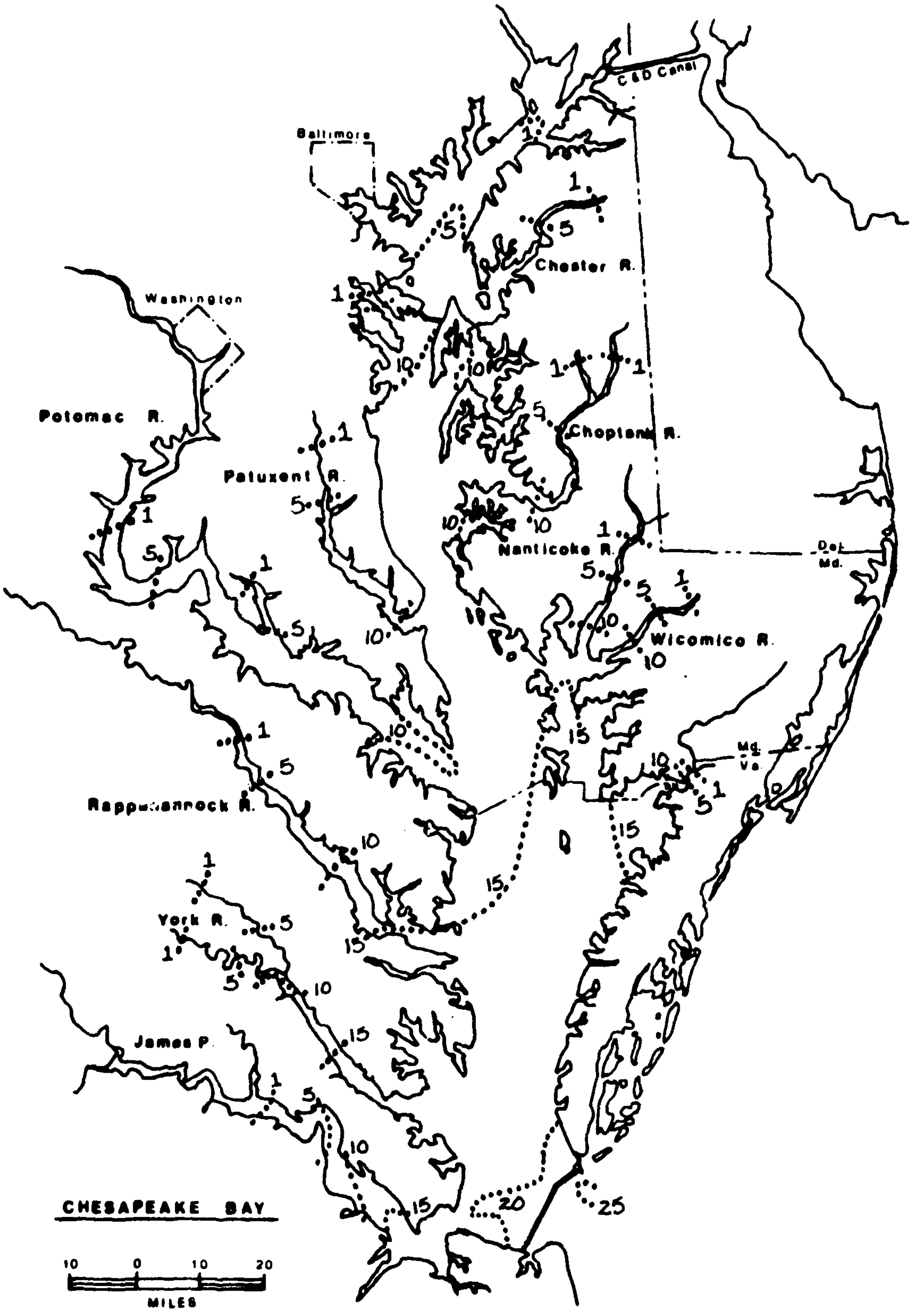


Figure III-7. Isohaline Map-Base Average;Summer;Surface Salinities (Source: Hydraulic Model Data)

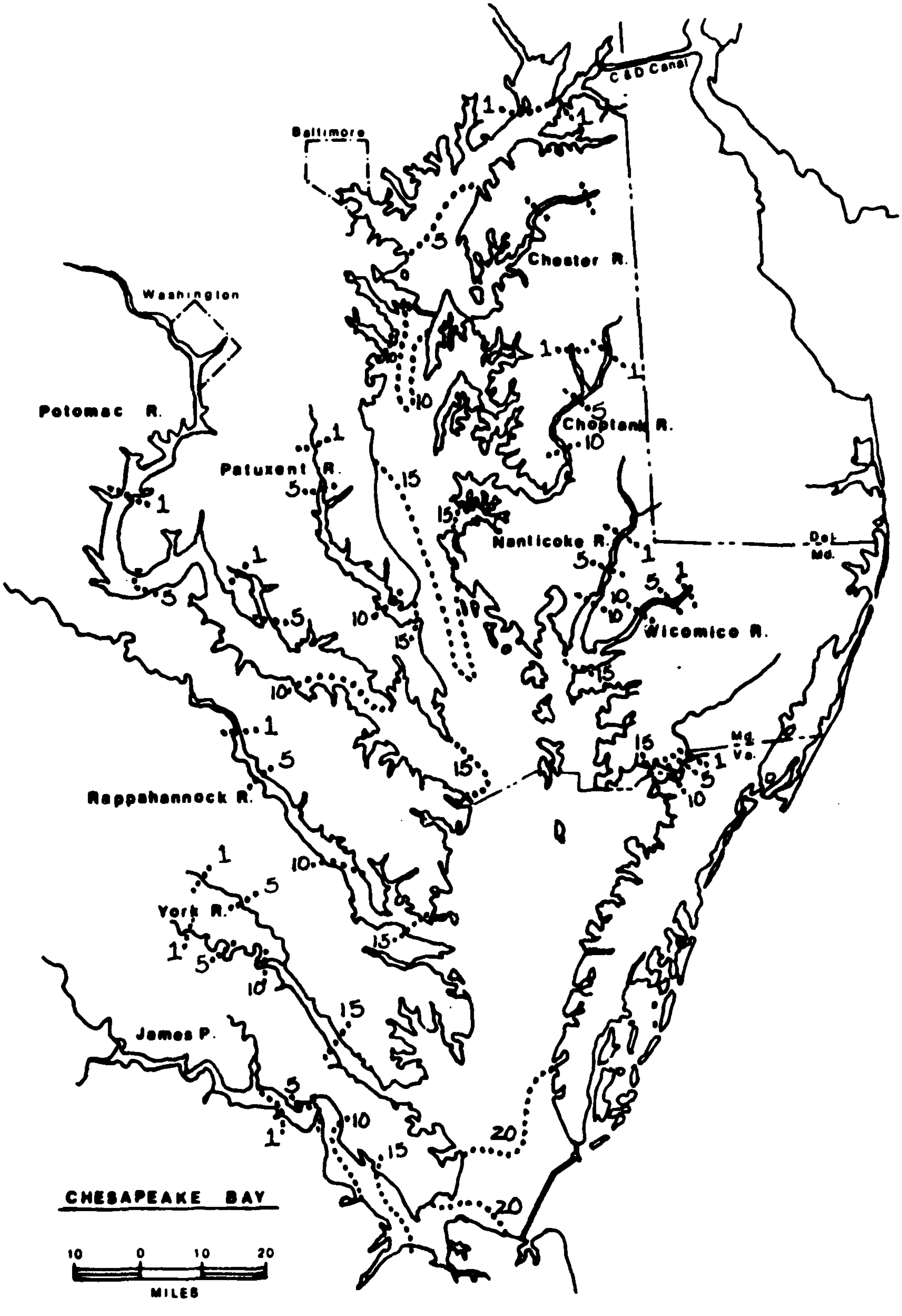


Figure III-8. Isohaline Map:Future Average;Summer;Surface Salinities
(Source: Hydraulic Model Data)

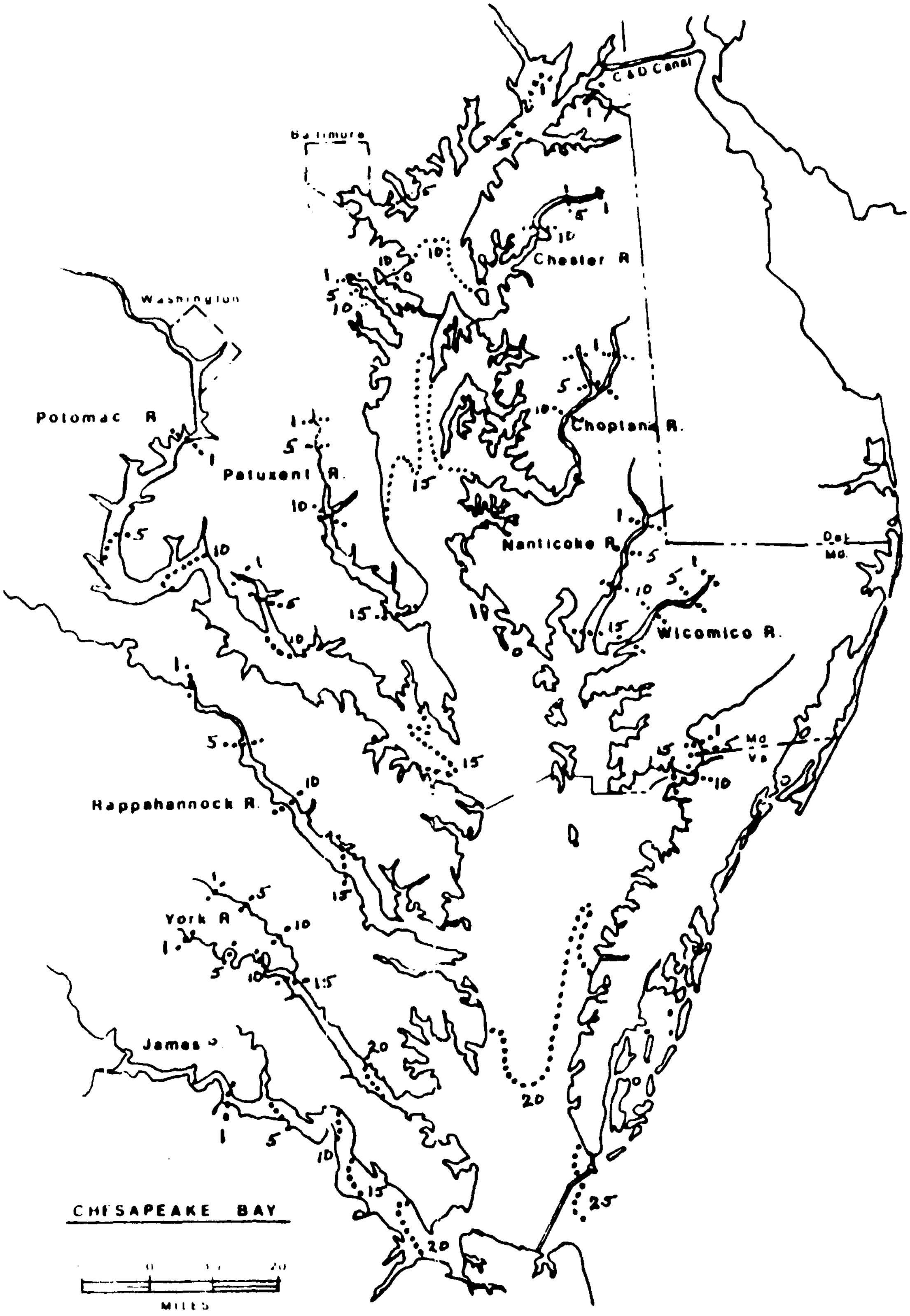


Figure III-9. Isohaline Map: Base Drought; Summer; Surface Salinities (Source: Hydraulic Model Data)

The historical drought, on the other hand, did cause a noticeable shift of the lower salinity isohalines into the tidal fresh regions. For example, notice the movement of the 1 ppt isohaline from the mouth of the Sassafrass River to well onto the Susquehanna Flats. On the Potomac River the 1 ppt boundary moves from about Douglas Point up to near Mt. Vernon. It is during the drought event that the greatest impact on the organisms in the Tidal fresh and oligohaline zones occurs.

During an historic drought reduced by projected consumptive losses (Future Drought scenario) both patterns of isohaline shifts occur cumulatively.

4. Extreme Values

Salinity extremes were calculated for 16 stations made up of 7 main bay stations, 3 Potomac River Stations and two stations each in the York, Rappahanock and James Rivers as described in Chapter II. The analysis showed that, in general, salinity extreme periods of two week duration seldom exceed the seasonal average by more than 2 $^0/00$. Where extreme values do occur, it is in almost all cases only once during a season. Exceptions to this rule are rare except in the spring season and during the drought and future-drought scenarios, where 2 or 3 extreme values sometimes occur. The term "extreme value" as used in this section refers to a maximum or minimum value which differs from the seasonal average by more than 2 $^0/00$ in either direction (a 1 $^0/00$ difference is used for 6 week periods). The 6-week period extreme values proved to be minimal in their magnitude and effects and are not discussed in detail below.

The purpose of the salinity extreme analysis (as discussed in Section II-E) was to search for departures from the seasonal average which have potential significance as biological limits particularly to sessile species. Tables III-1 and III-2 contain a sample of the results from selected stations and depths in Chesapeake Bay and the major rivers. A maximum extreme represents a salinity value 2 ^{0}/00 or greater above the seasonal average which persists 2 weeks. A minimum extreme represents a salinity value 2 ^{0}/00 or greater less than the seasonal average.

From Tables III-1 and III-2 it can be seen that within any one season the maximum number of salinity extremes is two while the median number of extremes is zero. The number of salinity extremes ($> 2^{0}$/00, 2 week) located by the search program showed a higher probability of occurrance of higher than average (maximum) extremes; 55% of the events were high side events versus 45% of the events which were low side events.

The seasons differed significantly ($p < 0.01$ where p = probability function) in the number of salinity extremes. As would be expected, spring has the most salinity extremes, 39% of the total, summer 35%, winter 17%, and fall 9%.

Surface station depths had 73% of the salinity extremes compared to mid-depths. The frequency of salinity extremes in the shallow waters is significantly greater than random ($p < 0.001$). Organisms in the shallow margins of the Bay or restricted to the surface layer will encounter salinity extremes far more frequently than deeper living organisms. There is no significant difference in number of salinity extremes between scenarios. Evidently, neither consumptive water loss nor drought affects the frequency with which a salinity spike occurs.

Normally, rivers are thought to exhibit more dynamic salinity behavior than the bay. River stations, however, did not show a significantly different probability of salinity extremes compared to the Bay stations.

Table III-1. Number of Two-Week Extremes (Maxima and Minima) at Near-Surface and Near-20 Foot Depths (Absolute Value of Season Average-2 week Average > 2ppt) at Chesapeake Bay Stations.

Station	Depth (ft)	Max/Min	Base				Drought				Future				Future Drought			
			F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su
CB0103	4	max	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0
		min	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	27	max	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		min	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CB0303	4	max	0	0	0	0	0	0	0	1	2	0	1	0	0	0	1	0
		min	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	1
	22	max	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0
		min	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
CB0504	2	max	0	0	1	0	0	2	1	0	0	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
	32	max	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
		min	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
CB0604	2	max	0	0	0	2	0	2	1	2	0	0	0	0	0	0	0	0
		min	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
	22	max	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0
		min	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CB0703	2	max	0	0	0	1	0	0	0	2	0	0	0	1	0	0	0	0
		min	0	0	0	1	1	0	1	2	0	0	0	2	0	0	0	2
	29	max	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0
		min	0	0	2	0	0	0	0	0	0	0	2	1	0	0	0	0
CB0803	5	max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Table III-2.

Station	Depth (ft)	Max/Min	Base				Drought				Future				Future Drought			
			F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su
JG202	1	max	0	2	2	1	0	0	1	0	0	2	1	0	0	3	2	1
		min	0	1	1	2	0	1	1	0	0	2	1	0	0	1	1	1
	23	max	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
		min	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
JG402	1	max	0	0	0	0	0	4	1	0	-	-	-	-	-	-	-	-
		min	0	0	0	1	0	0	1	0	-	-	-	-	-	-	-	-
	20	max	0	1	1	0	0	1	1	1	-	-	-	-	-	-	-	-
		min	0	0	0	1	0	0	1	0	-	-	-	-	-	-	-	-
PO202	2	max	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1
		min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	32	max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PO502	2	max	0	1	0	1	0	1	1	0	0	1	0	0	0	0	1	1
		min	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	1
	19	max	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0
		min	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
PO802	4	max	0	0	0	0	0	0	1	0	-	-	-	-	-	-	-	-
		min	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-
	18	max	0	1	0	1	0	0	0	0	-	-	-	-	-	-	-	-
		min	0	0	0	1	0	0	1	0	-	-	-	-	-	-	-	-
RG301	13	max	0	0	0	0	0	0	0	1	-	-	-	-	-	-	-	-
		min	0	0	0	0	0	0	0	2	-	-	-	-	-	-	-	-
	26	max	0	0	0	0	0	0	1	0	-	-	-	-	-	-	-	-
		min	0	0	0	0	0	0	0	1	-	-	-	-	-	-	-	-
YG102	5	max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	25	max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YG401	3	max	0	0	0	0	0	0	0	0	0	1	0	0	2	1	1	2
		min	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	2

Thus, the organisms most at risk to short term fluctuations of salinity would be sessile organisms in shallow water with a sensitive life stage occurring in the spring of the year. This indicates that aquatic vegetation and sessile animals are groups of organisms most at risk to salinity extremes. Spring spawning invertebrates would also be sensitive to salinity extremes although not necessarily in a negative manner. A rapid change in salinity of a few parts per thousand in either direction is necessary to induce spawning in the clam Rangia. It may well be that as our understanding grows of the life history requirements of other benthic organisms there will be other species identified who depend on a short term salinity extreme as a physiological trigger.

Few of the salinity extremes exceeded ± 2 ^{0}/00 from the mean although an occasional event provided departures from the mean of as much as ± 5 ^{0}/00 for a two week duration. It should also be remembered that these extreme events are averages at slack before ebb (high water slack) and do not address changes inherent within the tidal cycle.

5. Tidal Differences

Measureable changes in the tidal amplitudes were not expected to occur due to reduction in water inflow and none was detected. Tidal amplitude at any location is a result of a highly complex interaction of basin harmonics, wave reflection, relative solar and lunar positions and freshwater inflows. The maximum tidal amplitude at the mouth of the Bay is 3.75 feet on the spring tide and 2.55 feet on the neap tide. The relationship of tidal volume to total volume is important to the energetics of dynamic mixing and produces an observable change in salinity stratification, the "neap-spring" effect. This phenomenon is shown by the model; however, potential biological response is complex and the neap-spring effect will not be addressed as part of the Biota assessment.

There are differences in salinity at any given station, day, and depth, that reflect low-high slack tidal conditions. Although the data were mostly taken on high slack tides and these data were used exclusively for this report, it is instructive to note general patterns and differences on low slack tides.

High-low slack differences are generally in the range of 0-2 $^{0}/00$ for the entire data set. On certain occasions and in the upper river reaches, these latter large differences are far more common, reaching 5 $^{0}/00$ or more in rare instances. Drought and future conditions tend to amplify high-low slack differences slightly, particularly in the rivers and upper bay.

B. DIRECT EFFECTS ON ORGANISMS

1. Habitat Change

Comparison of the four scenario maps for the study species show that several types of habitat change occur:

1) Reduction in total potential habitat due to upstream shift of downstream habitat boundaries. An example would be: *Potamogeton* spp, (Figure III-10).

2) Increase in total potential habitat due to upstream shift of upstream boundaries, e.g. *Crassostrea virginica* (Figure III-11).

3) Shift in both upstream and downstream boundaries simultaneously. This may result in little overall change in potential habitat availability due to the greater shift of isohalines in the mid Bay region relative to those at head or mouth of Bay. Thus, the potential habitat becomes increasingly compressed with decrease in fresh water outflow, e.g. *Anchoa mitchilli* spawning areas (Figure III-12).

4) Occasionally one life stage is more affected than others, especially spawning and nursery areas of fish, e.g. *Morone saxatilis* eggs and larvae (Figure III-13).

5) A potential secondary effect due to changes in distribution of a major parasite or predator, e.g. *Minchinia nelsoni* (MSX) a serious oyster parasite (Figure III-14). A similar effect might be predicted with a shift in range of a major food source.

The generalization can be made that change in habitat area is usually less from Base Average to Future Average scenarios than from Base Average to Base Drought scenarios. There are, however, exceptions to this: e.g., *Minchinea nelsoni* shows a marked increase in habitat from the Base Average to the Future Average scenario (Figure III-14).

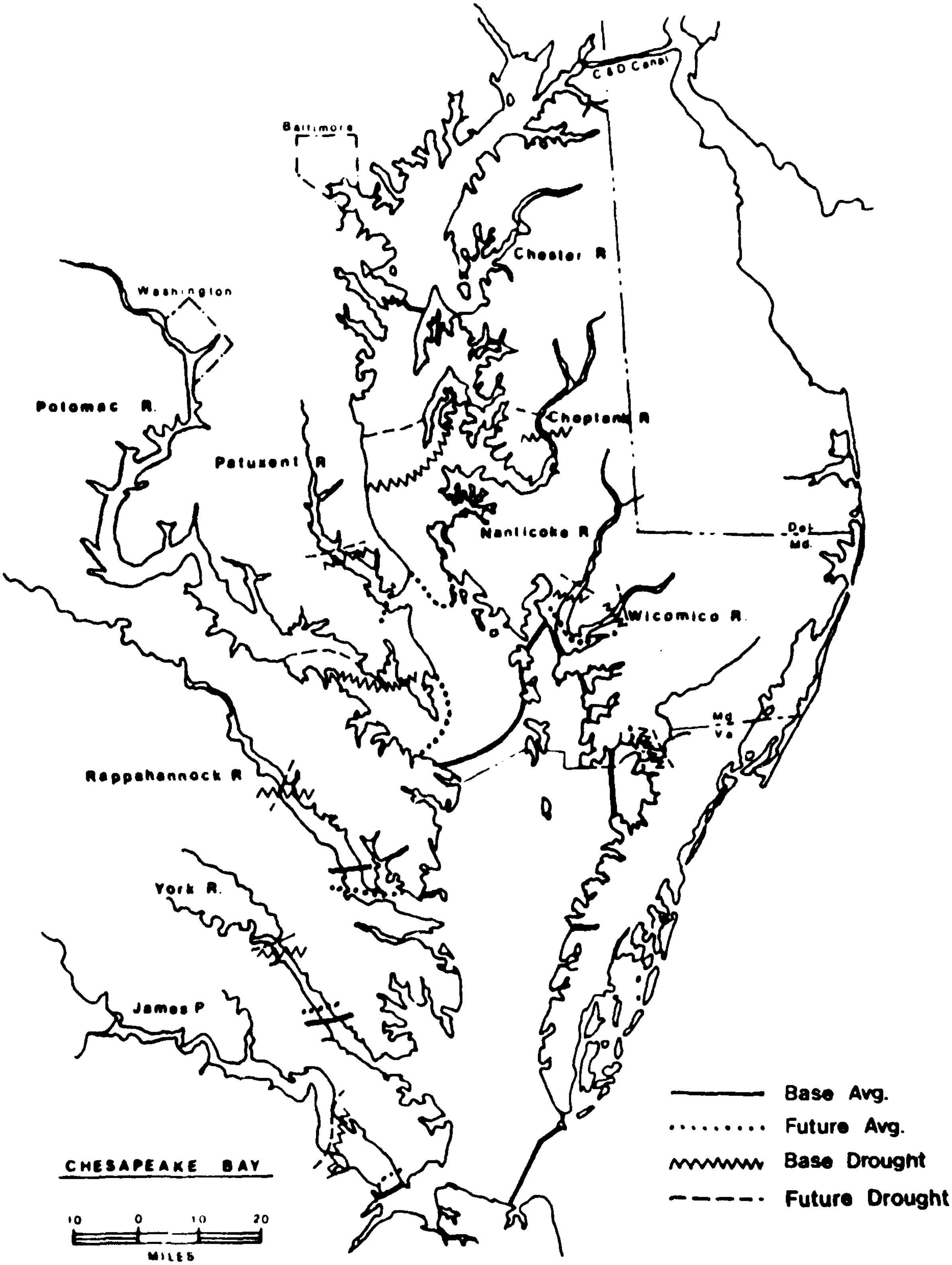


Figure III-10. *Potamogeton pectinatus* and *perfoliatus*
(Downstream boundary - summer, 3m., 0-12^{0}/00)

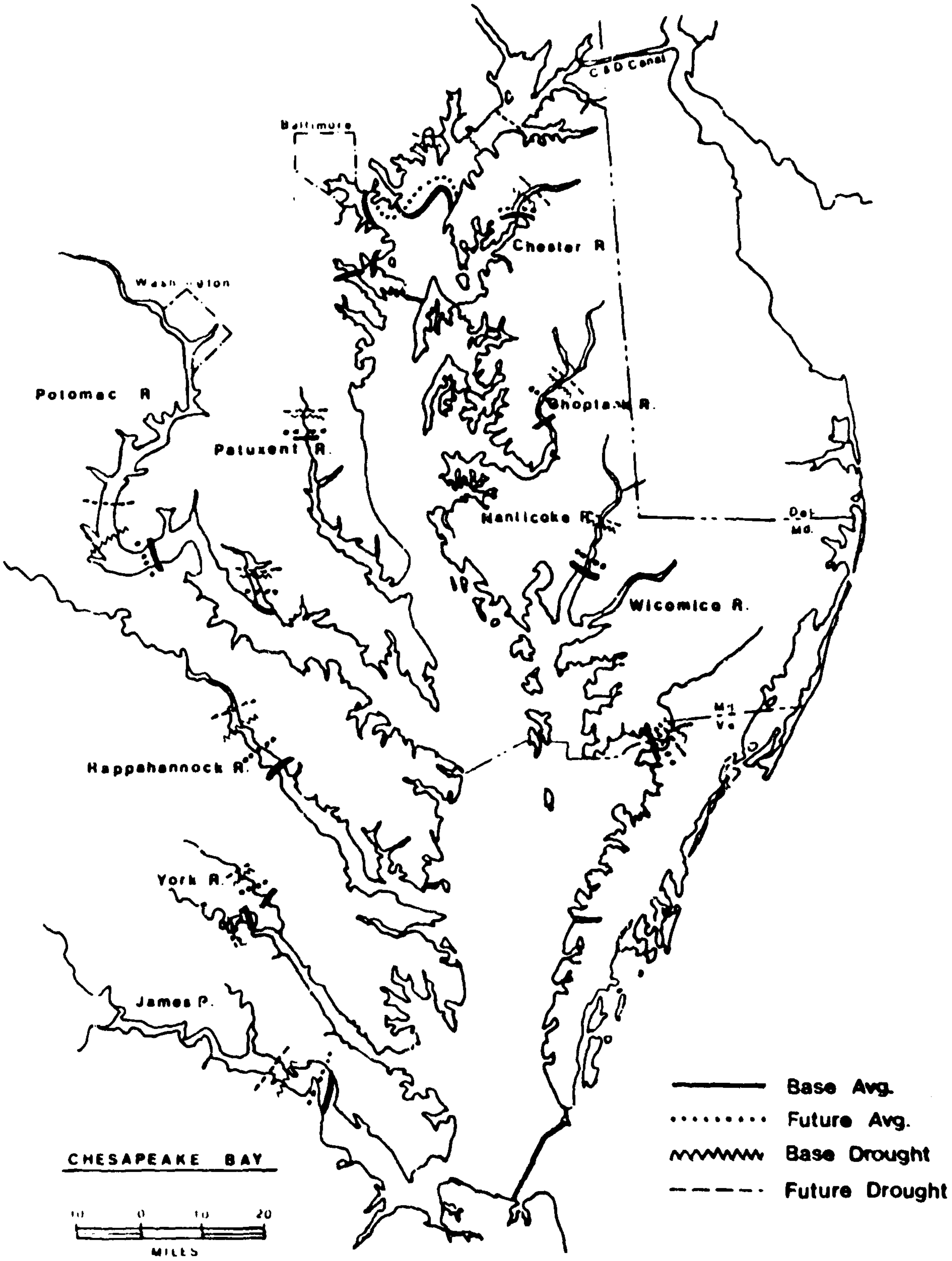


Fig. III-11. Crassostrea Virginica - Oyster
(Upstream boundary to bay mouth - summer)

(Source: Hydraulic Model Data)

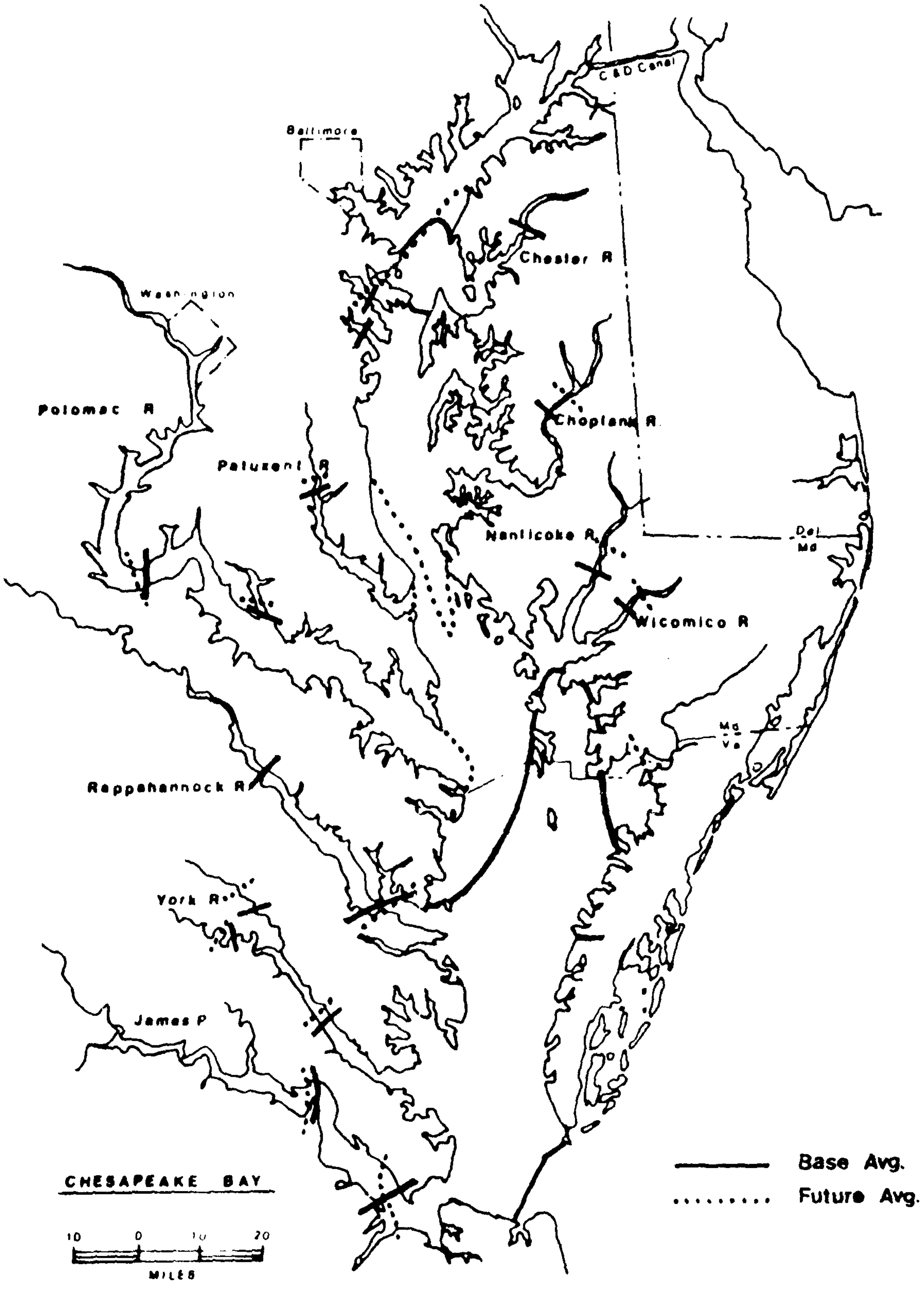


Figure III-12. *Anchoa mitchilli* - Bay Anchovy
(Spawning area - summer, 5-1 [illegible]

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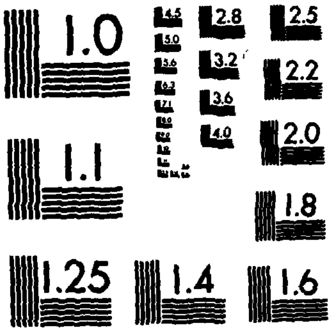

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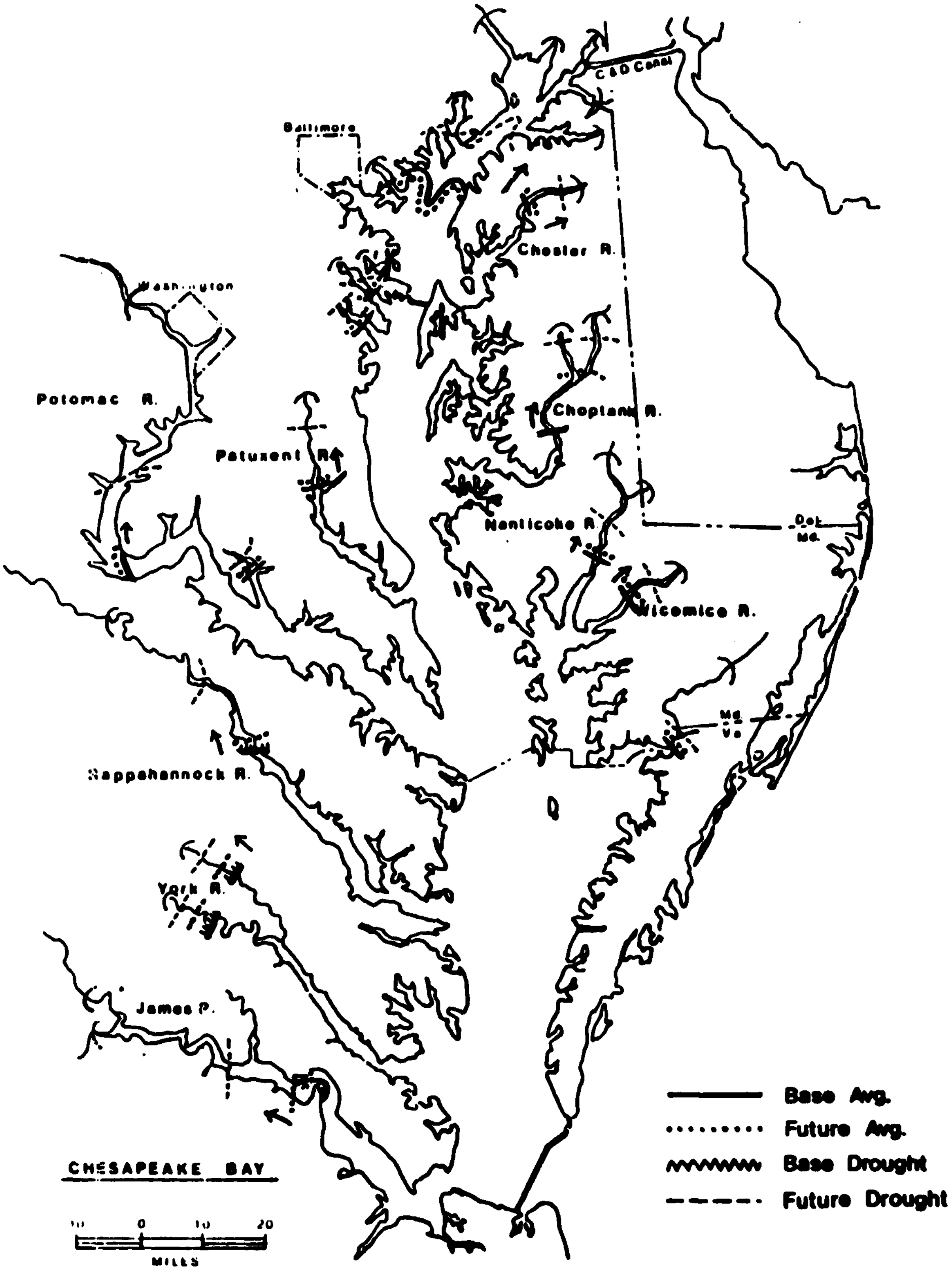

Figure III-13. *Morone saxatilis* - Striped Bass
Eggs and Larvae
(Head of tide downstream boundary-spring)

(Source: Hydraulic Model Data)

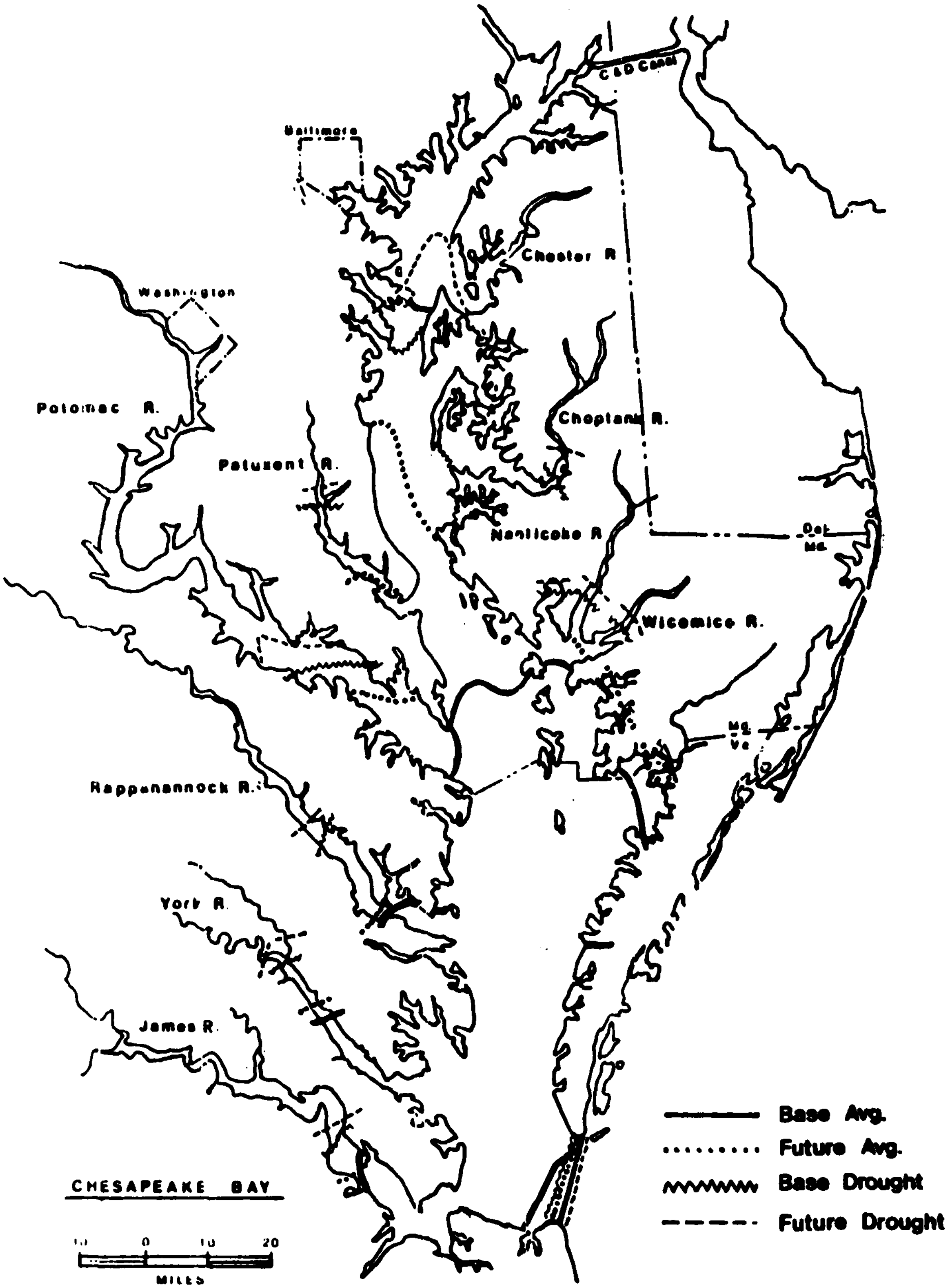

Figure III-14. *Minchinia nelsoni* ("MSX") and *Perkinsus marinus* ("Dermo") (Upstream boundary to bay mouth - summer)

(Source: Hydraulic Model Data)

Seasonality: Study species were mapped at their most sensitive season - generally at period of reproduction or maximum growth. In a number of cases, different life stages were mapped at different seasons, reflecting each stage's period of greatest sensitivity. For example, Morone saxatilis eggs and larvae are mapped in spring, adults in summer and winter (Figure III-13).

The amount of habitat change observed also reflects the season of mapping. That is, the observed change in salinity from modal to future scenario was somewhat greater in the fall, compared to the other scenarios. (In order: fall > winter > summer > spring). Similarly, change from modal to drought was most extreme in the fall. (In order: fall > winter > summer > spring). For that reason, the expected magnitude of habitat change would be greater in species whose most sensitive season is fall, relative to those mapped in spring.

Lifestage: For species mapped in several life stages, it is apparent that one stage may be more affected than another. This reflects not only the physiological greater sensitivity of that particular stage, but the location of its habitat and the season involved. As has been previously discussed, certain areas of the estuary show a more pronounced effect from reduction of fresh water inflow than do others. In general, maximum changes in salinity for each scenario occur in the midpoint of the Bay and tributary estuaries, and least near the boundaries. The transition zone, in particular, shows the greatest increase (Fig.III-7 to III-9). A lifestage occurring in these areas may exhibit the most habitat change. In this manner, the most sensitive life stages for a number of study species can be identified. For example, although the adults of Anchoa mitchilli, the Bay Anchovy, occur throughout the study area, a "compression effect" causes a marked reduction in available habitat for both the spawning (eggs) and nursery (larvae) areas (Fig.III-12). This effect is noted in all scenarios, and is most severe in the habitat available for spawning.

Other factors: Depth is an important mapping criteria for a number of study species. Shifts in location of a species potential habitat may move that habitat into a region where the bathymetry is less suitable for the species' survival, or conversely, may open additional areas to colonization. The main Bay north of Kent Island is relatively shallow, and would provide suitable habitat for numerous mesohaline species if salinities increased to a favorable level. Species such as blue crabs and striped bass, which utilize deeper areas in winter would be able to exploit areas further upstream in certain tributaries.

Sediment is a major habitat determinant for several benthic study species. Because of the distribution of sediments in Chesapeake Bay, relatively minor shifts in habitat location can produce significant effects on available area for these species. In general, the lower Bay is characterized by a dominance of larger grain size sediments, chiefly sand and muddy sand, with silts and clays (mud) primarily in the channel. In the mid Bay, muddy sand and sand occurs along the shore margins, with large areas of silts and clays offshore, although sand is still the predominate substrate. In the upper Bay, the predominant sediment type is silty clay (mud) with a narrow sand unit nearshore, except for the sand-dominated Susquehanna flats (Byrne et.al.1981). The sediment regime can be roughly characterized as a gradient seaward toward coarser grain size, with an overall predominance of sands (57.4%) (Byrne et.al.1981).

This gradient of sediment type from head to mouth of the estuary means that a shift in habitat location can move a species into an area where conditions are less favorable. Several species of concern occur in greater abundance in coarser sediments (Mercenaria mercenaria, for example) and although additional habitat will become available upestuary with increasing salinities, population density may not reach the levels found in the lower Bay.

In species where sediment is a criterion, differences in the species abundance in various substrates was taken into account in measuring potential habitat area, and calculating the extent of impacts.

2. Categorization of Habitat Differences

The study species can be characterized briefly by the type of habitat change observed:

- Reduction in total habitat due to upstream drift of downstream boundaries:

These include species and associations of the tidal fresh and oligohaline zones of the estuary, (e.g. Eurytemora affinis), as well as some estuarine endemics, (e.g. Callinectes sapidus males). Also in this group are spawning areas of eurytopic species of fish (e.g. Morone saxatilis) as well as nursery areas for these and other fish and invertebrates. Reduction in lower salinity areas also decreases available habitat for these species in the estuary. Twenty species and/or life stages are in the category (Table III-3).

- Increase in total habitat due to upstream shift of upstream boundaries: these include stenohaline marine species (e.g. Evadne tergestina), euryhaline marine species (e.g. Mercenaria mercenaria) and euryhaline opportunists, (e.g. Heteromastus filiformis). Penetration of these species into the estuary increases with the reduction of fresh water influences. Also affected are high salinity off-shore spawning areas of such species as Callinectes sapidus. Thirty-one species and/or life stages are in this category (Table III-3).

o Change in location of potential habitat due to simultaneous shift in upstream and downstream boundaries. These include primarily euryhaline opportunists, (e.g. Prorocentrum minimum) and estuarine endemics, (e.g. Macoma balthica) a few oligohaline species, as well as spawning and nursery areas for some species, (e.g. Anchoa mitchilli). The potential habitat for these species moves upstream in the estuary with increasing salinity, although there may not be a marked change in total area. Twenty-one species and/or life stages are in this category (Table III-3).

o A sensitive life stage is exhibited by a number of species, primarily among fish spawning and/or nursery areas. These life stages may show changes in potential habitat greater than that exhibited by the adult of the species. Twelve species have one or more sensitive life stages (Table III-3).

o A major predator, parasite, or competitor, whose distribution will change with decreasing freshwater inflow, affects five of the study species (Table III-3).

3. Effects of Short-term Extreme Salinity Values

A number of study species have salinity requirements well enough documented that the effect of short-term extreme salinity variations can be examined. As discussed earlier, potential habitat for the study species was mapped using seasonal averages, considered to be the best approximation of a species' response to the long-term

Table III-3

Species or life stages in each category of observed habitat change.

1) Reduction in total habitat with shift of downstream boundaries:

Tidal fresh phytoplankton (winter/spring)
Tidal fresh phytoplankton (summer/fall)
Ceratophyllum dermersum - hornwort
Potamogeton pectinatus - sago pondweed
Potamogeton perfoliatus - redhead grass
Zannichellia palustris - horned pondweed
Coastal fresh marsh associations
Brachionis calcyiflorus - rotifer
Eurytemora affinis - copepod
Bosmina longirostris - cladoceran
Limnodrilus hoffmeisteri - tubified worm
Callinectes sapidus - summer male blue crab
Alosa sapidissima - shad, eggs and larvae
Alosa sapidissima - shad, juveniles
Alosa pseudoharengus - alewife, eggs and larvae
Alosa pseudoharengus - alewife, juveniles
Morone americana - white perch, eggs and larvae
Morone saxatilis - striped bass, eggs and larvae
Morone saxatilis - striped bass, juveniles
Perca flavescens - yellow perch

2) Increase in total habitat with shift of upstream boundaries:

Polyhaline phytoplankton (winter/spring)
Hi Meso - Polyhaline phytoplankton (summer/fall)
Prorocentrum minimum - dinoflagellate, winter

Zostera marina - eelgrass
Ruppia maritima - widgeon grass
Coastal brackish marsh - *Spartina* spp
Brackish - Irregularly Flooded Marsh - *Juncus*
Mnemiopsis leidyi - ctenophore
Chrysaora quinquecirrha - sea nettle, medusa
Acartia clausi - copepod
Acartia tonsa - copepod
Evadne tergistina - cladoceran
Heteromastus filiformis - polychaete worm
Pectinaria gouldii - polychaete worm
Streblospio benedicti - polychaete worm
Urosalpinx cinerea - oyster drill
Crassostrea virginica - oyster
Minchinia nelsoni - MSX parasite
Mercenaria mercenaria - hard clam
Mulinea lateralis - coot clam
Mya arenaria - soft clam
Ampelisca abdita - amphipod
Callinectes sapidus - females, winter and summer
Callinectes sapidus - spawning area
Brevoortia tyrannus - menhaden, adults
Micropogon undulatus - croaker, adult
Leiostomus xanthurus - spot, adult
Menidia menidia - silverside
Morone americana - white perch, adult
Morone saxatilis - striped bass, adult
Aythya valisineria - canvasback duck

3) Shift in both upstream and downstream boundaries:

Oligohaline - low Mesohaline Phytoplankton - winter/spring
Mesohaline phytoplankton - winter/spring
Oligohaline - Low Mesohaline phytoplankton - summer/fall
Prorocentrum minimum - summer dino-flagellate
Chrysaora quinquecirrha - sea nettle, polyp
Scottolana canadensis - copepod
Podon polyphemoides - cladoceran
Scolecolepides viridis - polychaete worm
Macoma balthica - Baltic macoma
Rangia cuneata - brackish water clam
Balanus improvisus - acorn barnacle
Callinectes sapidus - winter male blue crab
Cyathura polita - isopod
Gammarus daiberi - amphipod
Leptocheirus plumulosus - amphipod
Palaemonetes pugio - grass shrimp
Brevoortia tyrannus - menhaden larvae and juveniles
Anchoa mitchilli - Bay anchovy, eggs
Anchoa mitchilli - Bay anchovy, larvae
Micropogonias undulatus - croaker, juveniles
Leiostomus xanthrus - spot, juveniles

4) Exhibits a sensitive life stage:

Chrysaora quinquecirrha - polyps
Mercenaria mercenaria - larvae
Callinectes sapidus - spawning area
Brevoortia tyrannus - larvae and juveniles
Alosa sapidissima - eggs and larvae

Alosa pseudoharengus - eggs and larvae
Anchoa mitchilli - eggs and larvae
Micropogonias undulatus - juveniles
Leiostomus xanthurus - juveniles
Morone americana - eggs and larvae
Morone saxatilis - eggs and larvae
Perca flavescens - eggs and larvae

5) Has major predator, parasite, or competitor:

Mnemiopsis leidyi - predator
Acartia tonsa - predator
Crassostrea virginica - predator, parasites
Balanus improvisus - predator
Palaemonetes pugio - competitor

characteristics of its environment. However, it can be hypothesized that some organisms may be affected - either positively or negatively - by much shorter term events. This would be primarily a phenomenon associated with the boundary or edge of the species' existing range. High (or low) salinity changes of a few days' or weeks' duration could eliminate the species from a portion of its habitat area, or allow it to expand beyond its seasonally determined range.

The magnitude of this effect would depend on: 1) the magnitude, seasonal occurrence and duration of the extreme event, 2) sensitivity of the species to salinity changes, 3) ability of the species to exploit new habitat, or rapidity of its elimination due to unfavorable conditions (by migration or death), 4) recovery period, after end of extreme event.

A group of study species was selected which could serve as models for the possible effects of such short-term events.

Most species inhabiting the estuarine environment are relatively eurytopic as regards salinity and other environmental variables. Nevertheless several taxa, particularly those of fresh-water/oligohaline and polyhaline affinities, have sufficient sensitivity to salinity changes (and these are well enough documented) to allow some prediction of these effects.

Assessment of the effect of extreme conditions was made for eight study species. This involved examination of maps of study species distribution (during critical seasons and/or life stages) to locate habitat boundaries, and comparison of these boundaries to the values calculated for extreme events. In the majority of cases, salinity changes at stations nearest to the species' boundaries were not of sufficient magnitude or duration to cause an impact. The exceptions are noted below:

Brachionis calyciflorus: In the summer-Base Drought scenario, a period of minimum salinities occurred which allowed the species' range to extend downestuary to midway between transects CB07 and CB06.

Crassostrea virginica: In the Base Average-summer and spring scenarios, upper bay salinities are reduced at this species' upstream limit to 4.3 ^{0}/00 from 7.0 ^{0}/00 for two weeks, possibly long enough to cause mortality of some individuals. In the Future Average summer scenario, salinities are reduced again at this upstream boundary by 2 ^{0}/00 for two weeks, again a potential negative effect. In the Future Drought summer, a decrease occurs from 9.8 ^{0}/00 to 5.6 ^{0}/00 for two weeks, possibly an impact.

Mercenaria mercenaria: The major effect here would be on the species during its spawning period. Reduction of salinities below 17.5 ^{0}/00 would prevent normal development of eggs and larvae.In the Future Average summer scenario,salinities at the boundary of "successful spawning area" are reduced for two weeks at least 2 ^{0}/00 below acceptable levels, and the minimum was 13.3 ^{0}/00. During this same period, salinities averaged 1 ^{0}/00 below acceptable levels for six weeks, with a minimum of 14.6 ^{0}/00.

Mulinia lateralis : There were no significant effects noted.

Rangia cuneata: There were no significant effects noted.

Urosalpinx cinerea: Minimum salinities ("freshets") are important in determining this species' range. In the spring Base Drought scenario, a minimum occurs at this species' upstream boundary (at 1 meter depth) for two weeks; the lowest salinity recorded was 4.5 ^{0}/00, which would exert a serious negative impact. However, at 4 meters the minimum salinity only reached

13.5 $^0/00$. Thus, individuals in shallow water would be killed, but those below the pycnocline would survive and possibly recolonize nearshore habitat.

Alosa sapidissima: In the spring Base Drought scenario, salinities increase at the downstream limit for spawning area for this species more than 2 $^0/00$ for two weeks (maximum 6.4 $^0/00$). This would shift location of Alosae spawning areas normally occurring from head of tide to 3 $^0/00$, and also cause compression of available habitat.

Morone saxatilis: There were no significant effects noted.

C. IMPACT RATIOS

1. Criteria and Calculation of Ratios:

Impact ratios are calculated from planimetered habitat areas, as discussed in Section II D. Four ratios were calculated:

Future Average: Base Average
Base Drought: Base Average
Future Drought: Base Average
Future Drought: Base Drought

It is important to realize that these ratios are based on areas of potential habitat, as defined by the habitat criteria of: salinity, depth, seasonality, substrate, and (in a number of cases) presence of other organisms. Not all habitat variables have been addressed, due to complexity and lack of sufficient data, but those used are the major parameters defining the range of study species.

In assessing the magnitude of impacts, consideration must also be given to ability of a species to colonize new habitat, need for dispersal mechanisms, and other mitigating factors (such as water quality). Impact ratios are the primary quantification step, based on changes in potential habitat. Other factors affecting each study species will be addressed in the individual species discussions in Section III-E.

In order to analyze impact severity, impact ratios were grouped by category. Table III-4 shows the categories of effects based on impact ratios (IR). Note that IRs from 0.90 to 1.10 are considered to fall within the minimal change category.

Table III-4. Impact Ratio Categories

IR	Category
0.90 to 1.10	Minimal habitat change
0.75 to 0.89	Moderate habitat change
1.11 to 1.35	
0.50 - 0.74	Large habitat change
1.36 - 2.00	
0.25 - 0.49	Very large habitat change
2.00 - 4.00	
< 0.25	Extreme habitat change
> 4.00	

$$IR = \frac{\text{potential habitat (scenario X)}}{\text{potential habitat (Base average scenario)}}$$

$IR > 1.0$ indicates habitat is increased

$IR < 1.0$ indicates habitat is decreased

The IR is in fact a percent - that is, an impact ratio of 0.57 indicates that 57% of the Base Average scenario's potential habitat area exists as the test scenario. It should be noted that for some cases (see Section III-E) the minimal category represents the range of potential computational error and may correspond to little or no impact.

2. Impact Ratio Results

Table III-5 gives impact ratios for the study species and associations. IRs for various life stages of a particular organism are presented separately. Likewise, in species with different density areas, IRs for each density are presented as well as that for the species' total habitat area.

Impact ratios as presented in this section show a response to low flow conditions for each species as an isolated entity. In reality, of course, organisms are part of a complex ecosystem, with links from one species to another through trophic, competitive, and other biological interrelationships. For example, a positive IR - an increase in habitat for a particular species - may not actually result in a long-term gain for that organism. The effect may be short-lived, or cancelled by simultaneous increase in a predator, reduction in an important food source, or other shift in the Bay's major ecosystems.

The final equilibrium state of the Bay's ecosystem will depend strongly on such interactions. We will attempt, within the limits of available data, to address the changes in impact of each species on overall ecosystem function based on these species interrelationships. This will be discussed in Section III-D, as well as in the individual species accounts to follow.

Table III-5. Impact Ratios for Study Species

	Species	Dens.	Impact Ratios FA:BA	BD:BA	FD:BA	FD:BD	Max. Cat.	+ -	BA Area (Km²)	Main Bay BA (Km²)	Main Bay Ratio FD:BA	Tributaries BA (Km²)	Tributaries Ratio FD:BA
1a	Tidal Fresh Phytos Wi/Sp	-	0.90	0.62	0.57	0.91	lg	-	2872	1237	0.70	1635	0.46
1b	Oligo-Low Meso Phyto Wi/Sp	-	0.95	0.52	0.50	0.93	lg	-	3121	1652	0.51	1469	0.48
1c	Meso Phytos Wi/Sp	-	0.67	0.55	0.51	0.94	lg	-	5245	3281	0.41	1965	0.68
1d	Polyhaline Phytos Wi/Sp	-	1.21	1.52	1.62	1.06	lg	+	4707	3448	1.42	1258	2.15
2a	Tidal Fresh Phytos Su/F	-	0.95	0.56	0.39	0.69	vl	-	1525	675	0.24	850	0.51
2b	Oligo Low Meso Phyto Su/F	-	0.95	0.54	0.50	0.91	lg	-	2203	1014	0.50	1188	0.50
2c	Hi Meso-poly Phyto Su/F	-	1.03	1.18	1.22	1.03	mo	+	8388	5654	1.14	2734	1.37
3a	Prorocentrum winter	-	1.21	1.36	1.42	1.04	lg	+	3551	2738	1.30	813	1.83
3b	Prorocentrum summer	-	0.93	0.73	0.58	0.79	lg	-	8578	5350	0.47	3228	0.74
5	Ceratophyllum	-	1.01	0.67	0.59	0.88	lg	-	1524	598	0.74	926	0.48
6&7	Potamogeton spp	-	0.91	0.65	0.61	0.94	lg	-	2444	1002	0.64	1442	0.60
8a	Zostera marina	-	1.04	1.44	1.51	1.04	lg	+	1513	808	1.37	705	1.68
8b	Ruppia maritima	-	1.00	1.10	1.14	1.04	mo	+	2867	1383	1.13	1484	1.15
9	Zannichellia	-	0.81	0.63	0.60	0.94	lg	-	3276	1510	0.58	1766	0.61
11	Coastal Fresh Marsh	-	0.92	0.68	0.50	0.73	lg	-	356	141	0.45	215	0.53
12	Spartina marsh	-	0.94	1.00	1.02	1.02	mi	+	1872	1019	1.06	853	0.96
13	Juncus marsh	-	1.14	1.17	1.22	1.04	mo	+	1535	912	1.18	623	1.28
14a	Mnemiopsis - summer	-	1.01	1.06	1.08	1.10	mi	+	9929	6326	1.07	3603	1.11
	Beroe ovata (predator)	-	1.70	2.72	3.01	1.10	vl	+	2485	1910	2.64	575	4.25
14b	Mnemiopsis-winter	-	0.97	1.20	1.27	1.05	mo	+	8261	3543	1.15	2718	1.50
15a	Chrysaora - adult	-	1.01	1.08	1.12	1.03	mo	+	10461	6734	1.08	3727	1.17
15b	Chrysaora - Polyps	-	1.04	1.04	0.97	0.92	mi	-	5829	3239	0.98	2590	0.96
16	Brachionis calcyiflorus	high	0.98	0.61	0.48	0.78	vl	-	946	336	0.51	610	0.45
16	" "	low	0.91	0.56	0.56	1.01	lg	-	1986	910	0.70	1076	0.44
16	" "	tot.	0.94	0.57	0.53	0.93	lg	-	2932	1246	0.65	1686	0.45
17	Acartia clausi	high	0.90	0.70	0.56	0.56	lg	-	5718	3432	0.53	2286	0.59
17	" "	low	1.31	2.04	2.47	1.20	vl	+	2715	1835	2.17	880	3.08
17	" "	tot.	1.03	1.13	1.17	1.03	mo	+	8433	5267	1.10	3166	1.29
18	Acartia tonsa	high	0.90	1.80	2.80	1.60	ex	+	1293	877	2.86	416	2.70
18	" "	pred	0.98	0.95	0.81	0.85	mo	-	9750	5857	0.78	3893	0.84
18	" "	low	0.82	0.42	0.24	0.58	ex	-	648	179	0.11	1469	1.34
18	" "	tot.	0.96	1.01	1.00	0.99	mi	0	11691	6913	1.02	4778	1.06

Key: mi=minimal, mo=moderate, lg=large, vl=very large, ex=extreme

* 1 km² = 100 hectares = 247 acres

** Values for main bay and tributaries are approximate, based on grid lines, not exact river mouth locations.

	Species	Impact Ratios					Max.		BA	Main Bay		Tributaries	
		Dens.	FA:BA	BD:BA	FD:BA	FD:BD	Cat.	+-	Area (Km^2)	BA (Km^2)	FD:BA	BA (Km^2)	FD:BA
19a	Eurytemora-spring	high	0.94	0.63	0.60	0.95	lg	-	5088	2575	0.63	2513	0.56
19a		low	0.45	0.46	0.51	1.10	vl	-	1120	469	0.53	651	0.49
19a		tot.	0.85	0.59	0.58	0.97	lg	-	6208	3044	0.62	3164	0.55
19b	Eurytemora-summer	-	0.95	0.55	0.42	0.76	vl	-	1290	508	0.26	782	0.51
20	Scottolana canadensis	high	0.82	0.54	0.49	0.90	vl	-	906	470	0.28	436	0.72
20		low	1.04	0.57	0.46	0.81	vl	-	1876	774	0.57	1102	0.38
20		tot.	0.97	0.53	0.47	0.89	vl	-	2782	1244	0146	1538	0.48
21	Bosmina longirostris	high	1.04	0.64	0.49	0.77	vl	-	984	543	0.24	441	0.79
21	" "	low	0.79	0.41	0.23	0.55	vl	-	554	136	0.15	418	0.25
21	" "	tot.	0.94	0.55	0.39	0.71	vl	-	1538	679	0.23	859	0.63
22	Evadne tergestina	high	2.06	4.55	8.48	1.86	ex	+	385	385	6.12	0	undef.
22	" "	low	1.60	1.90	1.81	0.95	lg	+	2313	1806	1.47	507	3.02
22	" "	tot.	1.66	2.27	2.76	1.21	vl	+	2698	2191	2.31	507	4.82
23	Podon polyphemoides	high	1.04	1.19	1.10	0.92	mo	+	7086	4630	0.94	2456	1.39
23	" "	low	1.05	0.84	1.15	1.37	lg	+	2001	988	1.46	1013	0.85
23	" "	tot.	1.04	1.11	1.11	1.00	mo	+	9087	5618	1.03	3469	1.23
24	Limnodrilus hoffmeisteri	high	0.99	0.59	0.49	0.84	vl	-	900	209	0.72	691	0.43
24	" "	low	0.74	0.64	0.47	0.73	vl	-	182	110	0.30	72	0.72
24	" "	tot.	0.95	0.60	0.49	0.82	vl	-	1082	319	0.57	763	0.45
25	Heteromastus filiformis	high	1.02	1.07	1.08	1.00	mi	+	5144	2826	1.03	2318	1.13
25	" "	low	0.98	1.07	1.01	0.94	mi	+	2324	1366	0.98	958	1.07
25	" "	tot.	1.00	1.07	1.05	0.98	mi	+	7468	4192	1.01	3276	1.11
26	Pectinario gouldi	high	1.24	0.78	2.08	1.17	vl	+	2608	1466	1.91	1142	2.31
26	" "	low	0.87	1.78	0.70	0.90	mo	-	4088	2835	0.63	1256	0.85
26	" "	tot.	1.01	1.17	1.24	1.06	mo	+	6696	4298	1.08	2398	1.54
27	Scolecolepides viridis	high	0.81	0.98	1.11	1.13	mo	+	110	39	1.18	71	1.07
27	" "	low	0.89	0.64	0.55	0.86	lg	-	4812	2648	0.55	2164	0.55
27	" "	tot.	0.89	0.65	1.56	0.87	lg	-	4922	4687	0.56	2235	0.57
28	Streblospio benedicti	high	1.06	1.02	1.10	1.10	mi	+	4708	2657	1.14	2051	1.03
28	" "	low	0.99	0.98	0.93	1.01	mi	-	3830	2719	1.01	1111	1.01
28	" "	tot.	1.01	1.04	1.06	1.02	mi	+	8538	5376	1.07	3762	1.02
29	Urosalpinx cinerea	-	1.06	1.24	1.36	1.09	lg	+	5118	3116	1.30	2002	1.45
30a	Crassostrea virginica	-	1.04	1.11	1.12	1.01	mo	+	6721	4013	1.07	2708	1.20
30b	MSX + "dermo"	-	1.27	1.64	1.83	1.11	lg	+	3322	2086	1.78	1236	1.92

	Species	Impact Ratios					Max.	+ -	BA	Main Bay		Tributaries	
		Dens.	FA:BA	BD:BA	FD:BA	FD:BD	Cat.		Area (Km^2)	BA (Km^2)	FD:BA	BA (Km^2)	FD:BA
31	Macoma balthica	high	0.66	0.55	0.36	0.60	vl	-	4634	2719	0.29	1915	0.45
31	" "	low	0.97	0.70	0.69	0.99	lg	-	1974	1127	0.45	847	1.05
31	" "	tot.	0.75	0.59	0.45	0.77	vl	-	6608	3846	0.33	2762	0.64
32	Mercenaria mercenario	high	1.23	1.64	1.69	1.02	lg	+	1851	1058	1.78	793	1.58
32	" "	low	1.15	1.63	1.75	1.07	lg	+	1766	970	1.68	796	1.84
32	" "	tot.	1.19	1.63	1.72	1.05	lg	+	3617	2028	1.73	1589	1.71
33	Mulinia lateralis	high	1.06	1.20	1.26	1.05	mo	+	5463	3249	1.20	2214	1.35
33	" "	low	0.86	0.79	0.73	0.92	lg	-	3115	1816	0.82	1299	0.60
33	" "	tot.	0.98	1.05	1.06	1.01	mi	+	8578	5065	1.06	3513	1.07
34	Mya arenaria	occas.	0.81	0.89	1.04	1.17	mo	-	159	95	0.68	64	1.55
34	" "	high	1.06	1.17	1.19	1.02	mi	0	4049	2234	1.16	1815	1.22
34	" "	low	0.99	1.03	0.96	0.93	mo	+	2142	1299	0.98	843	0.94
34	" "	tot.	1.03	1.11	1.11	1.00		+	6350	3628	1.08	2722	1.14
35	Rangia cuneata	high	0.83	0.73	0.62	0.85	lg	-	658	240	0.53	418	0.67
35	" "	low	0.78	0.52	0.41	0.79	vl	-	1189	616	0.25	573	0.57
35	" "	tot.	0.79	0.59	0.48	0.81	vl	-	1847	857	0.33	991	0.61
36	Ampelisca abdita	high	1.11	1.43	1.42	1.00	lg	+	1172	888	1.08	284	2.49
36	" "	low	1.29	1.54	1.54	1.00	lg	+	1635	1248	1.37	387	2.12
36	" "	tot.	1.22	1.50	1.49	1.00	lg	+	2807	2136	1.25	671	2.27
37	Balanus improvisus	high	0.71	0.47	0.36	0.76	vl	-	1295	688	0.25	607	0.49
37	" "	low	1.23	2.35	3.40	1.44	vl	+	964	604	3.69	360	2.90
37	" "	pred.	0.99	0.92	0.73	0.79	mo	-	6863	4154	0.66	2709	0.84
37	" "	tot.	0.98	1.01	0.96	0.95	mi	0	9122	5446	0.94	3676	0.98
38a	Callinectes sapidus *	high	0.74	0.56	0.52	0.92	lg	-	3255	1742	0.43	1513	0.62
	" "	low	0.97	0.88	0.74	0.84	mo	-	7064	4157	0.76	2907	0.70
	" "	tot.	0.89	0.78	0.67	0.86	lg	-	10319	5899	0.66	4420	0.67
38b	Callinectes sapidus **	high	1.04	1.24	1.32	1.07	lg	+	3678	2059	1.29	1619	1.37
	" "	low	1.04	1.04	1.04	1.00	mi	+	5269	3721	1.03	1548	1.04
	" "	tot.	1.03	1.12	1.15	1.03	mo	+	8947	5780	1.12	3167	1.21
39c	Callinectes - spawning	-	6.3	23.5	46.6	1.98	ex	+	17	17	36.88	0	undef.
39a	Callinectes - winter male	high	0.94	0.91	0.86	0.94	mo	-	401	301	0.81	100	1.01
	" " "	low	0.89	0.76	0.56	0.73	lg	-	1119	808	0.44	311	0.85
	" " "	tot.	0.90	0.80	0.64	0.79	lg	-	1520	1109	0.54	411	0.89
39b	Callinectes-winter female	high	1.64	1.64	5.07	3.08	ex	+	30	29	4.93	1	11.00
	" " "	low	1.81	2.39	3.96	1.65	ex	+	183	178	3.65	5	15.00
	" " "	tot.	1.79	2.28	4.12	1.81	ex	+	213	207	3.83	6	14.33

* summer males

	Species		Impact Ratios							Main Bay		Tributaries	
		Dens.	FA:BA	BD:BA	FD:BA	FD:BD	Max. Cat.	+ -	Area (Km^2)	BA (Km^2)	Ratio FD:BA	BA (Km^2)	Ratio FD:BA
40	Cyathura polita	high	0.95	0.83	0.67	0.80	mo	-	246	88	0.53	158	0.74
40	" "	low	0.90	0.64	0.55	0.87	lg	-	1828	899	0.40	929	0.70
40	" "	tot.	0.90	0.66	0.56	0.85	lg	-	2074	987	0.42	1087	0.70
41	Gammaros daiberi	high	1.04	0.59	0.56	0.96	lg	-	428	181	0.63	247	0.78
41	" "	low	0.85	0.87	0.71	0.82	lg	-	483	215	0.32	169	0.87
41	" "	tot.	0.93	0.73	0.64	0.87	lg	-	812	396	0.46	416	0.81
42	Leptocheirus plumulosus	high	0.99	0.70	0.70	1.00	lg	-	1874	765	0.80	1109	0.64
42	" "	low	0.75	0.49	0.42	0.86	vl	-	3802	2411	0.39	1391	0.47
42	" "	tot.	0.83	0.55	0.51	0.91	lg	-	5676	3176	0.49	2500	0.55
43	Palaemonetes pugio	high	0.68	0.65	0.57	0.87	lg	-	2083	1082	0.45	1001	0.69
43	" "	low	0.99	0.72	0.79	1.10	lg	-	450	200	0.68	250	0.88
43	" "	tot.	0.99	0.92	0.89	0.96	mo	-	2533	1282	0.49	1251	0.73
44a	Alosa sapidissima *	-	0.98	0.67	0.61	0.91	lg	-	553	226	0.57	327	0.64
44b	" " **	-	0.95	0.56	0.39	0.69	vl	-	1525	675	0.24	850	0.51
44c	Alosa pseudoharengus *	-	0.92	0.74	0.70	0.73	lg	-	960	376	0.86	584	0.60
	" "	-	0.98	0.57	0.39	0.68	vl	-	1502	647	0.24	855	0.51
45a	Brevoortia tyrannus **	-	0.85	0.59	0.35	0.59	vl	-	455	13	1.92	442	0.36
45b	" " -adult	high	0.96	0.71	0.57	0.79	lg	-	8834	5490	0.47	3344	0.73
	" " "	tot.	1.00	1.06	1.08	1.01	mi	+	10132	6414	1.06	3718	1.11
46a	Anchoa mitchilli-eggs	-	0.66	0.57	0.58	1.02	lg	-	5863	3272	0.57	2591	0.60
	" " -larvae	-	0.75	0.45	0.41	0.90	vl	-	1086	657	0.26	429	0.63
47a	Micropogonias ***	-	0.90	0.55	0.42	0.75	vl	-	652	354	0.38	298	0.49
47c	Leiostomus ***	-	0.90	0.55	0.42	0.75	vl	-	692	378	0.00	314	0189
47b	Micropogonias-adult	-	1.05	1.07	1.09	1.02	mi	+	6565	4518	1.11	2047	1.05
47d	Leiostomus - adult	-	1.01	1.05	1.06	1.01	mi	+	8079	5375	1.07	2704	1.05
48	Menidia menidia	-	1.01	1.05	1.07	-	mi	+	8145	5264	0.99	2549	1.13
49a	Morone americana *	-	1.04	0.64	0.57	0.88	lg	-	916	363	0.82	553	0.63
49b	Morone americana-juv.	-	0.96	0.59	0.52	0.88	lg	-	866	332	0.40	534	0.60
49b	Morone americana-adult	-	0.93	0.67	0.33	0.50	vl	-	10711	5291	0.43	4420	0.20
50a	Morone saxatilis *	-	1.01	0.70	0.56	0.79	lg	-	1332	480	0.61	852	0.53
50b	Morone saxatilis **	-	0.95	0.56	0.39	0.69	vl	-	1525	675	0.24	850	0.51
50c	" " sum.adult	-	0.99	1.06	1.10	1.03	mi	+	10091	6495	1.06	3596	1.19
50c	" " win.adult	-	1.00	1.01	1.01	1.00	mi	+	5184	3764	0.98	1420	1.11
51a	Perca flavescens ***	-	0.82	0.23	0.12	0.50	vl	-	622	159	0.28	463	0.06
51b	" " adult	-	0.85	0.59	0.35	0.58	vl	-	4686	2266	0.21	2420	0.47
54	Aythya valisineria	conc	0.80	0.72	0.48	0.58	vl	-	6029	3443	0.39	2586	0.59
	" "	gen'l	1.77	2.22	3.18	1.41	ex	+	1635	930	3.42	705	2.86
	" "	tot.	1.01	1.05	1.05	1.01	mi	+	7664	4373	1.04	3291	1.08

* eggs & larvae
** juveniles
*** early life stage

D. INTERACTIVE AND SECONDARY EFFECTS

This section will discuss trophic relationships and predator-prey interactions,relating these to the food webs formed by their combination. Major pathways of energy and material transfer within the Bay's ecosystems can be identified from the trophic diagrams produced as part of the secondary effects assessment:

o Phytoplankton Associations (Figure III-15; Table III-6): Energy fixed by photosynthesis is transferred from the phytoplankton compartment along several major pathways. Herbivorous zooplankton consume a major proportion of the phytoplankton in most areas, and are thus a key link in the transfer of phytoplankton production to higher trophic levels. The calanoid copepod *Acartia tonsa* alone is estimated to consume about half of the phytoplankton production in the Patuxent River during summer months (Heinle 1980). A certain amount of the ingested phosphorus and nitrogen-containing compounds are excreted by these zooplankton; these in turn are utilized by phytoplankton. In Chesapeake Bay, a major proportion of phytoplankton biomass and production is represented by nannoplankton, small species less than 10 microns in diameter (McCarthy *et al*. 1974). Probably the majority of production by these species is consumed by microzooplankton, such as rotifers, tintinnids and other protozoans, and nauplii of copepods. Relatively little is known about the role of these small zooplankton in Chesapeake Bay; however, larger invertebrates, primarily benthic suspension feeders, also consume a significant proportion of phytoplankton. In addition, feces and pseudofeces of invertebrates are acted upon by bacteria - either while suspended in the water column or deposited on the sediment.

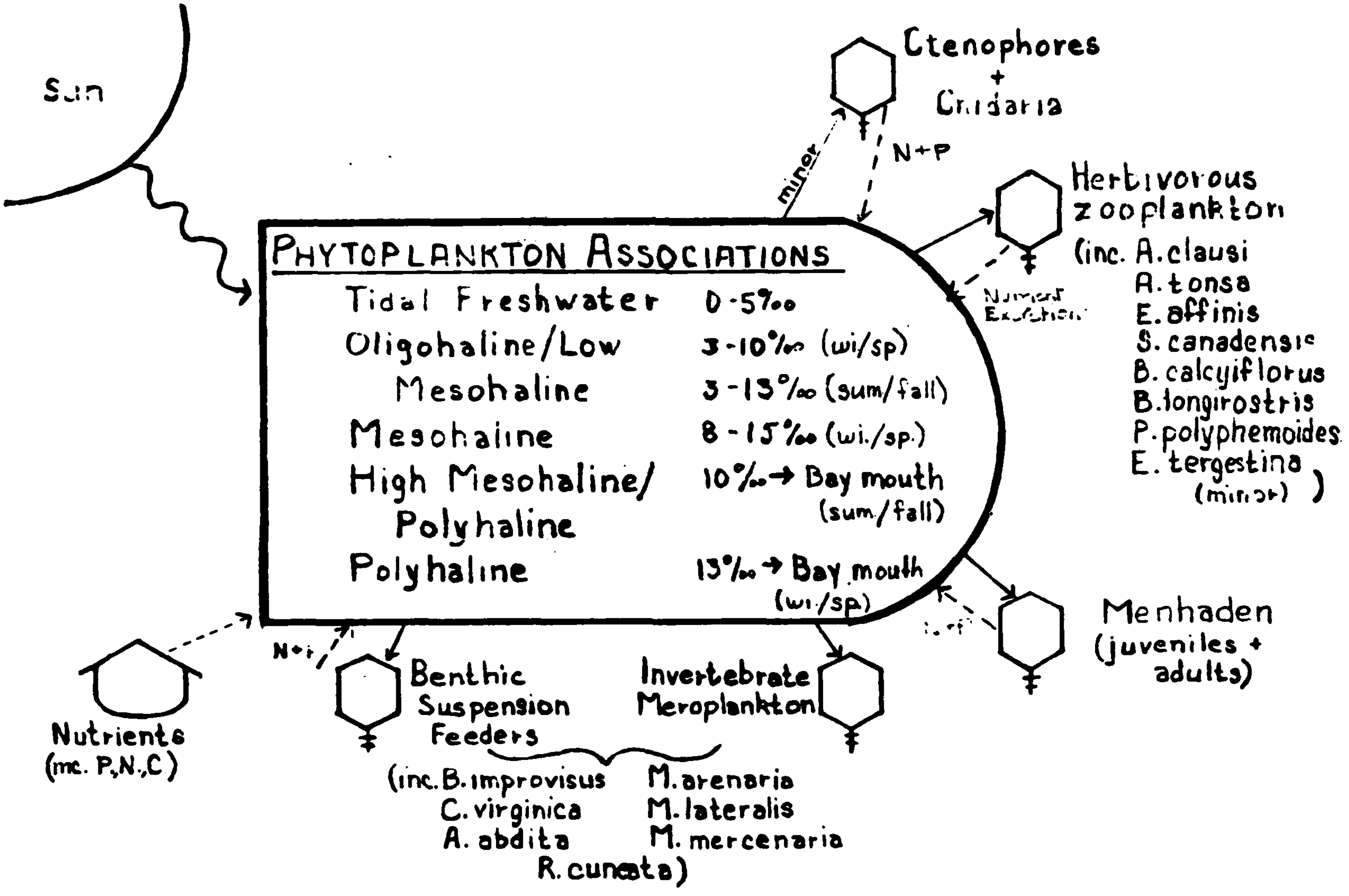

Fig. III-15. Phytoplankton Associations - Trophic Diagram

Key for Tables III-6 through III-11

(for visual clarity, latin names are not underlined)

Species Lifestages

l - larvae
j - juvenile
a - adult
m - medusa
p - polyp

Organisms
na - nannoplankton
net- net phytoplankton

Interactions
P - predator
F - food
D - disease
O - overlap
H - forms habitat
M - habitat modifier
C - competitor
PH - predator on habitat provided by the organism (i.e. epiphytes)

Method of reading - Begin with a species in the column on the left hand side of the page. The interactions indicate this species effect on a species in the top row: i.e. "P" indicates the species in the side column is a predator on the corresponding species on the top row. An "F" indicates the side column species provides food for the species in the top row, etc.

Table III-6. Phytoplankton Study Species	Tidal Freshwater Assoc. W/Sp	Tidal Freshwater Assoc. S/F	Oligo-low Mesohaline W/Sp	Oligo-Low Mesohaline S/F	Mesohaline W/Sp	High Mesohaline Polyhaline S/F	Polyhaline W/Sp	Prorocentrum minimum/Su	Prorocentrum minimum/W
Tidal FW Phyto			C	C					
Oligo-low Meso Phyto	C	C			C	C			
Mesohaline Phytos			C	C			C		
High Meso/Poly Phyto					C		C		
Polyhaline Phytos					C				
P. minimum			C/M	C/M	C/M	C/M			
Cnidaria & Clenophores			P	P	P	P	P	P	
Brachionis	P*/na	P*/na	P*/na	P*/na					
Other Microzooplankton	P/nan	P/na	P/na	P/na.	P/na	P/na	P/ na		
Bosmina	P*	P*	P*	P*/1					
Evadne					P/net	P/net	P		
Podon			P*	P*	P*	P*	P*	P*	
A. clausi			P*		P*		P		P*
A. tonsa		P	P	P*	P	P*	P	P	
E. affinis	P*	P*	P*	P*	P*				
S. canadensis	P	P	P	P	P				
copepod nauplii	P*	P*	P*	P*	P*	P*	P*		
crustacean larvae	P	P	P	P	P	P	P	P	
molluscan larvae	P	P	P	P	P	P	P	P	
Brevoortia (adult)								P*	
Brevoortia(juv.)								P	P*
Balanus improvisus			P	P	P	P			
Crassostrea			P/na	P/na	P/na	P/na	P/na		
Mya			P	P	P	P	P	P	
Mulinia			P	P	P	P	P	P	
Mercenaria					P	P	P	P	
Rangia	P	P	P	P					
Ampelisca					P	P	P		P
other suspension feeders	P	P	P	P	P	P	P	P	P
bacteria	M	M	M	M	M	M	M	M	M

Such bacteria-rich particles serve as food for other organisms, and as a substrate for the remineralization of nutrients. Another major pathway for phytoplankton production is through the menhaden, Brevoortia tyrannus, a planktivorous fish. Menhaden are particularly important as they represent a major pathway from primary producers directly to large harvestable organisms, and are an important food source for piscivorous fish. Minor pathways are represented by ctenophores and invertebrate meroplankton.

o Emergent Aquatic Vegetation (Figure III-16, Table III-7): This category comprises a variety of rooted vegatation species, which are grouped for purposes of impact analysis into three associations. Emergent aquatic vegetation (EAV) is found in partially submerged to irregularly flooded near-shore habitats. EAV's are primary producers, and are used directly as food by a variety of animals, primarily waterfowl and aquatic mammals, although the fresh water marsh species are primarily used directly. The major pathway through which marsh derived energy enters the estuarine trophic web is by detritus-based food chains. Dead and decaying plant material are acted upon by bacteria and other microorganisms, and these enriched particles serve as a food source for herbivorous zooplankton, such as Eurytemora affinis, and a variety of benthic detritivores and omnivores, such as Palaemonetes. EAV's provide a major habitat for fish and invertebrates, which can enter flooded marshes at high tide. Waterfowl and aquatic mammals (such as muskrats) also utilize marshes as habitat.

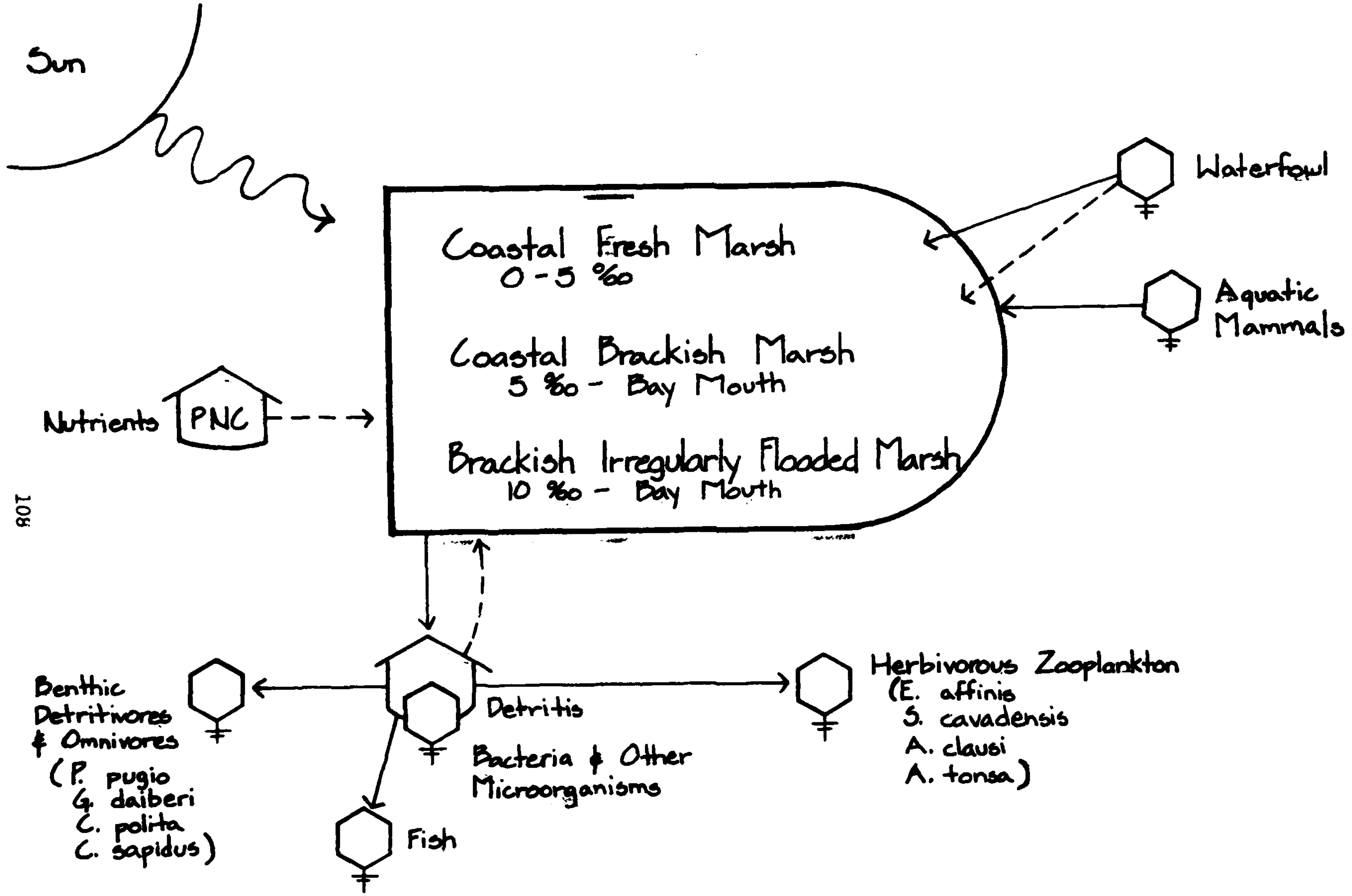

Figure III-16. Emergent Aquatic Vegetation - Trophic Diagram

Table III-7. Ecological Relationships
Emergent Aquatic Vegetation

Study Species	Coastal Fresh Marsh	Coastal Brackish Marsh	Brackish Irreg. Flooded Marsh
Coastal Fresh Marsh		C	C
Coastal Brackish Marsh	C		C
Brackish Irreg. Flooded		C	
Eurytemora affinis	P		
herbivorous zoopl.	P	P	P
Palaemonetes pugio	P/H	P/H	P/H
C. polita	P	P	P
G. daiberi	P	P	P
C. sapidus & other crabs	P/H	P/H	P/H
Benthic detritivores	P	P	P
Fish	H*	H*	H*
Waterfowl	F*/H*	F /H*	H*
Aquatic mammals	F*/H*	F/H*	F/H*

o Submerged Aquatic Vegetation (Figure III-17 , Table III-8):

Submerged aquatic vegetation (SAV) is a large category comprising a wide variety of rooted, attached, and free-floating plants (primarily phanerogams) living in relatively shallow near-shore environments. This ecosystem component has been reduced in both population density and range in recent years; the reason for this decline is not well known. SAV are primary producers, and are directly used as food by a variety of other species, particularly ducks, geese and other waterfowl, aquatic mammals, and some invertebrates. Dead and decaying plant tissue also enters the bay food web through the detritus pathway: bacteria and other micro-organisms act upon the plant material, and these enriched particles provide food for a number of benthic detritivores and omnivores, suspension feeders and zooplankton. The major role of SAV, however, is as a habitat for a host of other species, including epiphytes, epifauna, larval, juvenile, and adult invertebrates and fish. This diverse community has declined along with the reduction in SAV occurrence. The current "threatened or endangered" status of a number of invertebrates in Virginia is due to the loss of extensive stands of <u>Zostera marina</u> (Wass, pers. comm.).

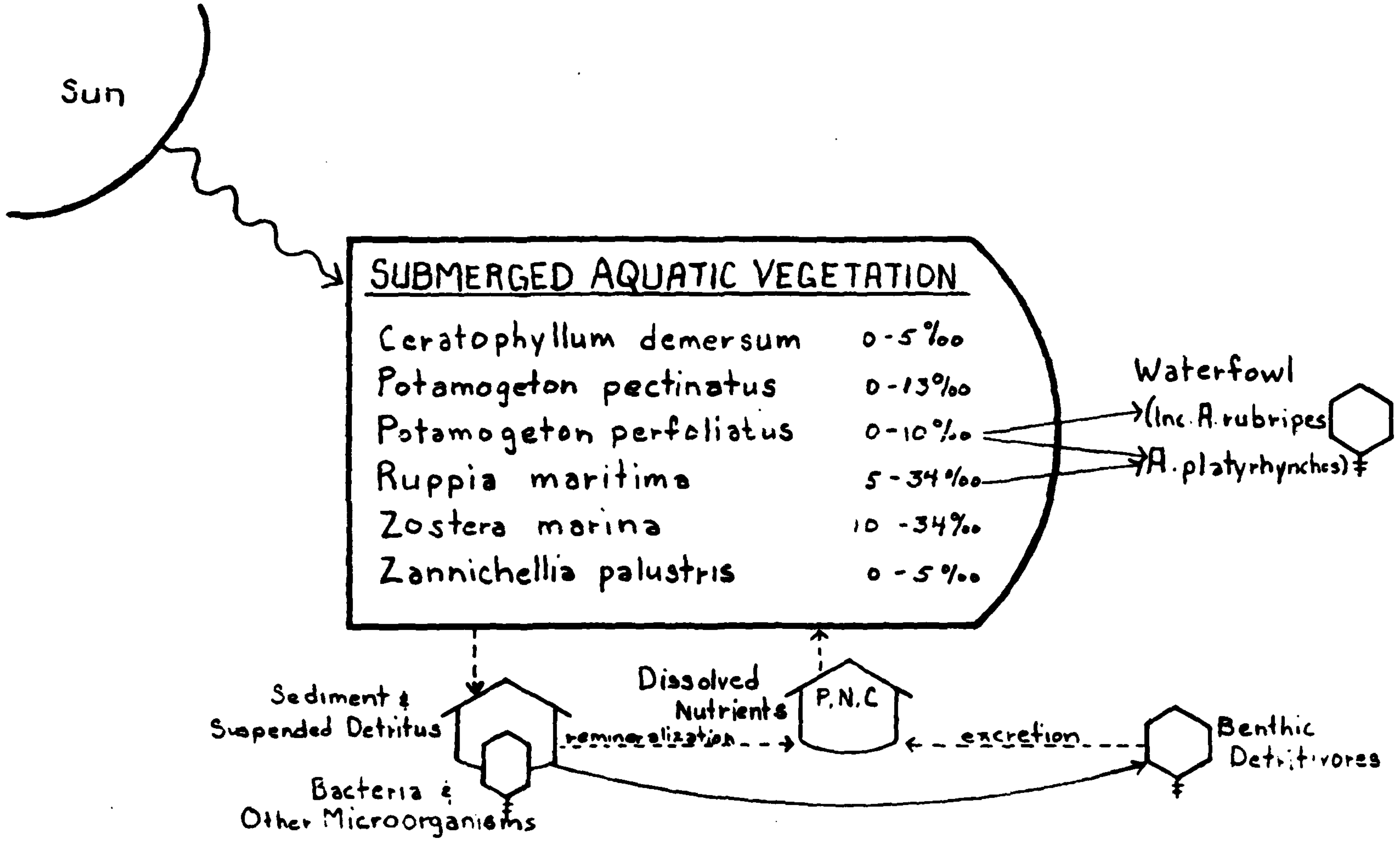

Figure III-17. Submerged Aquatic Vegetation - Trophic Diagram

Table III-8. Ecological Relationships
Submerged Aquatic Vegetation

Study Species	Ceratophyllum demersum	Potamogeton pectinatus	Potomogeton perfoliatus	Ruppia maritima	Zostera marina	Zannichellia palustris
Ceratophyllum						C
Potamogeton perf.		C				
Potamogeton pectin.			C			
Ruppia maritima					C	
Zostera marina				C		
Zannichellia	C					
Epifaunal invertebrates	PH	PH/P	PH/P	PH/P	PH/P	PH
Paloemonetes		PH	PH	PH	PH	
Callinectes		PH	PH	PH	PH	
Gammarus	PH	PH	PH	PH	PH	PH
Cow-nosed Ray				M	M	
Epiphytic algae	PH/C	PH/C	PH/C	PH/C	PH/C	PH/C
Athya valisineria	P	P*				P
Anas rubripes	P	P	P*	P*	P*	P
A. platyrhynchos	P	P	P*	P*		P
other ducks & geese	P	P*	P*	P*	P*	
other waterfowl	P	P	P	P*		
benthic detritivores	PF	PF	PF	PF	PF	PF
Bacteria	PF	PF	PF	PF	PF	PF
larval & juvenile fish	PH*	PH*	PH*	PH*	PH*	PH*
aquatic mammals	P	P	P			P

o Herbivorous Zooplankton (Figure III-19, Table III-9): These primary consumers channel phytoplankton-derived energy to a number of pathways. A major fraction of this compartment is consumed during the summer months by ctenophores and cnidaria. It is estimated that ctenophores could consume about 30% of the *Acartia* in the Patuxent during summer months (Bishop 1967), and Burrell (1972) found copepods virtually eliminated in areas of the York River where *Mnemiopsis* occurred in high densities. Copepods also represent an important food source for larval and adult fish, including menhaden. The latter species feed extensively on zooplankton when phytoplankton are predominantly less than 15 mm in size (Durbin and Durbin 1975). The importance to icthyoplankton and juvenile fish is well established, and high densities of certain copepods, cladocerans, and rotifers is critical to the survival and development of larval anadromous species in Chesapeake Bay. Minor pathways of energy transfer from herbivorous zooplankton run through carnivorous zooplankton other than ctenophores (eg., arrowworms), and larval invertebrates. Fecal material from the compartment enters the detritus/bacteria pathway, and may be in turn utilized as food by other species (including some herbivorous zooplankton). The benthic harpactacoid copepod *Scottolana* feeds more upon benthic diatoms, and bacteria-rich detritus; it represents a major food source for juveniles of demersal fish, especially sciaenids and flounder.

o Carnivorous Zooplankton (Figure III-19 Table III-9): Only one study species *Evadne tergestina*, falls into this subcategory, although in the Bay's ecosystem it shares the niche with a variety of other cladocerans, chaetognaths, mesoplankton, and ichthyoplankton. *Evadne* feeds primarily on large phytoplankton, particularly dinoflagellates, as well as rotifers, tintinnids and

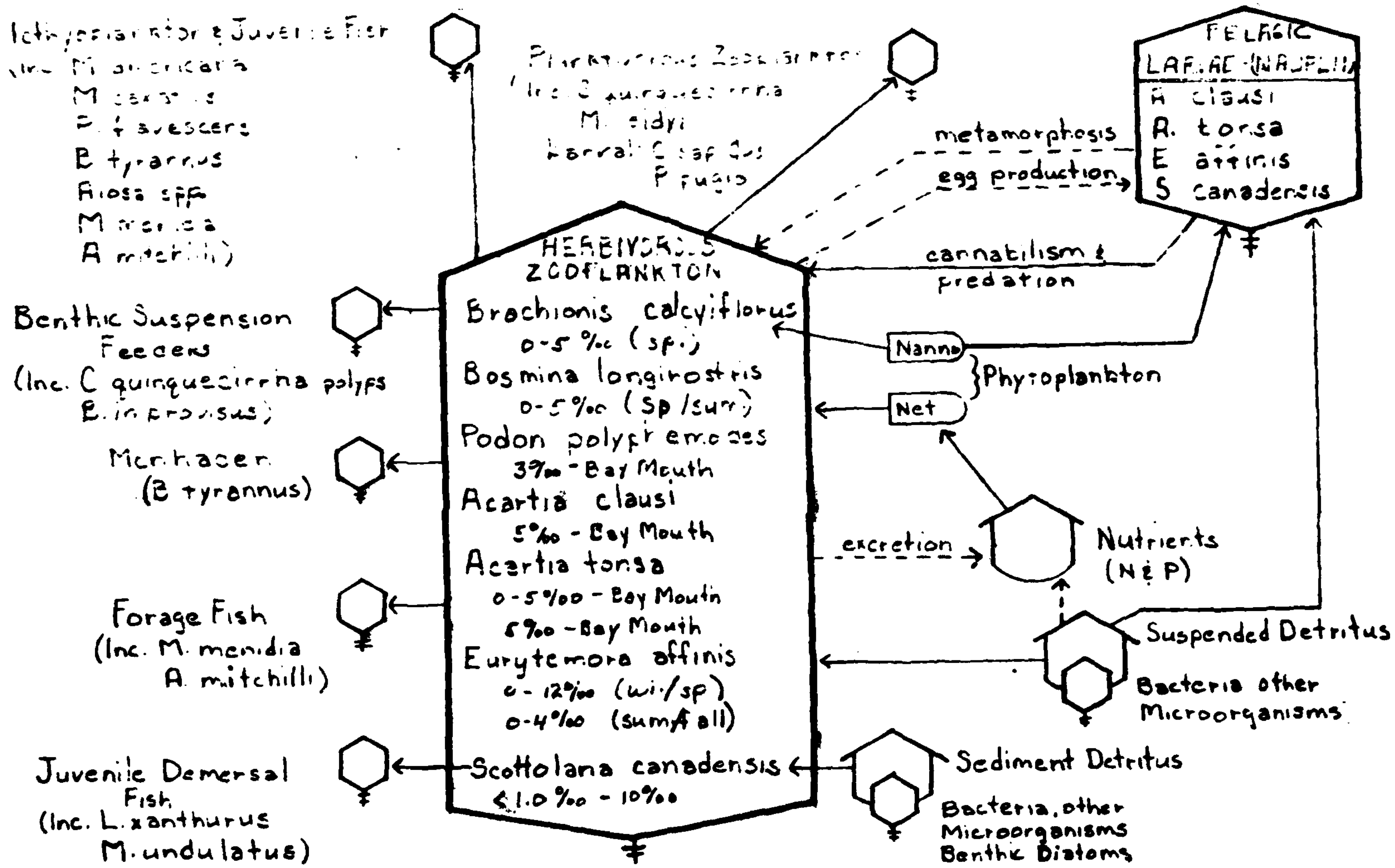

Figure III-18. Herbivorous Zooplankton - Trophic Diagram

Table III-9. Zooplankton Study Species	Mnemiopsis leidyi	Chrysaora quinquecirrha m.	Chrysaora quinquecirrha p.	Brachionis calcyiflorus	Bosmina longirostric	Podon polyphemoides	Evadne tergestina	Acartia clausi	Acartia tonsa	Eurytemora affinis	Scottolana canadensis	Copepod nauplii
Nannoplankton	M	M		F*	F*	F*		F	F	F		F*
Net Phytoplankton	M/F	M/F		F	F*	F*	F*	F*	F*	F*	F	F
Mnemiopsis		F			P	P*	P*	P*	P*	P*	P	P*
Chrysaora	P*			P	P	P	P*	P	P	P	P	P*
Beroe ovata	P*	P					P					
Brachionis					O	F						F*
Bosmina				O								C
other microzooplankton	F	F				F*	F*	F	F			C
Podon	F	F	F									P*
Evadne	F	F										
Acartia clausi	F*	F	F						C			P
Acartia tonsa	F*	F*	F					C		P/C		P
Eurytemora affinis	F*	F*	F					C	F /C			
Scottolana	F	F	F						O	O		
Copepod nauplii	F*	F*	F				F*	F	F			
Callinectes larvae	F	F					P	P	P			P
Palaemonetes larvae	F	F					P	P	P			P
other meroplankton	F	F					P	P	P			P
Brevoortia (adult)						P	P	P	P	P		P*
Leiostomus (juv)		F				P	P	P	P	P	P*	P
Micropogonias (juv.)		F				P	P	P	P	P	P*	P

Table III-9. Zooplankton (cont.)

Study Species	Mnemiopsis leidyi	Chrysaora quinquecirrha m.	Chrysaora quinquecirrha p.	Brachionis calcyiflorus	Basmina longirostris	Podon polyphemoides	Evadne tergestina	Acartia clausi	Acartia tonsa	Eurytemora affinis	Scottolana canadensis	Copepod nauplii
Morone amer. (larvae & juv.)		F		P*	P*	P		P	P	P*	P	P*
Morone sax. (larvae & juv.)		F		P*	P*	P		P	P	P*	P	P*
Perca (larvae)		F		P*	P*	P		P	P	P*		P*
Brevoortia (larvae)		F		P	P	P	P	P	P	P		P*
Alosa (larvae, juv.)		F		P*	P*	P	P*	P	P	P*		P*
Menidia (larvae)		F		P*	P*	P	P	P	P	P*	P	P*
Anchoa (larvae)		F		P*	P*	P	P	P	P	P*	P	P*
Menidia (adult)		F			P	P	P*	P	P	P	P	P*
Anchoa (adult)		F			P	P	P*	P	P	P	P	P
Peprillus (adult)	P	P*										
Bacteria	F*	F*		F*	F*	F	F	F	F	F*	F*	F*
Detritus	F	F*		F	F*	F	F	F	F	F*	F*	F*
Balanus improvisus				P	P	P	P	P	P	P	P	P
Chrysaora polyps				P	P	P	P	P	P	P	P	P
Molluscan suspension feeders (minor)				P	P	P	P	P	P	P	P	P

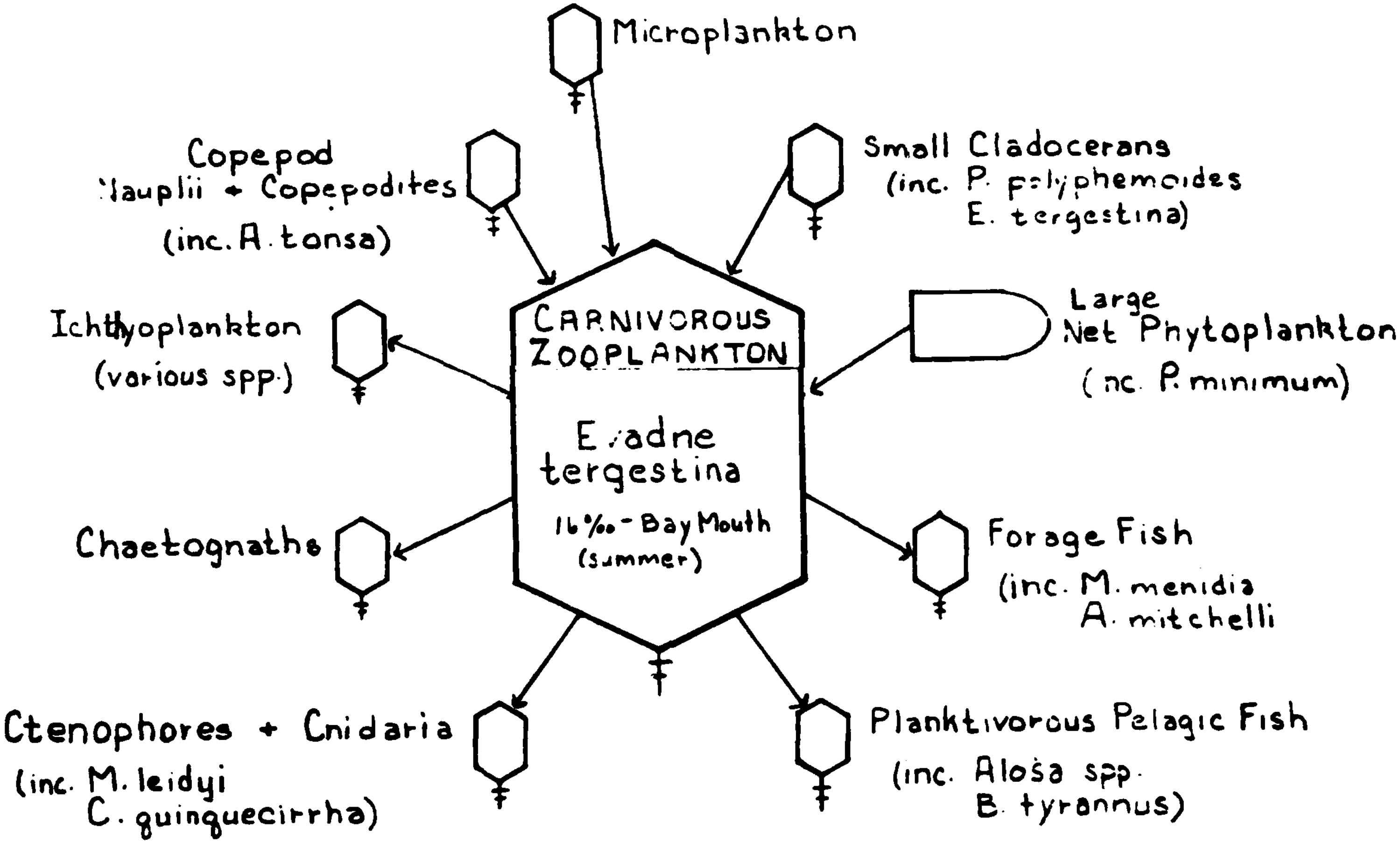

Figure III-19. Carnivorous Zooplankton - Trophic Diagram other protozoans, copepod nauplii and copepodites, and small cladocerans (including young *Evadne*). In turn it is a source of food for other carnivorous zooplankton, especially the chaetognath *Sagitta*, juvenile and adult planktivorous fish, ctenophores, and cnidarians.

o Ctenophores and Cnidarians (Figure III-20, Table III-9): Combjellies and jellyfish are an important fraction of the Bay's plankton community. Particularly during the summer months, they exert a significant grazing pressure on other zooplankton. In addition, these primitively organized species excrete a large proportion of their ingested organic nitrogen and phosphorus, and are thus important to nutrient cycling. While the primary food of these organisms is zooplankton, they also ingest a certain amount of larger phytoplankton, detritus (and associated bacteria), ichthyoplankton, and in the case of cnidarians, juvenile and small adult fish. Ctenophores and cnidarians are fed upon by relatively few other organisms, although the predaceous ctenophore *Beroe ovata* significantly reduces the numbers of *Mnemiopsis* in the lower Bay. *Chrysaora* also feeds upon ctenophores to an extent. The butterfish and harvestfish (*Peprilus* sp), more common in the lower Bay, are also predators of ctenophores and cnidarians. The sessile polyp stages of *Chrysaora* and other jellyfish feed upon zooplankton.

o Infaunal Deposit Feeders (Figure III-21, Table III-101) This subcomponent includes a wide variety of benthic organsims, including oligochaete and polychaete worms, mollusks, and some crustaceans. Six study species are represented in this category. The major energy/material pathway for this subunit is through ingestion of sediment detritus and associated bacteria, microorganisms, and benthic algae. Occasionally, suspended detritus

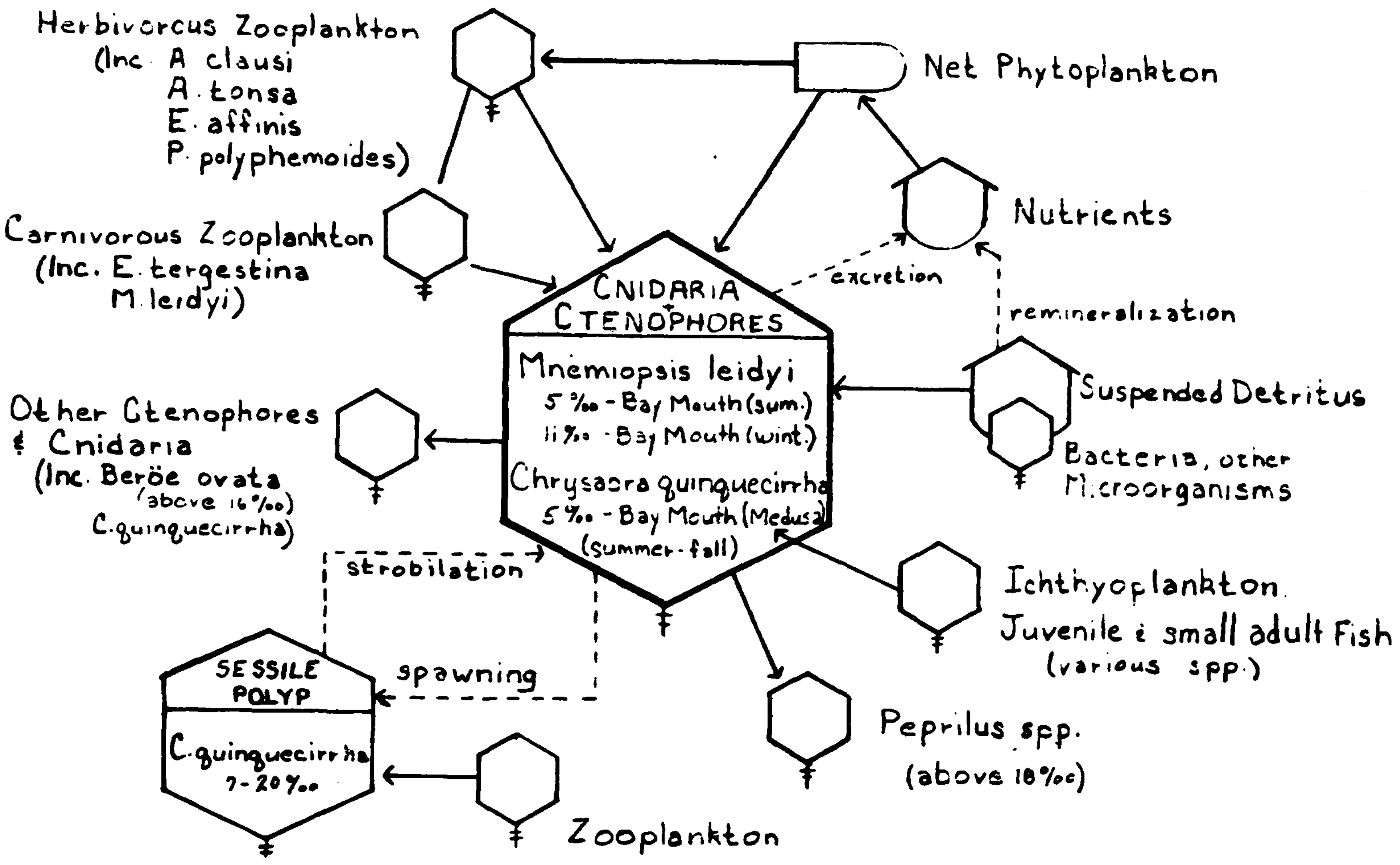

Figure III-2Q Ctenophores and Cnidaria - Trophic Diagram

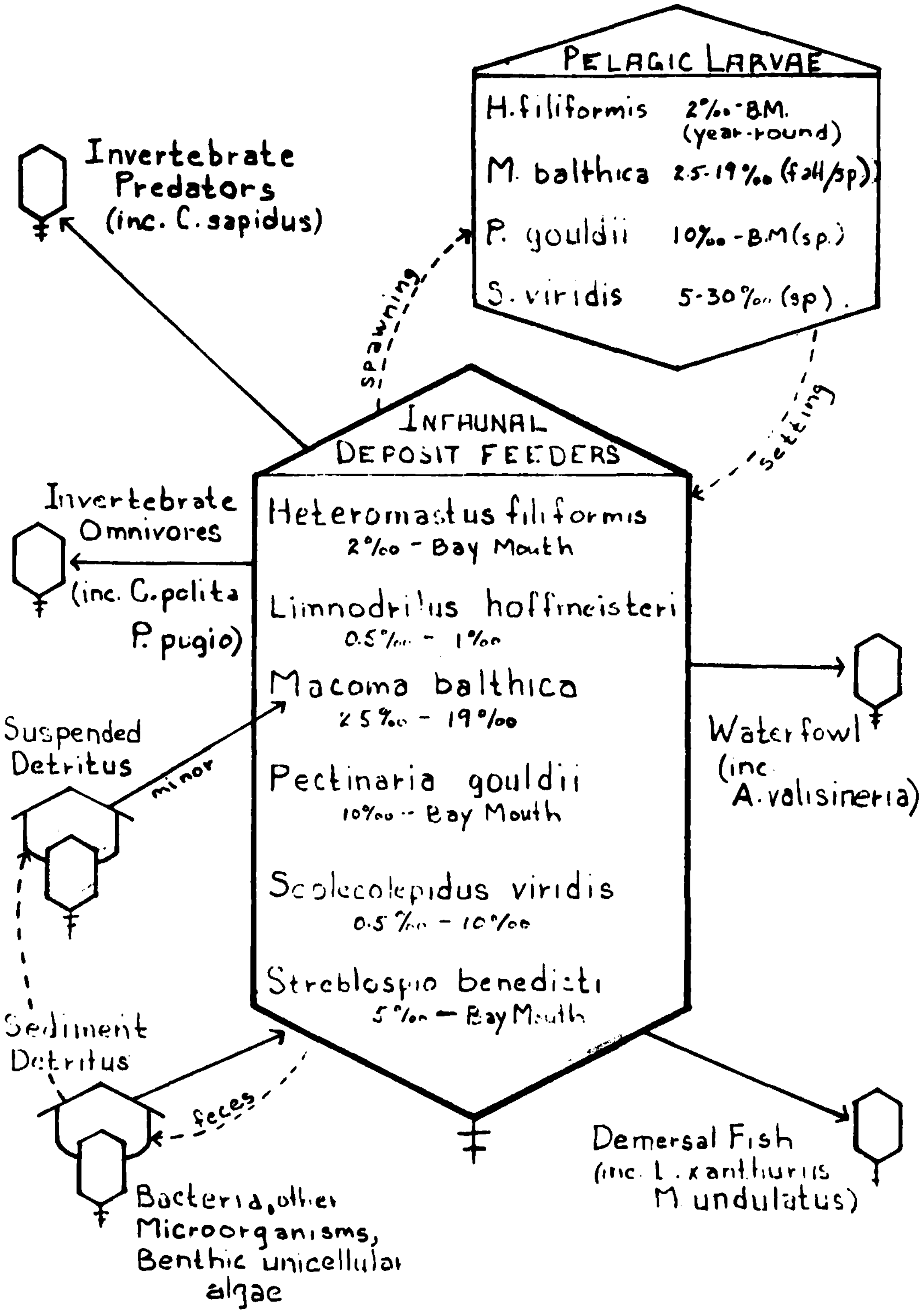

Figure III-21. Infaunal Deposit Feeders - Trophic Diagram

Table III-10A.
Benthic Organisms

Study Species	Hetercmastus filiformis	Limnodrilus hoffmeisteri	Macoma balthica	Pectinaria gouldii	Scolecolepides viridus	Streblospio benedicti	Cyathura polita	Gammorus daiberi	Leptocheriros plumulosus	Palaemonetes pugio	Balanus improvis
nannoplankton			F						F		F
net phytoplankton									F		F
benthic algae	F*		F*	F*	F*	F*	F	F	F		
Zostera marina	M		M				M			F/H*	
Ruppia maritima	M		M				M			F/H*	
other SAV			M		M		M	F/H		F/H*	
Chrysaora											
Chrysaora polyps											
Mnemiopsis											
microzooplankton									F		F*
copepods(A.& nauplii)					F				F		F*
cladocerans											
Palaemonetes pugio				P		p*					
Callinectes & other crabs	P*	P	P	P*	P*	P*	P*	P*		P	P*
Cyathura polita		P		P	P	P*					
Urosalpinx cinerea			P								P*
Stylochos ellipticus											P*
Leiostomus (A. & J.)	P*			P*	P*	P*	P*	P*	P*	P*	
Micropogonias(A.&J.)	P*			P*	P*	P*	P*	P*	P*	P*	
Morone saxatilis	P			P	P		P			P*	
Morone americana	P	P			P		P	P	P	P*	
Perca flavescens	P	P			P		P	P	P	P*	
Balanus improvisus											
Aythya valisineria		P	P*								
other waterfowl	P	P	P	P	P*		P	P	P	P	
Bacteria	F*	F*	F*	F*	F*	F*	F	F	F*	F*	F*
detritus, decaying matter	F*	F*	F*	F*	F*	F*	F*	F*	F*	F*	F
invertebrate larvae					F			F	F		F
Crassostrea							M				M
mollusks					F		F	F		F	
polychaete worms				C	F		F	F		F	
Minchinia (MSX)											
Perkinsus ("dermo")											
Streblospio	M		M								

Table III-10B.
Benthic Organisms (cont.)

Study Species	Crassostrea virginica (adult)	Crassostrea larvae	Rangia cuneata	Mya arenara	Mulinia lateralis	Mercenaria mercenaria	Other bivalve larvae	Urosalpinx cinerea	Ampelisca abdita	Callinectes sopidus (adult)	Crustacean larvae
nannoplankton	F*	F*	F*	F*	F*	F*	F*		F		F*
net plytoplankton	F		F*	F*	F*	F*	F*		F		F*
benthic algae				F	F				F*	F	
Zostera marina	M			M	M	M				F/H*	
Ruppia maritima	M			M	M	M				F/H*	
other SAV	M		M	M	M	M				F/H*	
Chrysaora	P*						D*				P*
Chrysaora polyps		P					P				P
Mnemiopsis		P*					P*				P*
microzooplankton		C		F*	F*		C				C
copepods(A.& nauplii)		C					C				C/F
cladocerans		C/P					C/P				C/F
Palaemonetes pugio										F	
Callinectes & other crabs	P*		P*	P*	P*	P		P	P	F	
Cyathura polita										F	
Urosalpinx cinerea	P*			P/juv	P	P/juv		P			
Stylochos ellipticus	P*										
Leiostomus (A. & J.)			P/juv	P*/juv	P*	p/juv			P	P	
Micropogonias(A.&J.)			P/juv	P*/juv	P*	p/juv			P	P	
Morone saxatilis				/juv	P	P/juv				P*	
Morone americana			P/juv							P	
Perca flavescens			P/juv								
Balanus improvisus	C	P					P	F*		F	P*
Aythya valisineria			P	P/juv	P						
other waterfowl	P		P	P	P	P			P	P	
Bacteria	F*	F*	F*	F*	F*	F*	F*		F*		F*
detritus, decaying matter	F*	F	F*	F*	F*	F*	F*	F	F*	F*	F*
invertebrate larvae		C									C
Crassostrea	C	H				M	M	F*/H		F*	M
mollusks	M	M					M/C	F*		F*	
polychaete worms	M	M					M			F*	
Minchinia (MSX)	D*										
Perkinsus ("dermo")	D*										
Streblospio				M	M		M		C		

is taken. Feces and pseudofeces return to the substrate, to be acted upon by bacteria and protozoans; these particles are reingested by deposit feeders. These organisms are an important source of food for invertebrate and vertebrate predators, particularly demersal fish, crabs, and waterfowl. In addition, they play an important role in nutrient recycling through release of nitrogen and phosphorus from the sediment.

o Epifaunal Suspension Feeders (Figure III-22, Table III-10) Organisms in this category typically live attached to hard or firm substrates. The relative paucity of such substrates in Chesapeake Bay limits the available habitat for these species. However, they occur with abundance on oyster beds, pilings, and are often referred to as "fouling organisms." Suspension feeders derive a major portion of their energy from phytoplankton and suspended detritus (with associated micro-organisms), and in many cases also ingest microzooplankton, and even larger organisms. A major study species, Crassostrea, feeds primarily on particles less than 12 μ size, with 1-3 μ the largest single size fraction (Haven and Morales - Alamo 1970). Thus, they represent a major pathway from nannoplankton and bacterial production to a large, harvestable species. Balanus ingests a wider range of food, including small zooplankton and larger phytoplankton, and even its own nauplii. Pelagic larvae of suspension feeders become food for a wide variety of planktivorous invertebrates and fish. Feces and pseudofeces are deposited, and enter the detritus food chain. A wide variety of invertebrate predators feed upon these organisms, particularly crabs, flatworms, and carnivorous mollusks.

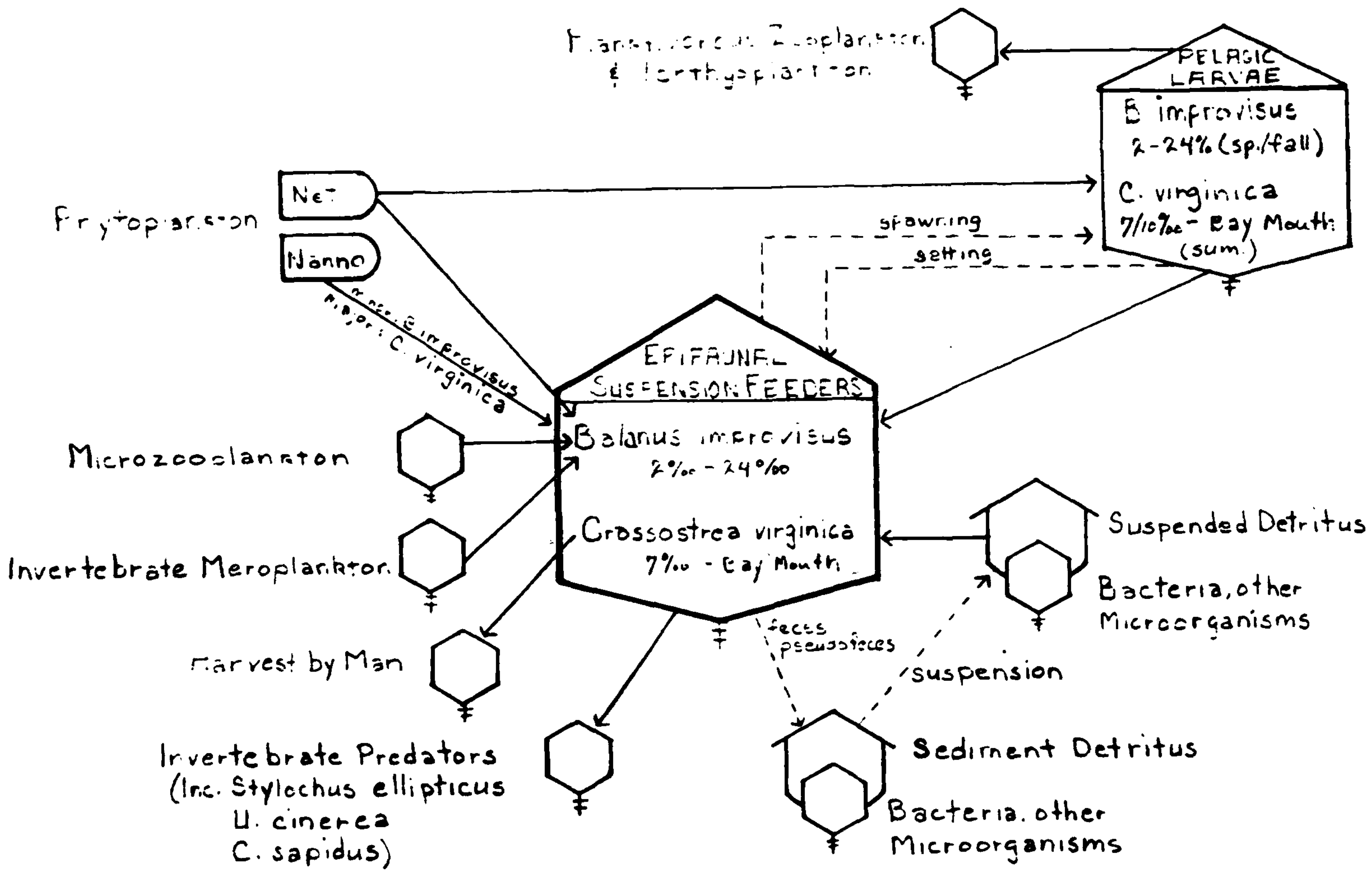

Figure III-22. Epifaunal Suspension Feeders - Trophic Diagram

- Infaunal Suspension Feeders (Figure III-23, Table III-10): This category includes a wide variety of mollusks, crustaceans, and a few worms; five study species are represented. These organisms derive a major portion of their energy from phytoplankton; a few may also feed upon microzooplankton. Suspended detritus, with associated microorganisms, is also ingested. These species serve as food for predaceous invertebrates, particularly crabs, as well as demersal fish, and waterfowl. Many are harvested by man. Feces and pseudofeces are deposited, and acted upon, by bacteria and other microorganisms; if resuspended, these bacteria-rich detrital particles become a source of food for suspension feeders. Pelagic larvae of a number of species are fed upon by planktivorous invertebrates and fish.

- Benthic Omnivores (Figure III-24, Table III-10): This category includes a group of mixotrophic feeders, which derive their energy from a variety of pathways. Most feed upon detritus, and also consume living organisms - benthic algae, small benthic animals - as well as decaying plant and animal tissue. They are opportunistic feeders, and are rarely selective or restrictive in their diets. In turn, they are fed upon by pelagic and demersal fish, large invertebrate predators such as crabs, waterfowl, and shorebirds. Certain of these omnivorous species represent an important link between relatively refractory material such as marsh plant detritus and higher trophic levels.

- Invertebrate Predators (Figure III-25, Table III-10): This category includes relatively large, mobile organisms which actively seek and capture living prey, and is composed chiefly of

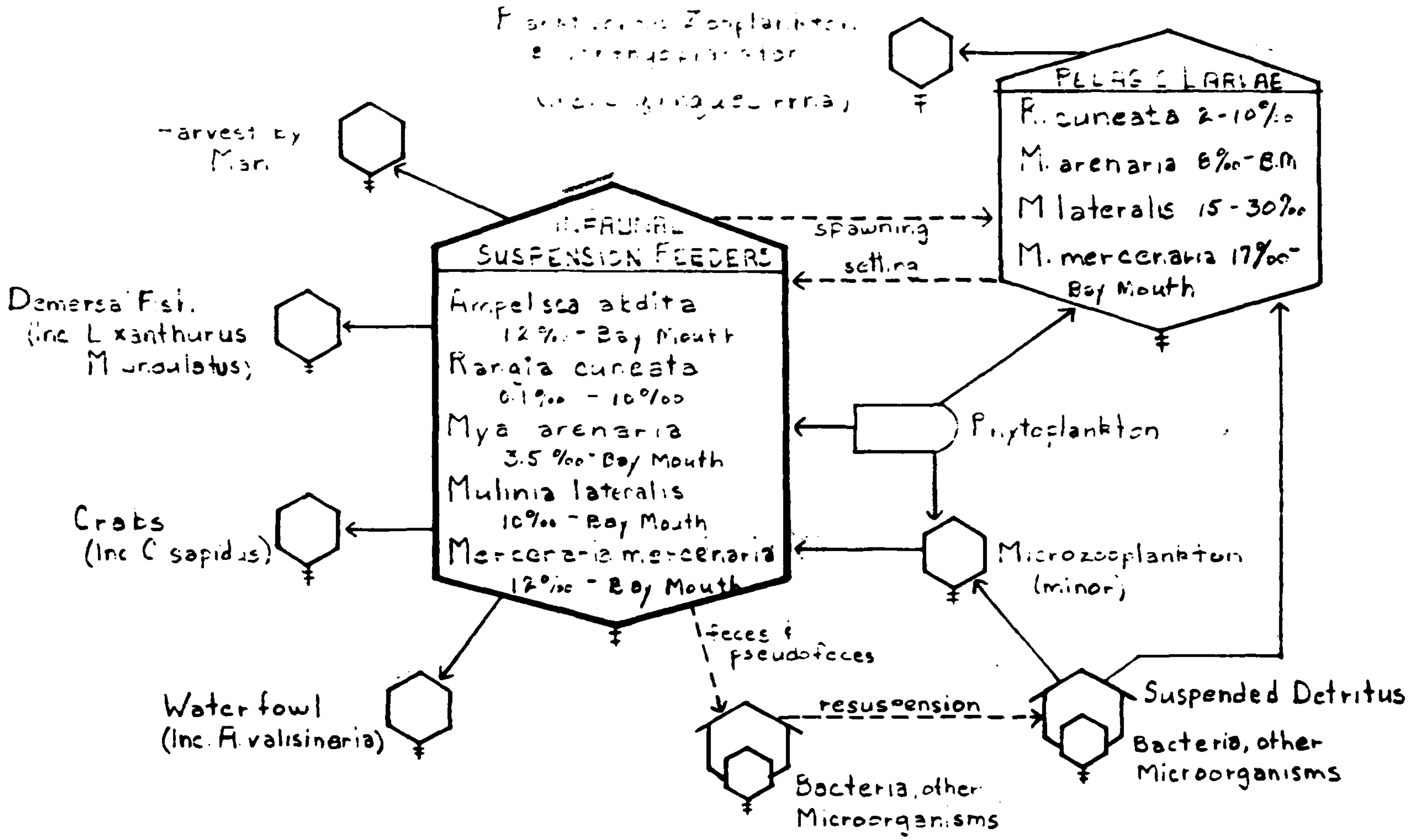

Figure III-23. Infaunal Suspension Feeders - Trophic Diagram

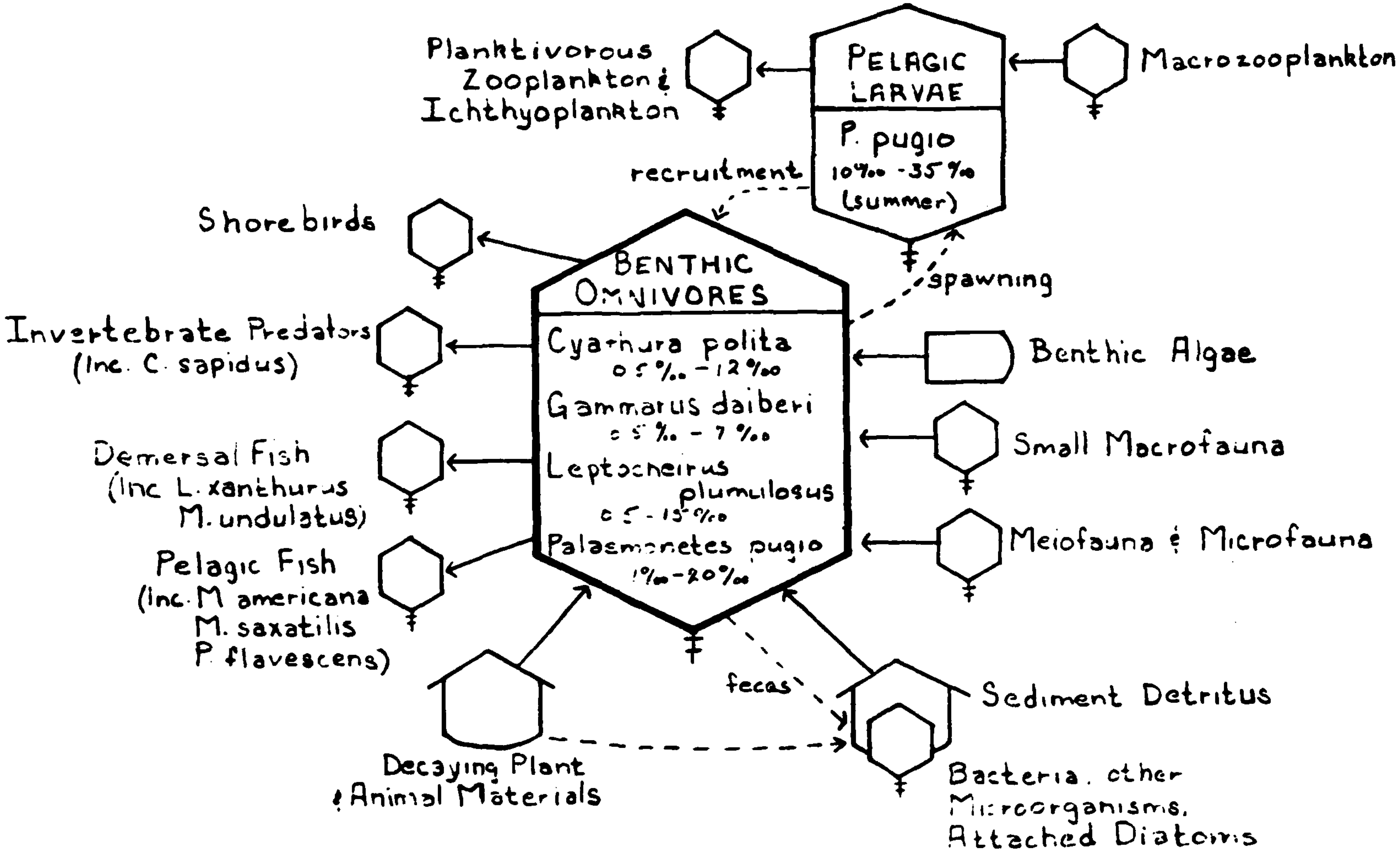

Figure III-24. Benthic Omnivores (Mixotropic Feeders) - Trophic Diagram

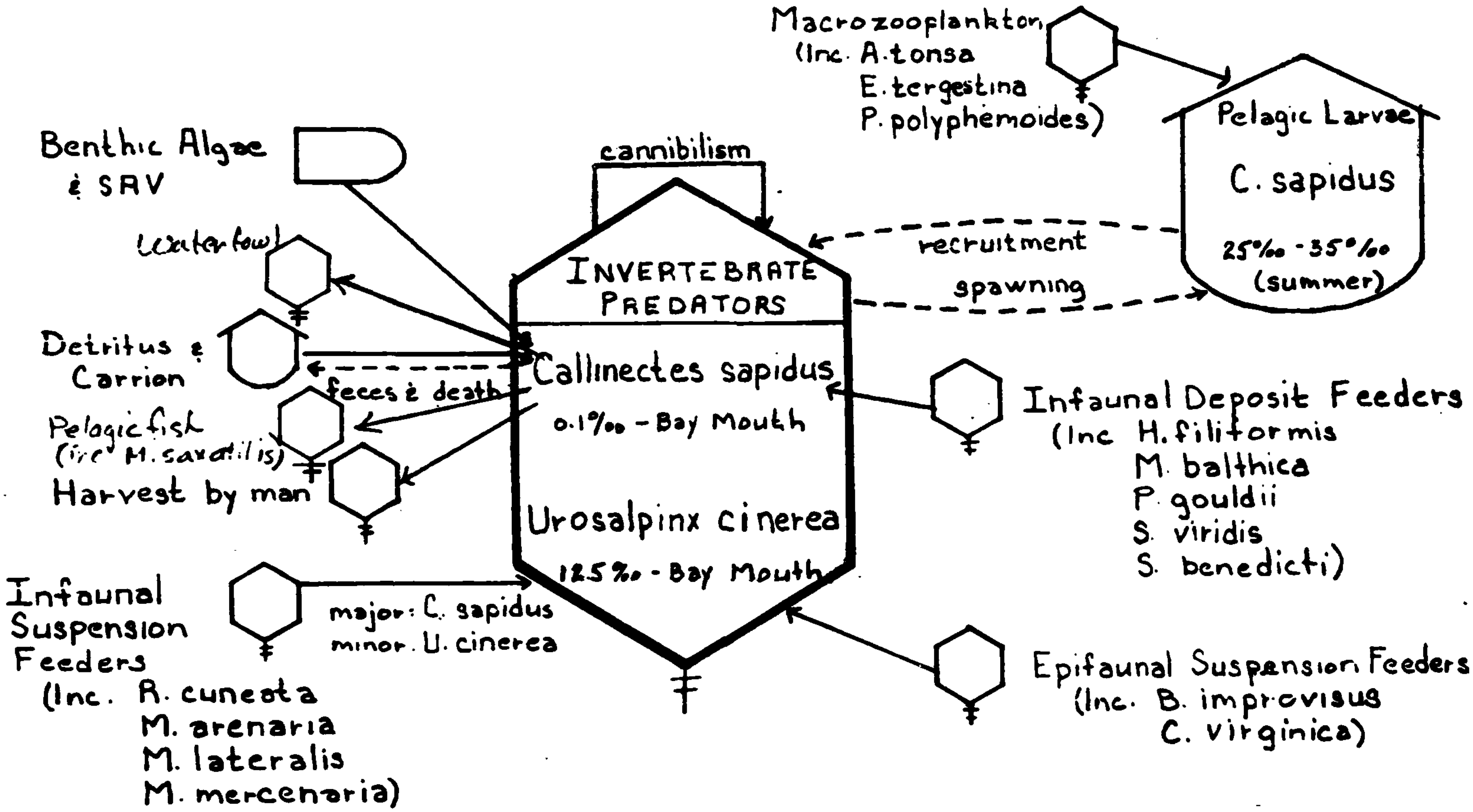

Figure III-25. Invertebrate Predators - Trophic Diagram crustacea, such as crabs, and carnivorous gastropods. Snails such as Urosalpinx feed primarily upon hard-shelled prey organisms, drilling through the shell and rasping out the flesh. Crabs and other crustacea are more opportunistic feeders, and also ingest soft bodied prey, small fish, detritus, decaying plant and animal material, submerged aquatic vegetation, and benthic macroalgae. In this subunit, as well, occur such species as the starfish Asterias, and the whelk Busycon, both of which feed on bivalves by forcing open the prey's shells. The latter two species may invade the lower Bay in greater numbers during reduced flow regimes. Pelagic crab larvae feed upon larger zooplankton such as copepods and cladocerans. Invertebrate predators are in turn fed upon by their conspecifics, predaceous fish and waterfowl, and some are harvested by man.

o Vertebrates (Figures III-26-31, Table III-11)

Piscivorous fish are not highly specialized feeders in general. This can be seen in the number of study species fish which serve as food for other study species fish. For top predators the single most important forage fish is the menhaden because of its dense schooling and high food value. Significant changes in the menhaden population within the Bay would be reflected in increased or decreased feeding pressure directed against other species.

The alosid juveniles depend on anchovy and silversides as well as the young menhaden for their growth in the shallow low salinity regions.

Dietary requirements are most exact for larval fishes. Because of their restricted mobility, food must be available in high densities. Because of their small size and weak mouth structure the size of the food particles is critical. To maximize the return on energy spent for capture the food quality must be high, maximum protein for a given particle size. Rotifers such as *Brachionis* and Cladocerans such as *Bosmina* are critical items in the diet of larval *Alosa* (Domermuth & Reed-1980) and *Morone* species. The concentration of these species in the nursery area has been shown (Miller 1978, Beaven & Mihursky, 1980) to strongly influence larval growth rates and survival.

Three species of larval fish (menhaden, spot, croaker) are in the low salinity portions of the estuary during the winter months and early spring which have highly specific food requirements. The major food organism for these larvae appears to be *Scotolana canadensis* which occurs in very high densities on the substrate during the winter and early spring. As these fish grow the menhaden switches to pelagic plankton and the drums move to larger benthic

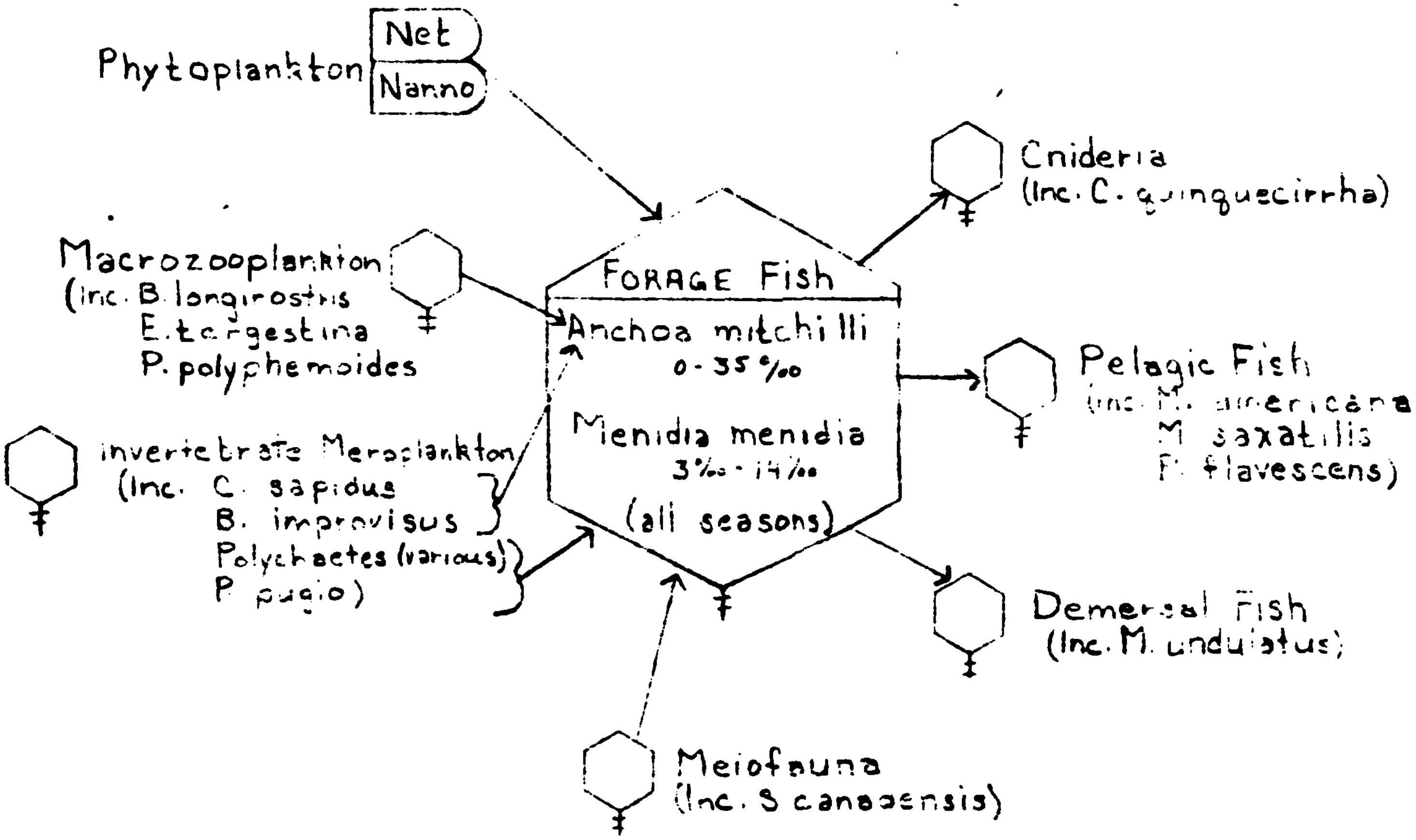

Figure III-26. FORAGE FISH - TROPHIC DIAGRAM

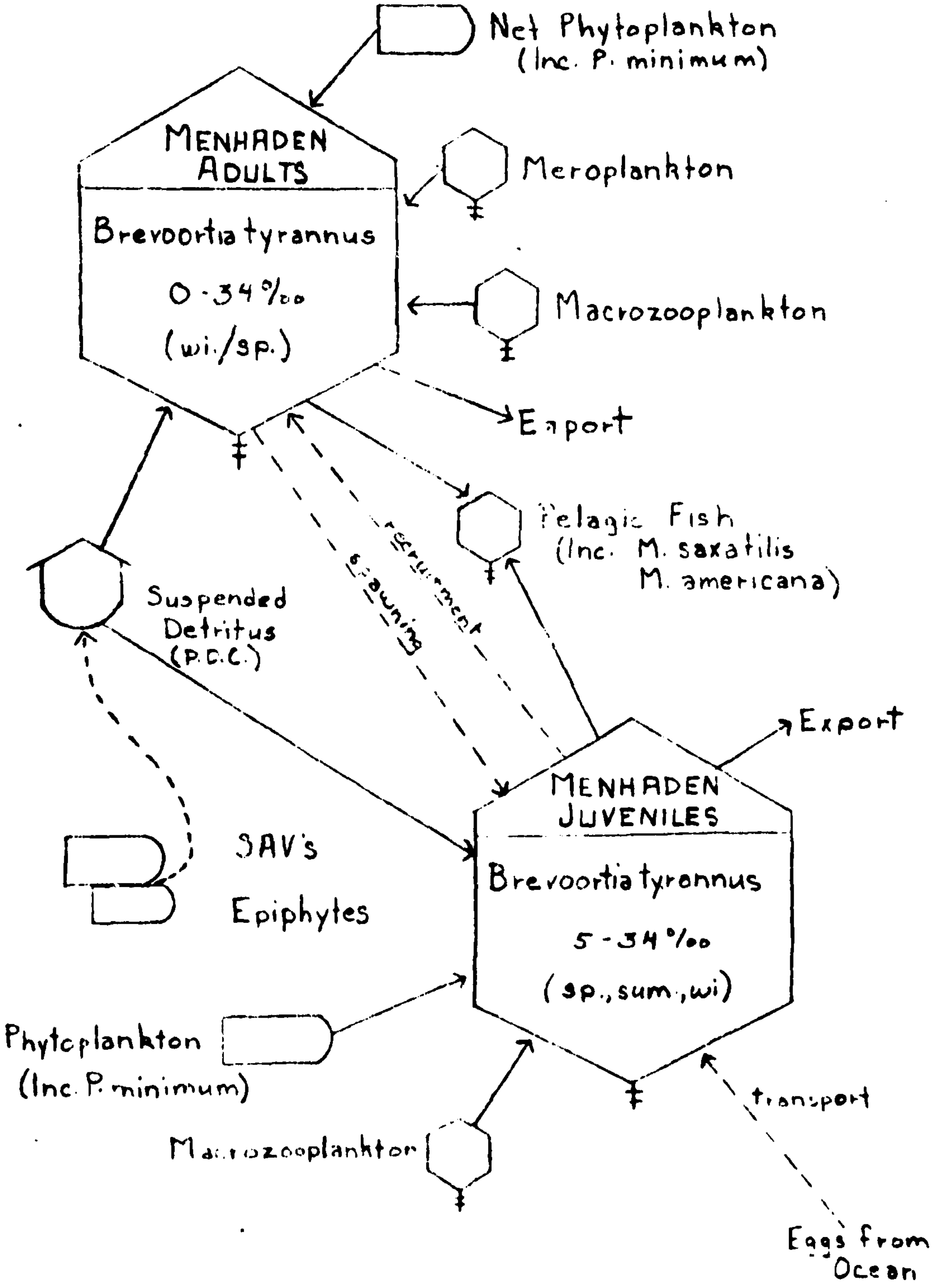

Figure III-27. MENHADEN - Trophic Diagram

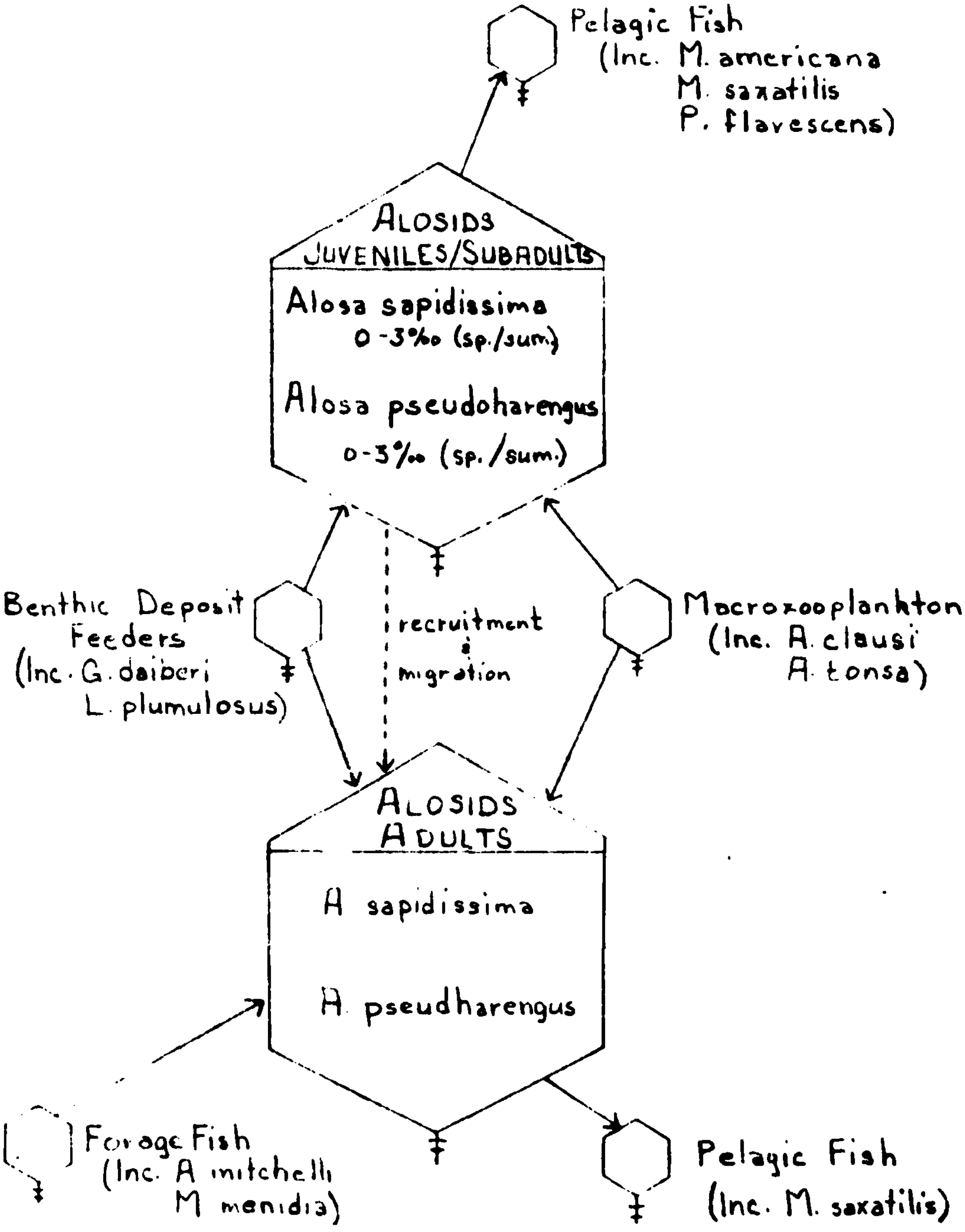

Figure III-28. ALOSIDS - Trophic Diagram

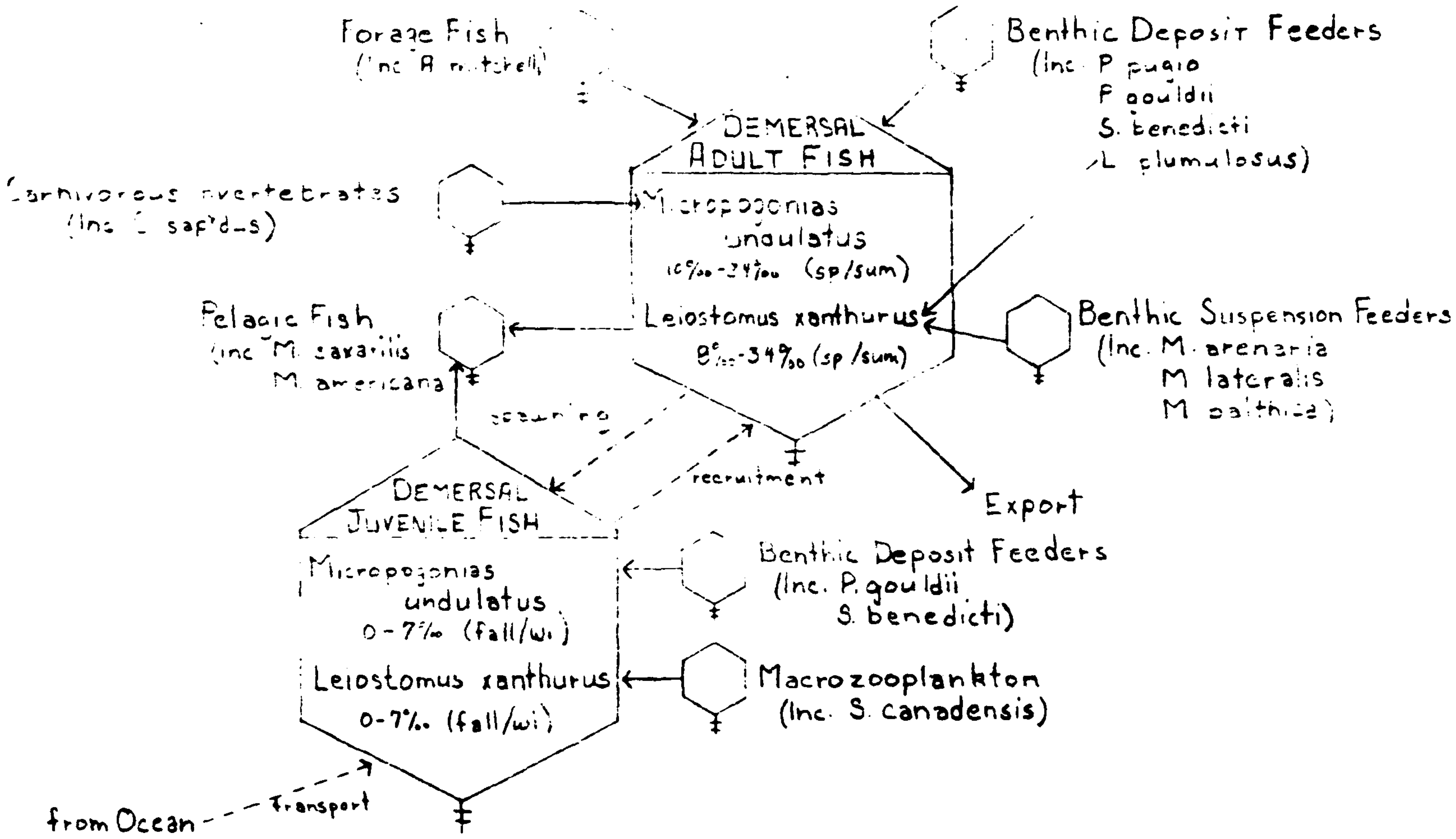

Figure III-29. DEMERSAL FISH - Trophic Diagram

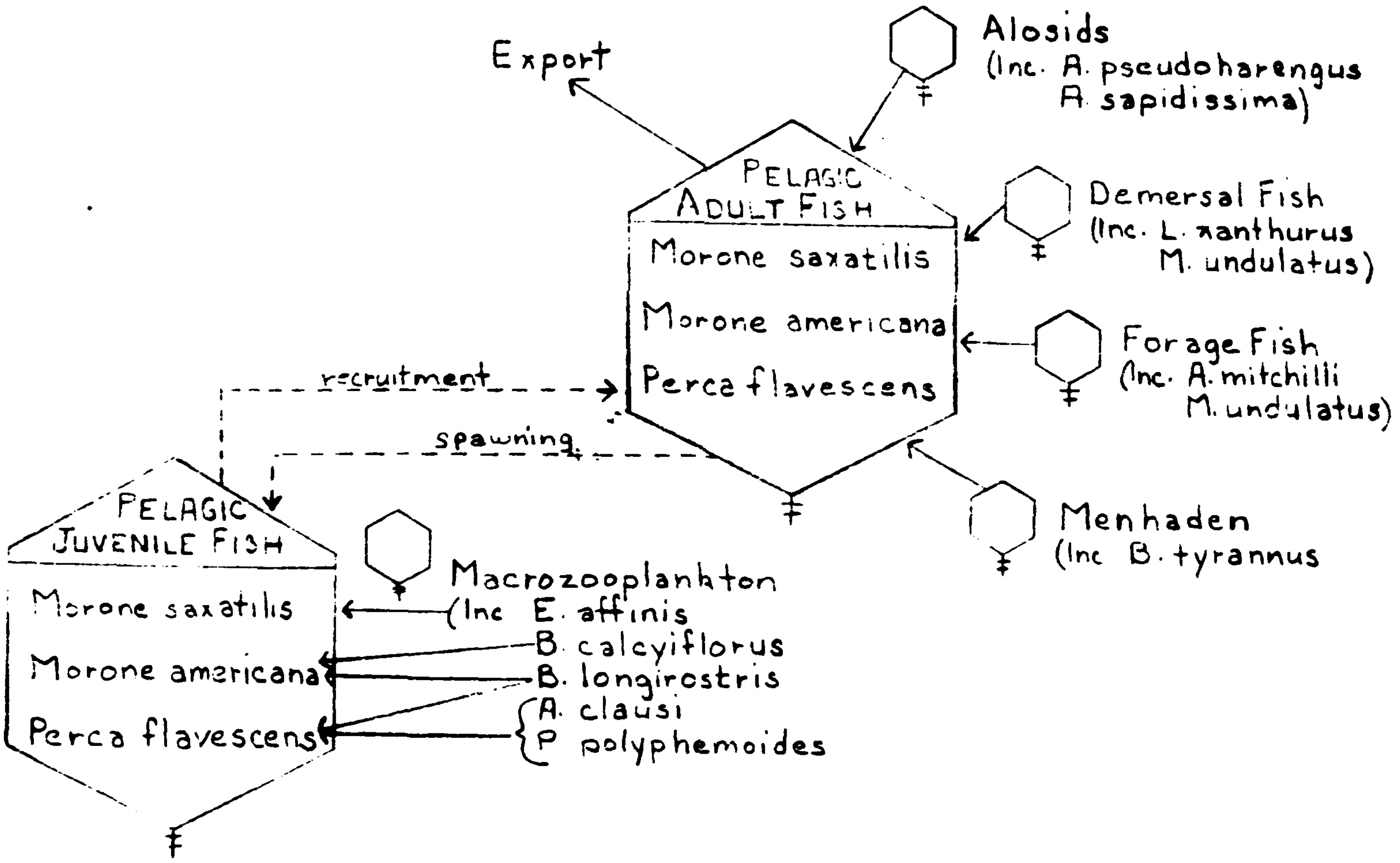

Figure III-30. PELAGIC FISH - Trophic Diagram

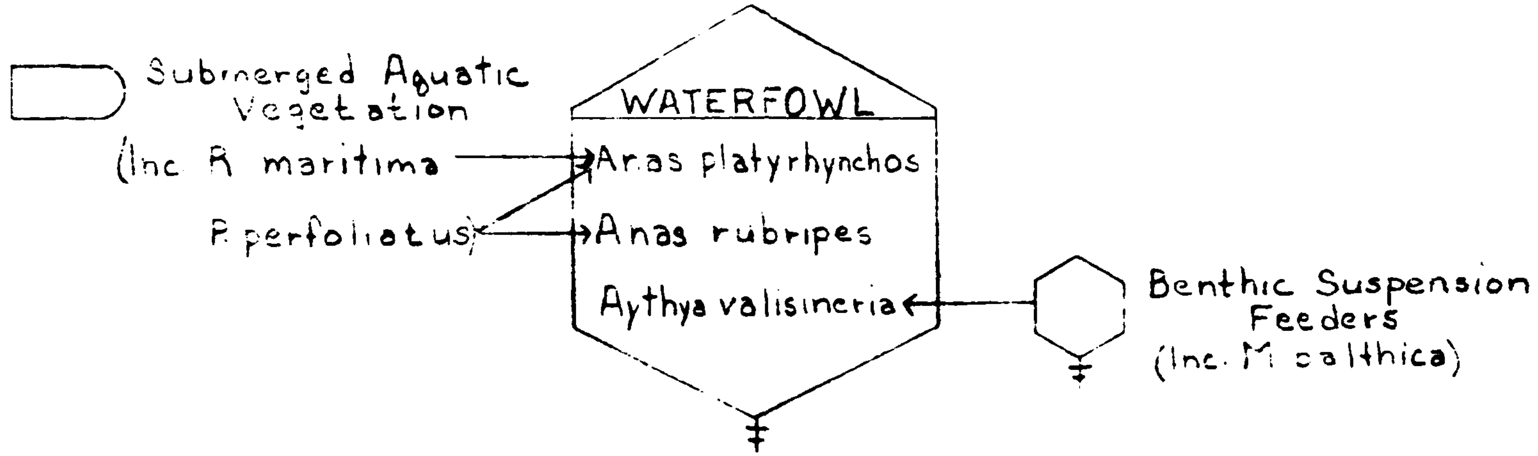

Figure III-31. WATERFOWL - Trophic Diagram

Table III-11A. Vertebrates

Study Species	Alosa sapidissima Juveniles	Alosa pseudoharengus Juveniles	Brevoortia tyrannus larvae	Brevoortia tyrannus adults	Anchoa mitchelli larvae & adult	Leiostomus xanthurus larvae & juv.	L. xanthurus adults	Micropogonias undulatus -l & j	M. undulatus adults	Menidia menidia	Morone americana larvae &Juv.	M. americana adults	M. saxatilis larvae & juv.	M. saxatilis adults	Perca flavescens larvae	P. flavescens adult
Alosa sapidissima-J.		C	P		P	P					P	F	F	F		F
Alosa pseudoharengus-J.	C		P		P	P					F	F	F	F		F
Brevoortia tyrannus-L.	F	F									F		F		F	
B. tyrannua-A.												F	F	F		
Anchoa mitchelli-L.	F	F														
A. mitchelli-A.							F		F		F	F	F			F
Leiostomus xanthurus-L.											F		F			F
L. xanthurus -A.												F		F		
Micropogonias undulatus L.											F		F			F
M. undulatus-A.	P	P			P									F		
Menidia menidia		F									F				F	F
Morone americana- J.	F	F				P				P			F	F		F
M. americana -A.	P	P	P		P		P	P		P				F	P	
M. saxatilis-J.			P		P	P		P		P		F				F
M. saxatilis -A.	P	P		P	P		P		P		P	P				P
Perca flavescens-L.																
P. flavescens-A.	P	P	P			P		P		P						
Evadne					F											
Brachionis	F	F	F		F*	F		F		F	F		F*		F	
Basmina	F*	F*	F		F	F		F			F		F*		F	
Acartia clausi	F	F		F	F			F		F						
Acartia tonsa	F	F	F	F	F					F						

Table III-11B.
Vertebrates (cont.)

Study Species	Alosa sapidissima juveniles	Alosa pseudoharengus juveniles	Brevoortia tyrannus larvae	Brevoortia tyrannus adults	Anchoa michelli larvae & adults	Leiostomus xanthurus larvae & juv.	L. xanthurus adults	Micropogonins undulatus - L. & J.	M. undulatus adults	Menidia menidia	Morone americana larvae & Juv.	M. americana adults	M. saxatilis larvae & Juv.	M. saxatilis adults	Perces florestens larvae	P. flavescens adults	Aytnya valisineria
Podon	F	F		F	F				F				F				
Palaemonetes							F		F	F		F				F	
Neomysis							F		F*			F*					
Pectinaria							F		F			F				F	
Streblospio							F		F								
Scolecolepides							F		F			F					
Scottolana			F*		F	F*		F*									
Leptocheirus			F			F	F	F		F	F	F				F	
Gommarus	F	F	F			F*	F	F		F	F						
Mya							F		F								
Mulinea							F										F
Macoma							F		F								F*
Balanus-L.				F	F								F				
Callinectes				F	F				F			F					
Chrysaora	P	P			P					P							
Crassostrea									H								
Phytoplankton				F*													
Zostera			H			H	H	H	H	H	H		H			H	
Potomogeton	H	H								H	H		H				F
Zannichellia	H	H								H	H		H				F
Vallisneria																	F*

prey organisms. Changes in the concentration of Scottolana would impact the growth and survival of larval spot, croaker and to some extent menhaden, although the food requirement of the latter is by no means clear cut.

The oyster Crassostrea is a habitat modifier for a variety of benthic invertebrates which in turn are food for the croaker. Croakers tend to associate with oyster reefs and major changes in the extent or condition of the oyster reefs would be reflected in the growth and condition of the croaker. Spot are primary grazers of the soft bottom where they may harvest the bulk of the new production of worms and clams. To the extent that croakers are forced from the hard bottom and oyster communities they will come into increasing competition with the spot.

Eel grass, Zostera marina, is a major habitat modifier for fish providing cover for forage fish, richer species diversity for benthic grazers and an additional food source in the form of epiphytes. An increase in the extent of Zostera beds would increase the juvenile populations of silverside, spot, croaker and white perch.

The current dependence of the Canvasback duck, Aythya valisineria, on Macoma balthica, has been noted elsewhere in the report. The species formerly depended on wild celery, Vallisneria americana (as reflected in the species name). If neither of these items of diet are abundant in the future the recovery of the Canvasback to its former numbers may be in doubt.

E. IMPACT ANALYSIS BY SPECIES

A number of study species or certain life stages of species fall into the category of "minimal" habitat change. They are:

Zooplankton:

Mnemiopsis leidyi - summer (very large predator effect, however)
Chrysaora quinquecirrha - polyps
Acartia tonsa - total area only
Podon polyphemoides - total area only

Benthics:

Heteromastus filiformis - all densities
Streblospio benedicti - all densities
Mulinia lateralis - total area only
Balanus improvisus - total area only

Fish:

Brevoortia tyrannus adults - total area only
Micropogonias undulatus - adult
Leiostomus xanthurus - adults
Morone saxatilis - summer and winter adults

Birds:

Aythya valisineria - total area only

Other species will be discussed in more detail below.

a. Phytoplankton:

Tidal Freshwater Phytoplankton, Winter/Spring and Summer/Fall

Description: Winter/Spring Freshwater Phytoplankton are dominated by diatoms and chlorophytes such as *Melosira granulata*, *Cyclotella* spp., *Skiletonema potamos*, *Pandorina*. Summer/Fall Tidal Freshwater

Phytoplankton are dominated by these and other diatoms, blue-green algae such as Anacystis, chlorophytes such as Scenedesmus, desmids, and euglenoids.

Impact Ratios and Categorization: Reduction in habitat area for both winter/spring and summer/fall tidal freshwater phytoplankton associations in future average conditions is minimal, with Irs of 0.90 and 0.95 respectively. Habitat reduction for both associations in the Base Drought is large, however, with IRs of 0.62 and 0.56 respectively. Winter/spring phytoplankton habitat is reduced in the Future Drought scenario, again with a large impact of 0.57; summer/fall associations exhibit a very large change in the Future Drought scenario, with an IR of 0.39 - that is, habitat for summer/fall tidal fresh phytoplankton during the Future Drought scenario is only 39% of the Base Average area. This association is thus strongly affected by consumptive loss during drought conditions.

Oligohaline - Low Mesohaline Phytoplankton, Winter/Spring and Summer/Fall

Description: Winter/Spring Oligohaline - Low Mesohaline Phytoplankton are dominated by diatoms such as Skeletonema costatum and potamos, Asterionella formosa, and the dinoflagellate Katodinium rotundatum. The summer/fall association is dominated by diatoms such as S. costatum, Diatoma hemale, Nitzschia spp, dinoflagellates such as Gymnodimium nelsoni, G. splendens and Prorocentrum minimum.

Impact Ratios and Categorization: These associations show a similar pattern as the preceding. That is, reduction of habitat is minimal between the Base Average and the Future Average (IR of 0.95 for both). However, in the Base Drought (IRs of 0.52 and 0.54 respectively) and the Future Drought scenarios (IRs of 0.54 and 0.50 respectively) the habitat reduction is categorized as "large."

Again, these associations are more seriously affected by drought conditions than by consumptive water losses alone.

Mesohaline Phytoplankton Associations (Winter/Spring)

Description: This association is dominated by diatoms such as S. costatum, Asterionella japonica, Ceratulina bergonii, Chaetoceros spp. and others, the dinoflagellate K. rotundatum, and various chrysophytes.

Impact Ratios and Categorization: Impact of habitat reduction in all three scenarios is large. Only sixty-seven percent of original base habitat remains in the Future Average scenarios (IR = 0.67). In Base Drought and Future Drought scenarios, further habitat reduction takes place (IRs = 0.55 and 0.51 respectively). Distribution of these phytoplankton will be significantly affected by consumptive water loss and by drought events.

Hi-Mesohaline - Polyhaline Phytoplankton Associations - Summer/Fall

Description: This phytoplankton association is dominated by dinoflagellates such as Ceratium furca, and diatoms such as S. costatum, Ditylum brightwelli, various Chaetoceros spp. and Thallassionema nitzschoides, and is found from approximately 10 $^{0}/00$ to the Bay Mouth.

Impact Ratios and Categorization: Habitat available for this association increases with decrease in freshwater: Change in the Future Average scenario is minimal (IR = 1.03) but Base Drought and Future Drought scenarios show a moderate impact (IRs = 1.18 and 1.22 respectively). These phytoplankton are thus more affected by drought events than by consumptive water loss alone.

Polyhaline Phytoplankton Associations - Winter/Spring

Description: Winter/spring phytoplankton in Chesapeake Bay is dominated by dinoflagellates such Peridinium triquetrum, Prorocentrum micans and minimum, and diatoms such as Nitzschia pungens, A. japonica, S. costatum, Rhizosolenia spp. and Chaetoceros spp. These and other high-salinity forms are the primary component of the early spring phytoplankton bloom in lower Chesapeake Bay.

Impact Ratios and Categorization: This high salinity phytoplankton community shows a significant positive habitat increase produced by reduced fresh water inflows in all scenarios. Habitat increase in the Future Average scenario is moderate (IR - 1.21), but in both of the drought scenarios the increases are large (IRs of 1.52 and 1.62). These phytoplankton are more affected by the drought scenarios, but consumptive loss alone results in a 21% increase in habitat.

Prorocentrum minimum - Dinoflagellate

Description: This small dinoflagellate has a complex seasonal distribution in Chesapeake Bay, closely linked to estuarine circulation (Tyler and Seliger 1978). It normally produces extensive "red water" in the upper Bay in June, but is found only in the higher salinity regions in winter months.

Impact Ratios and Categorizations: Impacts of consumptive water loss alone (Future Average) on summer distribution of this species is minimal. (IR= 0.93), but there is a moderate habitat increase in the winter (IR = 1.21). Base Drought and the Future Drought scenarios produce high impacts on winter Prorocentrum (IRs = 1.36 and 1.42 respectively) with increase in available high salinity habitat. Conversely, summer shows a reduction in habitat with decreasing fresh water input: only 73% of the normal habitat remains in Base Drought and 58% in the Future Drought predictions. In addition to habitat reduction, Prorocentrum could exhibit further adverse impact due to decrease in upstream transport rates streamflow in lower Chesapeake Bay tributaries, important in initiating upstream transport (Tyler and Seliger 1979, Seliger et al 1979), and flushing rates of subestuaries. Also, input of allochthonous nutrients will be reduced in future flow regimes, affecting this species, other phytoplankton, and rooted aquatics.

In the present (1980-81) drought, summer blooms of Prorocentrum have appeared reduced in extent and prominance, except in localized areas, compared to previous years (J. Allison, pers. comm.). If significant, such an observation could have implications for *this and other species* which utilize estuarine circulation for part of their lifecycle.

Sources: Seliger et al. 1979; Tyler and Seliger 1978, 1979

b. Submerged Aquatic Vegetation:

Ceratophyllum demersun

Description: This species is more important in Virginia waters, where it was found in 35% of vegetated samples taken by Orth et al. 1979. It is primarily a freshwater and oligohaline species, found in salinities less than 7 ^{0}/00.

Impact Ratio and Categorization: Consumptive water loss alone, in the spring months, does not affect potential habitat (IR = 1.01), but further reductions due to drought and drought plus consumptive water loss causes a large impact (IR = 0.67 and 0.59 respectively).

Ceratophyllum is only one of numerous members of the diverse freshwater/oligohaline SAV community, all of which would be similarly impacted by fresh water inflow reductions. In addition, input of nutrients from riverine sources will be reduced, also a potential adverse effect.

Potamogeton pectinatus - Sago Pondweed
Potamogeton perfoliatus - Redhead Grass

Description: Both of these species are important rooted aquatic plants in the freshwater oligohaline, lower mesohaline regions of Chesapeake Bay. As with other SAV species, they have been reduced in extent in recent years, for a number of reasons not yet well understood. Turbidity and growth of epiphytes have been implicated by recent studies (Kemp et al. 1981) in their decline.

Impact Ratio and Categorization: Reduction in available habitat is not significant in the Future Average scenario with only consumptive losses(IR = 0.91). However, drought conditions show a large impact (IR = 0.65), and habitat is further reduced in the Future Drought scenario (IR = 0.61). Low flow could have additional impacts, though, both positive and negative. Two positive effects would be reduction in turbidity, most particularly during drought conditions, and possible increase in epifaunal grazers to reduce epiphytic encrustation. Reduction of input of certain nutrients might favor SAV, as eutrophication has been cited as favoring phytoplankton over rooted vegetation. This would also result in decrease in turbidity, due to phytoplankton profileration.

The current drought has been suspected in decline and elimination of Potamogeton stands near the southern boundary of its range in Chesapeake Bay (J.C. Stevenson, pers. comm.).
Source: Kemp et al. 1981

Zostera marina - eelgrass

Description: This is an extremely important submerged aquatic angiosperm, usually limited to salinities greater than 8-10^0/00. In former years it formed extensive beds in the lower Chesapeake Bay, but like other SAV species has declined in recent years. Reasons for this decline are under investigation but appear to be related to turbidity, light reduction by epiphytes, as well as other causes (Wetzel et al 1981, Orth et al 1981). As Zostera supports a large and diverse in-and epifaunal and epiphytic community, as well as providing shelter and habitat for young of larger species such as crabs and fish, its decline has had serious repercussions throughout the lower Bay (Wass, pers. comm.)

Impact Ratios and Categorization: Reduction in fresh water inflow increases available habitat for this species, although the increase from Base Average to Future Average is minimal (IR = 1.04). Increase in habitat measures 41% in Base Drought and 51% in the Future Drought, categorized as a large impact. Additional positive effect on Zostera from reduced flows might be,as for other species, reduction in turbidity, eutrophication, input of herbicides and toxic substances, and enhancement of epifaunal grazers such as the snail Bittium (Orth et al. 1981), which in turn reduce thickness of epiphytic species on the plant leaves. Ability of Zostera to recolonize former habitat is limited, however, and this would be a primary factor in its response to increased habitat.

Sources: Wetzel et al. 1981
Orth et al. 1981

Ruppia maritima - widgeon grass

Description: This submerged plant is often found in association with Zostera, although it is more tolerant of low salinities and occurs in shallower water than that species. It is still relatively abundant in Chesapeake Bay, where it is a very important food for waterfowl.

Impact Ratios and Categorization: Increase in habitat for this species is only moderate at most. There is no change in available area in the Future Average scenario ; and increase in Base Drought and Future Drought are moderate (IR's = 1.10 and 1.14 respectively). This species might benefit from similar secondary effects as the other SAV species: reduced turbidity, eutrophication, and input of toxic materials as a result of low freshwater inflow.

Zannichellia palustris - Horned pondweed

Description: This species is found in fresh and low-salinity brackish waters, often in association with Potamogeton spp., Chara, Vallisneria and Myriophyllum. It is reduced in Maryland, and has been placed on the Watch List of potentially threatened Maryland plants by the Nature Conservency Maryland Heritage Program (L. Morse, pers. comm.)

Impact Ratios and Categorization: Reduction in freshwater inflow produces a marked reduction in available habitat - impact in the Future Average scenario is moderate (IR=0.81), but large in Base Drought and Future Drought (IRs = 0.63 and 0.60 respectively). While Zannichellia will probably benefit from reductions in turbidity and pollution due to low flow, further restriction of its habitat may cause some concern in regard to this species.

c. Emergent Aquatic Vegetation

Coastal Fresh Marsh Association:

Description: This association consists of a diverse assemblage of rooted species, including Typha spp., Phragmites, Zizania, Hibiscus, Sagittaria, and many others. These plants are very important as a source of food and habitat for waterfowl and aquatic mammals. Period of inundation is as important as salinity in determining species present (Boon 1977), so changes in tidal amplitude or drainage patterns resulting from reduced inflow will also affect distribution of emergent aquatic vegetations.

Impact Ratios and Categorization: Reduction in habitat for this association is minimal in the Future Average (IR = 0.92) but becomes large in Base Drought and Future Drought events. Impact of consumptive water loss in addition to drought reduces available potential habitat by 50% (IR = 0.50). This association is more seriously affected by drought events. Marshes are an important source of detritus to zooplankton in spring; reduction in river flows would affect these detrital-based food chains.
Sources: Boon 1977

Coastal Brackish Marsh Association

Description: Most of the species found in this association are restricted to brackish water by competition, rather than intolerance of fresh water. Diversity is usually lower than that of the preceding marsh type: some important species are Spartina spp., Distichlis, Scirpus spp., and Baccharis.

Impact Ratios and Categorization: There is a moderate increase in available habitat for this association in all three scenarios: 14% in the future, 17% in the drought, and 22% in the future drought. Possible secondary impacts may, as above, result from changes in marsh drainage patterns and reduction in detrital input.

d. Zooplankton:

Mnemiopsis leidyi - Ctenophore

Description: This species is found from the upper oligohaline to the polyhaline zone of Chesapeake Bay, primarily in warm months.

Its abundance may be reduced in polyhaline areas due to predation by the ctenophore Beroe ovata.

Impact Ratio and Categorization: The direct effect of any of the reduced flow scenarios on this species' summer habitat is minimal. However, its primary predator Beroe shows a marked increase: there is a large impact under Future Average (IR = 1.70), and very large change under Base Drought (IR = 2.72) and Future Drought (IR = 3.01). If previously observed effects of Beroe predation on Mnemiopsis again occur, its numbers could be reduced over much of its range. This has implications for survival of zooplankton of which Mnemiopsis is a major predator (Burrell 1972). Beroe's range extended to the lower Patuxent during the 1960's drought (Herman et al. 1968), which also is predicted by the hydraulic model data. Mnemiopsis shows an increase in habitat during winter months, but only in the two drought scenarios (IRs = 1.20 and 1.27).

Chrysaora quinquecirrha - Sea Nettle

Description: This relatively large jellyfish exerts considerable impact on recreation in the mesohaline and polyhaline areas of Chesapeake during the summer months. Sessile polyps release ephyrae in early summer; these mature into medusae, which first appear in Bay tributaries, then in the mainstem.

Impact Ratio and Categorization: Increases of habitat for this species - medusa and polyp - are minimal save for the jellyfish stage in the Future Drought. Then habitat increase is moderate (IR = 1.12). However, although these increases are modest in relation to the total habitat for this species, it represents a considerably incursion into the Bay. That is, Chrysaora penetrates

35 km farther upestuary in the Future Drought compared to the Base Average in the main Bay, and 26 km further upstream in the Potomac. This could result in significant economic impact in areas not usually affected by sea nettles.

Prolonged periods of low salinities ($< 7\ {}^{0}/00$) can kill the polyps, thus reducing later medusa abundance. This would be a possible control mechanism if flows can be regulated in the future.

Brachionis calcyiflorus - Rotifer

Description: This species is most common in tidal fresh water areas, but can be found to 5 ${}^{0}/00$ or so. This is an important food species for striped bass and other small fish larvae (Beaven and Mihursky 1980).

Impact Ratios and Categorization: All scenarios cause a reduction in habitat for this species, but it is minimal under Future Average. However, the effect of both drought events cause high impacts, and total area available for this species in the Base Drought scenario is 57% of the original, while only 53% remains during the Future Drought. This has great potential impact on possible survival of larval fish during these drought events, when their habitat is itself being reduced significantly.

Acartia clausi - copepod

Description: This species is an important member of the zooplankton community during the winter and early spring months, particularly in the polyhaline lower Bay. It is sometimes reduced in density by carnivorous neritic zooplankton which extend their range into the lower Bay in winter (Grant and Olney 1979).

Impact Ratios and Categorization: Total area for this species is increased slightly as fresh water flows are reduced; these effects are only moderate. However, the area of major concentration of this species is reduced significantly in the drought events: Base Drought IR is 0.70, and Future Drought 0.56. Simultaneously, area of impact of neritic predators shows great increase, even under Future Average (31%). These potential habitat changes are very large in Base Drought and Future Drought scenarios (IRs = 2.04 and 2.47 respectively). One important neritic predator, the arrowworm Sagitta, was reported at Calvert Cliffs during the 1981 drought (R. Gallagher, pers. comm.)

Sources: Grant and Olney 1979

Acartia tonsa - Copepod

Description: This species is found throughout the year in Chesapeake Bay, although most abundant in summer, and is by far the dominant copepod. It can be reduced severely by Mnemiopsis predation in areas between 5-20 $^0/_{00}$, and again by neritic species near the Bay mouth.

Impact Ratios and Categorization: Change in total available habitat for this eurytopic species is essentially non-existent in all scenarios. However, there is a marked increase in available high density habitat in Base Drought (IR = 1.80) and Future Drought scenarios (IR = 2.80). This could have significant impact on both phytoplankton populations, and on planktivorous invertebrates and fish. However, any increase in planktivorous species (Mnemiopsis, Sagitta, and many others) due to reduced flow would have an adverse secondary impact on this important copepod.

Eurytemora affinis - Copepod

Description: This is an estuarine endemic species, found into mesohaline regions in spring, and restricted to tidal fresh and oligohaline areas in summer. It is probably the single most important zooplankton in the oligohaline and tidal fresh nursery grounds of certain fish (particularly alosids and moronids). It is important to the survival of striped bass larvae, and can constitute 72% of their food (Beaven and Mihursky 1980). When algae production is insufficient to meet the carbon requirements for this species, it utilizes marsh-derived detritus transported to the lower estuary by spring runoff (Allan et al. 1977)

Impact Ratios and Categorization: Habitat changes for this important species are significant for all scenarios. Reduction in total spring habitat in the Future Average (consumptive loss) scenario is moderate (IR = 0.85). The Base Drought and Future Drought scenarios reduce habitat even more in the spring (IRs of 0.59 and 0.58 respectively). While reduction in summer habitat is minimal under Future Average, Base Drought and Future Drought produce marked effects (IR = 0.55 and 0.42 respectively). In addition to these direct impacts, this species may suffer adverse effects from reduction of marsh-derived detritus input in spring when algae production is often insufficient to support copepod populations. This could have a potentially serious impact on larval and juvenile fish which depend upon this species in their nursery areas.

Sources: Allan et al. 1977

Scottolana canadensis - Copepod

Description: This is a harpactacoid copepod, typically epibenthic (or meiofaunal), but seasonally abundant in the zooplankton. It is an estuarine endemic, reaching its greatest density in oligohaline areas. It is an important component in the food of juvenile sciaenid fishes, as well as other benthic feeders.

Impact Ratios and Characterization: As with most other oligohaline animals, available habitat is reduced progressively with reduction in fresh water inflow. Total habitat reduction in the Future Average scenario is minimal (IR = 0.97), but is large in the Base Drought (IR = 0.53)and very high in the Future Drought scenario (IR = 0.47). In addition to these direct effects, reduction of detrital inputs may affect food supply for this species. The adverse impact of low flow on Scottolana may cause secondary impacts on the juvenile fish which depend on this and similar species.

Bosmina longirostris - Cladoceran

Description: This is a small oligohaline and fresh water cladoceran, most abundant in spring and summer. It is an important food organism for larval and juvenile alosids, such as the blueback herring, and also larval striped bass.

Impact Ratios and Categorization: Again, this freshwater and oligohaline species is significantly impacted in most scenarios. Total area decreases only minimally in the Future Average, but the reduction is large in Base Drought (IR = 0.55) and very large in the Future Drought. Consumptive water loss when coupled with drought reduces habitat to only 39% of that available during the Base Average. This implies a potential serious impact on larval fish which depend on this species as a source of food.

Evadne tergestina - Cladoceran

Description: This is a neritic cladoceran, which occurs in polyhaline areas of Chesapeake Bay, primarily in summer months. It is predaceous, and feeds upon large dinoflagellates and small zooplankton. In turn, it is used as food by larger predacious zooplankton, larval and juvenile fish, and some adult fish.

Impact Ratios and Categorization: This species showed one of the most marked responses to reduced fresh water inflows. Total available habitat increases by 66% under Future Average and area of higher density increases over 100% (IR = 2.06). In the drought scenarios, increase of area is even more pronounced: total area in Base Drought shows a severe increase (IR = 2.27) as does area in the Future Drought (IR = 2.76). Higher density habitat increases tremendously in the Future Drought (IR = 8.48). Incursion of this carnivorous species into Chesapeake Bay may exert increased predation pressure on zooplankton communities. During the 1960's drought, this species was recorded as far north as Calvert Cliffs (Boesch and Taylor 1968); habitat increase of this magnitude is predicted by the hydraulic modal data.

Sources: Boesch and Taylor 1968

Podon polyphemoides - Cladoceran

Description: Podon is an estuarine endemic species most abundant in the mesohaline regions of the estuary, particularly in spring and autumn. When abundant, it exerts a significant grazing pressure on phytoplankton and microzooplankton. It is preyed upon by larval fish, crabs, and planktivorous fish.

Impact Ratios and Categorization: Change in total area for this species under the Future *Average* is *minimal* (IR = 1.04), but moderate increase is observed in Base Drought and Future Drought (IRs = 1.11 for both). This species apparently maintains itself in the mid-estuary by utilizing the upstream flow of water at depth (Bosch and Taylor 1973), so changes in estuarine circulation patterns could produce an adverse effect.

e. Benthic Organisms:

<u>Limnodrilus</u> <u>hoffmeisteri</u> - Oligochaete worm

Description: This is an oligochaete worm inhabiting tidal fresh and low oligohaline areas, tolerant of pollution, feeding upon detritus and associated micro-organisms. In fresh water areas, these and other oligochaetes represent a major link in converting detrital energy to food for higher predators such as fish, birds, and insect larvae.

Impact Ratios and Categorizations: As with previously discussed tidal fresh water and oligohaline species, habitat is reduced under all scenarios. This change is minimal under Future Average but becomes more significant in the drought scenarios. Total habitat in Base Drought is only 60% of that available during Base Average and Future Drought habitat is further reduced to 49% of the original area. Reduction of detrital input due to low flow may alter suitability of some habitats for this species.

<u>Pectinaria</u> (<u>Cistena</u>) <u>gouldii</u> - Polychaete worm

Description: This large tube-building worm is confined to high mesohaline and polyhaline regions of Chesapeake Bay. It is more abundant in fine sands, muddy sands and sandy muds. This species was severely reduced in Chesapeake Bay after Tropical Storm Agnes, due to low salinities and has yet to recover completely. It is considered a species of "special concern" in Virginia (M. Wass, pers. comm.)

Impact Ratios and Categorization: Total habitat for this species increases minimally in the Future Average (IR = 1.01), but available habitat for higher concentrations shows a moderate increase (IR = 1.24). This reflects the inclusion of greater areas of favorably sediment type within the species salinity range. This effect is shown at all scenarios: total habitat during Base Drought increases moderately (IR = 1.17) while area of higher density shows a large level of increase (IR = 1.78). In the Future Drought scenario, total available habitat again increased, by 24%, while available high density areas increased 108%. Ability of this species to recolonize areas where previously depleted would be the key to its exploitation of new habitat. It has a pelagic larvae, but the young worms are subject to heavy predation pressure (Peer 1970).

Sources: Peer 1970

<u>Scolecolepides</u> <u>viridis</u> - Polychaete worm

Description: This is a small burrowing worm, inhabiting a mucous-lined burrow in the oligohaline and low mesohaline areas of the estuary. It is important to sediment stabilization and nutrient recycling, and is also used as food by a wide variety of predators. It is considered one of three characteristic species of the oligohaline zone.

Impact Ratios and Categorization: As with other inhabitants of the oligohaline zone, Scolecolepides shows a reduction in total available habitat with decreased fresh water inflow. Between Base Average and Future Average the decrease is moderate (IR = 0.89), but becomes reduced to 65% in Base Drought, a large impact, and 56% of Base Average during Future Drought. Increase in available high density habitat, however, reflects inclusion of greater areas of favorable sediment type with the salinity boundaries.

This species needs salinities in excess of 5.0 $^0/00$ for eggs to be fertilized and larvae to develop. Evidence exists that sexually mature individuals migrate downstream to favorable salinities, and the developing larvae may be transported upestuary by bottom currents to recolonize the oligohaline zone (Dauer et al. 1980). Thus, alternations of estuarine circulation by reduced flows may exert additional stress on Scolecolepides.

Urosalpinx cinerea - Oyster Drill

Description: This small predaceous snail is found in the highest mesohaline and polyhaline zones in Chesapeake Bay. It feeds upon bivalves, barnacles, and other hard-shelled invertebrates. The species has non-planktonic larvae, and is slow to recolonize areas from which it has been depleted, as by Tropical Storm Agnes. It is a principle predator of young oysters and spat, where it occurs in abundance.

Impact Ratios and Categorization: As with other species from the polyhaline zone, its habitat increases with decreasing fresh water input. This effect is only minimal under Future Average (IR = 1.06). Increases of 24% in Base Drought and 36% in the Future Drought are observed. Ability of this species to colonize newly available habitat is the key to low flow effect on Urosalpinx. Transplant of infected oyster shell or seed could spread this predator.

Crassostrea virginica - American Oyster

Description: The large epifaunal bivalve is found on firm substrates in low mesohaline to marine waters, but may be reduced by disease or predators in higher salinity areas, particularly by the protozoan parasites Minchinia nelsoni ("MSX")and Perkinsus marinus ("dermo").

Impact Ratios and Categorization: Direct effect of reduced flows on this eurytopic species are only moderate, at most. Change, from Base to Future Average is minimal, and increases in the Base Drought and the Future Drought are 11% and 12% respectively. Major impacts on this species will probably result from increase in areas impacted by the above-mentioned protozoan parasites, as well as predators such as Urosalpinx, Callinectes, Rhithropanopeus, and Stylochus. For example, there is a 27 percent increase in the area impacted by MSX in the Future Average alone (IR = 1.27) and drought conditions cause even greater incursion of this species into oyster habitat. Minchinia habitat increases by 64% in Base Drought, and 83% in the Future Drought. High flows in spring are important in reducing incursion of organisms such as Urosalpinx or "Dermo"; if these flow regimes are reduced by drought or manipulation of the hydrograph for flood control, these oyster problems could penetrate further upstream. High salinities are beneficial to oyster recruitment, however. The recent drought years have shown excellent spat set in many areas (G. Kranz, pers. comm.; D. Haven, pers. comm.). However, increase in density of predators such as Stylochus has eliminated many of these young oysters (D. Haven, pers. comm.). Reduction in turbidity and pollution as a consequence of reduced flows are also beneficial both to adult oysters and to recruitment. Changes in circulation due to low flow may alter or reduce transport and accumulation of oyster larvae, and thus affect location of "seed" areas, recruitment at upstream beds, etc.

Thus, low fresh water inflows could have both positive and negative effects on this important commercial species. Maintenance of high flows - freshets - in spring will be important in reducing impacts of some predators and parasites (Andrews, 1981). Also, care in avoiding transplant of infected seed can reduce ability of these species to infect newly available habitats.

Sources: Andrews, 1981

Macoma balthica - Baltic Macoma

Description: This small infaunal clam inhabits the oligohaline and mesohaline areas of Chesapeake Bay. It is a deposit feeder, and is in turn utilized as food by a wide variety of fish, invertebrates, and waterfowl. It is currently a major source of food for the canvasback duck Aythya valisineria.

Impact Ratio and Categorization: This species' available habitat exhibits the effects of compression. In the Future Average, total available habitat decreases 25%, while only 59% of the original habitat is available in the Base Drought, and 45% in the Future Drought. The latter is a very large effect, but even more impact is shown by the area of high density habitat, which is only 66% in the Future Average scenario (a large impact), 55% in Base Drought, and 36% in the Future Drought. In addition to this marked habitat reduction, M. balthica may show impact from reduced detrital inputs and expanded range of both predators and potential competitors such as M. tenta (Boesch 1971). Impact of reduction of Macoma balthica may be significant for the canvasback duck, as the clam now represents 95% of its food (Perry and Uhler 1976).

Sources: Boesch 1971
Perry and Uhler 1976

Mercenaria mercenaria - Hard Clam

Description: This large euryhaline marine clam is found in the upper mesohaline and polyhaline areas of Chesapeake. It is an important (or potentially important) commercial species, and younger individuals are used as food by fish, crabs, and waterfowl. Harder and coarser substrates (shell or sand) favor this species.

Impact Ratios and Categorization: Mercenaria shows significant increase in habitat in all scenarios. Consumptive water loss alone increases available habitat by nearly 20%, while during Base Drought and Future Drought scenarios these increases are large(IRs = 1.63 and 1.72, respectively). This species exhibits sporadic recruitment in the Bay, as larvae fail to develop below 17.5 $^0/00$. Areas where recruitment can occur increase as well: in the Future Average , the 17.5 $^0/00$ line encloses most of Tangier Sound and reaches almost to the Potomac River mouth. Improvement in the status of this species, however, will depend upon ability to colonize new habitat, and also upon potential new predators such as Busycon.

Mulinia lateralis - Coot Clam

Description: Mulinia is a small infaunal bivalve which inhabits areas of the Bay where salinities are above 10 $^0/00$; eggs and larvae are more sensitive than adults to salinity changes. This species is heavily used by fish, crabs and waterfowl, and may be reduced in summer months by such predation.

Impact Ratios and Categorization: Changes in total available habitat for this species is minimal in all scenarios. However, habitat suitable for higher densities - greater than 15 $^{0}/00$, shallow areas - increases moderately in Base Drought and Future Drought (IRs = 1.20 and 1.26, respectively).

M. lateralis is an opportunistic species, and can be expected to rapidly invade new habitat. Individuals can become sexually mature in two months, and spawning is maximal in late fall and early spring. Incursion of new predators into its range may reduce the positive impacts of low flow.

During the 1960's drought, this species extended its range upstream to the mouth of Romney Creek (Pfitzenmeyer 1970); this is also predicted by hydraulic model data.

Mya arenaria - Soft Clam

Description: This large bivalve inhabits permanent burrows in a variety of substrates, from the oligohaline through the polyhaline zone. It may be reduced by predation in higher salinities, particularly by crabs on the smaller clams. It is also subject to sediment disturbance, from physical factors, bioturbation, and man's harvesting practices.

Impact Ratios and Categorization: There is an increase in total available habitat with decreasing flows, but the effect is minimal for the Future Average scenario (consumptive loss only). Habitat increase is approximately 11% in Base Drought and Future Drought. Additional positive effect for this species might result from reductions in turbidity due to low flow conditions. However, it can be expected that predation might increase with increasing salinities. During the 1981 drought, the numbers of Mya decreased dramatically during the summer (A.J. Lippson, pers. comm.). The reason is not known: predation has been postulated, but large clams were eliminated as well as the (usually) more affected smaller individuals.

Rangia cuneata - Brackish-Water Clam

Description: This medium-sized clam was first seen in Chesapeake Bay in 1960, and had spread to the upper Bay by 1968. It is found in tidal freshwater, oligohaline, and low mesohaline zones of the estuary and most tributaries. This species is an estuarine endemic, extremely eurytopic as to salinity as an adult, but more sensitive in the larval stage. Sexually mature Rangia require a change in salinity to induce spawning (Cain 1975).

Impact Ratios and Categorization: As with other oligohaline species, Rangia's available habitat decreases markedly with reductions in fresh water inflow. In the Future Average scenario, habitat is moderately reduced (IR = 0.79). Drought events exert even more stress on this species: Base Drought habitat is only 59% of that available during the Base Average. The Future Drought shows an even more severe impact, with 48% of original habitat remaining.

Additional impacts on Rangia would result from elimination of variations in the hydrograph, as such changes are necessary to induce spawning. Regulation of river flows may have as much effect on many benthic species as salinity changes per se. Anoxic conditions possibly resulting from low river flows could also eliminate this clam from deeper areas.

Sources: Cain 1975

Ampelisca abdita - Amphipod

Description: This small burrowing amphipod is found from the high mesohaline to the polyhaline zone. It is most numerous in fine sediments, and its tubes help bind the substrate, and provide shelter and attachment for other organisms. Ampelisca is preyed upon by waterfowl, fish and invertebrate predators.

Impact Ratios and Categorization: Ampelisca habitat increases with decrease in fresh water input, in all scenarios. The impact is large even for Future Average (IR = 1.22), and can be categorized as very high in the two drought scenarios (Base Drought IR = 1.50, Future Drought IR = 1.49). Available high density habitat - finer sediments - increases 11% in the future, and 42% in Base Drought and Future Drought.

Ability of this species to colonize newly available habitat will be the primary factor in whether it will respond as predicted from the hydraulic model data. Females brood their eggs, and release immature individuals which then disperse. Lack of a planktonic larval stage may, however, slow rate of incursion into the Bay.

Balanus improvisus - Barnacle

Description: This small barnacle is common in the low intertidal and subtidal zones; in Chesapeake Bay it is primarily confined to the oligohaline and low mesohaline areas, being reduced by predation in higher salinity waters. This is one of the primary bio-fouling organisms, and thus any possible changes in its range will be of concern to the public.

Impact Ratios and Categorization: Change in total habitat area is minimal for this species. However, area of high density for this species (5 - 10 $^{0}/00$) is markedly reduced (71% during Future Average, 47% in the Base Drought, and 36% in the Future Drought). Low density area increases proportionally (IRs = 1.23, 2.35, 3.40 respectively). Reduced freshwater inflow thus will exert a generally negative impact on Balanus improvisus. Incursion of important barnacle predators, especially Stylochus and Urosalpinx, will be a major result of low flow. However, translation of salinity zones upestuary will result in barnacles entering areas previously relatively free of these organisms.

Barnacle nauplii are numerous in spring and fall, and represent an efficient means of dispersal of this species into new habitat.

Callinectes sapidus - Blue Crab

Description: This large swimming crab is one of the most important commercial and recreational species in Chesapeake Bay. They are found from near freshwater to the Bay mouth, but there are distinct differences in the ranges of males and females. In summer adult males range from freshwater into the polyhaline zone, with maximum concentrations in mid-Bay. Females are found in greatest concentrations from mid-mesohaline to the Bay mouth, reflecting orientation to their high salinity spawning areas. Zoea are released in water over 23 $^0/00$ salinity in the lower Bay or over the shelf. These zoea tend to be carried away from the Bay in surface waters, and megalops may reenter the estuary in bottom currents and also in surface transport (A. Provenzano, pers. comm.). Winter distribution of adults is in depths greater than 10-15 meters; females are again concentrated in the lower Bay.

Impact Ratios and Categorization: Major area of summer habitat for males is reduced in all scenarios, moderately in Future Average, but impacts in the Base Drought and the Future Drought scenarios are large (IRs = 0.78 and 0.67, respectively). This impact is greatest in the 3-15 0/00 area where male crabs tend to be concentrated. Conversely, areas of concentration of summer females expand; this expansion is minimal in the Future Average, but moderate in the two drought scenarios (IRs are 1.12 and 1.15, respectively). Changes in available wintering habitat also result from reduced flows. Again, male habitat is reduced and female expanded. The extreme increase in female winter habitat results from aspects of bathymetry of the lower Bay - translation of isohalines upestuary include a larger amount of habitat greater than 12.5 meters in depth. The most extreme impact of low flows on this species involves the incursion of suitable spawning area into the Bay. During an average flow year, most of the spawning area is in the extreme lower Bay and out over the shelf. With decreasing freshwater, salinities suitable for spawning extend much further into the estuary. It might be hypothesized that as more spawning takes place within the Bay, fewer zoea will be dispersed out of the estuary. The result might be larger year classes of crabs; then availability of food for development of increased numbers of young crabs might become a limiting factor (A. Provenzano, pers. comm.) As the blue crab is an important predator on benthic invertebrates, change in its range or density could have significant secondary impacts on the Bay's ecosystem.

In the 1981 summer season, during the current drought, crab densities were very high but many animals appeared unthrifty or stunted (A. Provenzano, pers. comm.). This might reflect location of spawning areas the previous summer, also during a low flow period. In August,1981 male crabs were captured at Washington, D.C. during 1981, even at the mouth of Rock Creek; such an incursion is also predicted by Bay hydraulic model data.

Cyathura polita - Isopod

Description: This moderate-sized isopod constructs tubes in stable substrates, both intertidally and subtidally, in the oligohaline through mid-mesohaline zones. It is a characteristic oligohaline species, often abundant, and is an important prey species for many fish species.

Impact Ratios and Categorization: As with other species numerous in the oligohaline portions of the estuary, its available habitat decreases with reduced freshwater inflows. These reductions are minimal in the Future Average, but both Base Drought and Future Drought conditions produce large impacts (IR = 0.64 and 0.55, respectively). This species does not range widely, has no planktonic stages, and will probably not respond quickly to change in optimal habitat location.

Gammarus diaberi - Amphipod

Description: This is a small epibenthic amphipod, living in oligohaline and low mesohaline environments. It is most abundant in areas which provide shelter, such as oyster bars and SAV beds. It is important in transfer of detrital material to higher trophic levels and is one of the major food items of juvenile and adult demersal fish (Thomas 1971).

Impact Ratios and Categorization: Again, this oligohaline species has reduced habitat with all three low flow scenarios. This impact is minimal with consumptive water loss alone (Future Average) , but becomes large in Base and Future Droughts (IR = 0.73 and 0.64, respectively). As with Cyathura, this species broods its eggs and will be slower than organisms with planktonic stages to react to changes in location of habitat area.

Sources: Thomas 1971

Leptocheirus plumulosus - Amphipod

Description: This burrowing amphipod is abundant in oligohaline and mesohaline habitats in Chesapeake Bay. Pfitzenmeyer (1970) characterized this species as one of three permanent dominant upper Bay species (the others are C. polita and S. viridis). It is most numerous in soft sediments, and in shallow areas. It is a major food item for benthic feeding predators, particularly fish (Holland et al. 1980).

Impact Ratios and Categorization: Leptocheirus exhibits the same response to reduced flows as other members of the oligohaline community: that is, reduction in available habitat occurs in all scenarios. This reduction is moderate in the Future Average (IR = 0.83), but becomes high in the Base Drought and Future Drought scenarios (IRs - 0.55 and 0.51). Again, this is a species lacking planktonic means of dispersal, and would be relatively slow to react to upstream migration of optimal habitat zone.

Sources: Holland et al. 1980
Pfitzenmeyer 1970

Palaemonetes pugio - Grass Shrimp

Description: A small decapod, abundant in nearshore habitats, especially in areas which provide shelter (SAV beds, oyster bars, pilings, etc.). It is more abundant in oligohaline to polyhaline areas. Above about 15 $^0/00$, it occurs with its conspecific P. vulgaris, a potential competitor. It is particularly important as a detritivore, and a link from marsh detritus to higher trophic levels.

Impact Ratios and Categorization: Reductions in total habitat area are minimal in Future Average and Base Drought, and only moderate in the Future Drought (IR = 0.89). However, the high density habitat (5-15 $^0/00$) is more seriously impacted: only 68% remains in the Future Average, 65% in the Base Drought and 57% in the Future Drought. It is probable that the more polyhaline species P. vulgaris will increase in importance. This species is less tolerant of low dissolved oxygen, high detritus, and poor circulation, and may not perform the exact role as P. pugio in recycling marsh detritus (Welsh 1975).

Reduction of SAV beds will also exert a negative impact on P. pugio, as will decreases in detrital input from marshes.

Sources: Welsh 1975

f. Vertebrates:

Vertebrates on the study species list include only fish and birds. The fish have different sensitivities at each life stage. The general pattern of ocean spawners versus anadromous spawners is an important determinant of requirements for spawning. Because of this, impact ratios were calculated for separate life stages for many fish species.

Alosa sapidissima, American shad

Description: This is an anadromous species requiring spring runoff for successful spawning. Spawning begins as soon as a temperature of $13^{o}C$ is reached and continues to $19^{o}C$ (Gusey 1976). The young remain in the estuary until the fall overturn then leave for the shelf. Adults return to sea after spawning. Therefore, impact ratios were calculated only for the spawning habitat (eggs and larvae) in spring and for the juvenile habitat during summer.

Impact Ratios and Categorization: Spawning habitat under the projected consumptive loss (Future Average) scenario is 98 percent of habitat available under Base Average. The high spring runoff is so much greater in magnitude than the consumptive loss that there is little change from the Base condition.

Spawning habitat available under the Base Drought scenario is 67 percent of Base Average habitat .The lack of spring runoff pushes the tidal fresh zone up into the narrower portions of the rivers and up against both natural and man-made barriers (i.e., Great Falls on the Potomac and Conowingo Dam on the Susquehanna). The possibility of an effective fish passage at Conowingo Dam some time in the future is a major imponderable in the restriction of shad spawning habitat for future scenarios. Shad spawning habitat is clearly more sensitive to the drought event than to consumptive water losses in the range of the projections.

The occurrence of drought and consumptive water loss simultaneously (Future Drought scenario) reduces the shad spawning habitat to 61 percent of the habitat originally available.

Habitat for the juvenile shad extends to the low mesohaline zone in the rivers and upper Bay. The projected consumptive loss scenario leaves the juvenile shad with 95 percent of their Base Average habitat available. This habitat is the zone of the richest zooplankton food sources in the rivers and is utilized in sequence by many species of fish during their high growth phase.

The Base Drought scenario reduces the habitat available to juvenile shad to 56 percent of the original habitat.

The Future Drought scenario indicates a pronounced compaction of the juvenile habitat into 39 percent of the habitat available under Base Average. This would have serious consequences for the shad which is already so stressed that Maryland DNR has closed the fishery for it.

Alosa pseudoharengus, alewife

Description: This fish is an anadromous river herring with a similar life history to that of the American shad. However, they partition the spawning habitat differently. Alewives will move into very shallow water, often only a few inches deep and they arrive 2 months earlier. The alewives will also spawn in the main stem of tributaries where the shad spawn (Lippson et al. 1979). Thus, the alewife has a less restricted spawning habitat than the shad, but a habitat also subject to greater potential for alteration in the shallow water portion.

Impact Ration and Categorization: The spawning habitat (eggs and larvae) available under Future Average conditions is 94 percent of the spawning habitat under the Base Average while the habitat available under the Base Drought is 74 percent of that available under Base Average. Under Future Drought conditions 70 percent of the Base Average habitat would be available assuming that the combination of increased water consumption and drought did not result in the large scale drying up of the shallower portions of the tributaries which form part of the alewife's spawning habitat. The same observation applies to the alewife as to the shad, that actions taken to provide a bypass to physical barriers in a number of watersheds could have a major impact to each species by increasing access to spawning habitat in the fresh water zone.

Juvenile alewives occupy much the same habitat as the juvenile shad but are larger at any given time due to their earlier spawning date. The impact ratios are similar for juvenile shad and alewives. Juvenile alewives have 98 percent of the Base habitat available under Future Average and 58 percent of Base habitat under Base Drought conditions. The Future Drought reduces habitat to 39 percent of Base Average conditions, a severe negative impact.

Although the habitat impact ratios are calculated separately for each life stage, the effect of a drought event on a year class does not act independently on each life stage. The historic catch record provides little help in assessing the impact of a low flow event such as the 1963-66 drought. Commercial landings in Chesapeake Bay did decline during the drought period but they also declined to a greater extent during the 1957 to 1960 period which was a period of stable and close to average inflows. (NMFS, 1974)

Brevoortia tyrannus, Atlantic menhaden

Description: The menhaden is an ocean spawning member of the herring family. The larvae use the low salinity areas of the estuary as a nursery area where they feed on a variety of detrital and planktonic food sources. As juveniles the menhaden generally remain in the estuary until cold water temperatures trigger a migration. However, some menhaden do remain in deeper water throughout the year. Within Chesapeake Bay menhaden concentrate in regions of high plankton productivity within the mesohaline zone, particularly along fronts and shear zones where phytoplankton collect.

Impact Ratios and Categorization: Consumptive water losses reduce the nursery area of Atlantic menhaden to 85 percent of Base Average habitat. The menhaden occupies the nursery area during the winter and early spring when the river flows are small in comparison to the spring runoff peak. The smaller inflow volumes mean that the consumptive losses are a larger percentage of the seasonal flow and produce a more observable effect on the winter spawners than on the spring spawners.

Drought reduces the nursery habitat to 69 percent of Base Average while the Future Drought reduces menhaden nursery habitat to 41 percent of the Base Average. The mid-Atlantic landings of Atlantic menhaden dropped precipitously during the historic drought of 1963-1964 and thereafter remained at reduced levels through 1978. The initial decline is believed due to poor year class survival. The subsequent failure of landings to recover is believed due to over-fishing of the reduced stocks (Gusey 1976). Although the poor year classes coincided with the low inflow event there is no proof of causality.

The movement of mesohaline zone up the estuary expands the area available to the adult menhaden. The habitat impact ratio shows an increase in habitat during drought events while the habitat available under the consumptive loss scenario remains unchanged from the Base Average value.

The Base Drought increases the total amount of adult habitat available by 6 percent and the Future Drought scenario increases the habitat by 8 percent over that of the Base Average scenario. However, due to the compression of the mesohaline zone, the prime grazing area where the adult menhaden are concentrated (in future) is 96% of the area available under Base Average conditions. The Base Drought reduces the area of primary grazing to 71 percent. Consumptive water loss appears to have an additive effect with drought. The impact ratio indicates 57 percent of modal area of concentration will be available during Future Drought scenario. This does not take into account the possible effects on menhaden of changes in the composition of the plankton which was discussed in Section D.

Anchoa mitchilli - Bay Anchovy

Description: Anchovies are important small forage fish for many of the commercial pelagic species such as blue fish and striped bass. The adults are generally distributed throughout the estuary. However, the larvae utilize the same oligohaline nursery area which was used by the Sciaenids and menhaden in winter and by the Alosids, perch and striped bass in the spring. The anchovy larvae are in the nursery area during the summer. Eggs are released in the low mesohaline region and are transported up the estuary into the nursery area by the estuarine circulation (Lippson et. al. 1979).

Impact Ratios and Categorization: Consumptive water loss reduces the area of egg deposition to 66 percent of the area under Base Average. This species shows more clearly than most the effect of the compression of isohalines in the upper Bay discussed in section A.3.b. Drought reduces the area of egg deposition to 57 percent of the spawning area under Base Average conditions. However, both Base Drought and Future Drought conditions cause the same change in spawning area (58 percent).

Nursery habitat for the larvae under projected consumptive loss conditions is 75 percent of the habitat area under Base Average. Drought reduces the nursery area to 45 percent of the nursery habitat area available in the Base Average. Clearly the early life stages of the bay anchovy are sensitive to both consumptive water losses and to drought. Without landings data there is no way to judge even relative changes in the stock during historic low flow events. The Future Drought scenario indicates nursery habitat area to be 41 percent of the area available during Base Average conditions.

Leiostomus xanthurus - Spot

Description: The spot is a Sciaenid (drum family) winter season, ocean spawner whose young use the low salinity nursery area in the early spring. Growing juveniles move shoreward into shallower water as the water temperatures increase. Spot are a significant predator of benthic invertebrates throughout their range of occurrence in the estuary. Larval spot are dependent on estuarine circulation to reach their nursery area from their oceanic spawning grounds.

Impact Ratios and Categorization: Low flows due to consumptive losses leave the spot with 91 percent of its Base nursery area. The chronic effects on circulation of flows depressed by consumptive losses do not seem to be large enough to interfere with larval transport up the estuary although stratification is reduced by low flows. The effect of the 50 foot shipping channel in enhancing the up bay transport within the channel may alter the distribution of the incoming larvae somewhat although the area of nursery shows little change.

The Base Drought reduces the area of spot nursery to 52 percent of Base Average. Future Drought reduces the available nursery habitat to 41 percent of the Base Average habitat area. This is in the range of a very large negative impact and would probably have a substantial effect on the population of young spot.

Adult spot usually leave the estuary during the fall and spend the winter on the continental shelf. It has not been determined if spot reenter the same estuary they entered as larvae or if they enter any convenient estuary in the spring. If the adults are not tied to a particular estuary,loss of nursery habitat may not show up in population changes of adult spot caught in Chesapeake Bay. Habitat for adult spot seems relatively insensitive to low flow events. A one percent increase in the spots' Base Average adult habitat is available in the Future Average and 5 percent increase over Base Average is available in the Base Drought scenario.

Spot have historically responded rapidly to environmental fluctuations from many sources but no clear indication of their response to the historic drought. The Future Drought scenario indicates a 6 percent increase over Base Average habitat will be available.

Micropogonias undulatus - Atlantic croaker

Description: This is an ocean spawning Sciaenid which has a life history similar to the spot. The spawning season of the croaker is quite protracted, possibly lasting all year. The larval croakers enter the estuary starting in the fall, earlier than other drums. The larvae continue arriving during the winter in large groups often associated with offshore winter storms. Estuarine circulation carries the larvae into the oligohaline nursery areas where they remain in the deeper channels throughout the winter. The translocation of the oligohaline zone up the rivers into shallower water subjects the young croaker to increased exposure to cold surface water temperatures during the winter, which have been demonstrated to cause mass mortality.

Impact Ratios and Categorization: Croaker nursery habitat during the projected Future Average scenario is 89 percent of Base Average nursery habitat. During the Base Drought event the nursery habitat is reduced to nearly half, 57 percent. The combined low flow event, the Future Drought, reduced nursery habitat to less than half, 43 percent, of the Base Average area.

Adult croaker overwinter on the continental shelf. The adult croaker enter Chesapeake Bay in March and leave in September. They prefer deeper water and harder substrate than the spot but their food is generally the same assemblage of benthic invertebrates. The habitat of the adult croaker is insensitive to the effects of low inflow events expanding only slightly as higher salinities penetrate further up the Bay.

Future Average conditions (consumptive loss) give the adult croaker 4 percent more habitat than Base Average conditions. A drought event increases the habitat available to the croaker by 7 percent compared with Base Average. The Future Drought increases adult habitat by 9 percent.

It is difficult to say just what effect the low flow events would have on the population, when the same event is decreasing nursery habitat while increasing adult habitat. Fewer, better fed adults might be the logical expectation in a closed system. But with the population entering from and exiting to the shelf annually, reduced recruitment from Chesapeake Bay could be compensated for by increased recruitment from other estuaries.

Menidia menidia - Atlantic silverside

Description: The silverside is a small forage fish distributed throughout the Chesapeake Bay and tributaries up to 3 $^0/00$ and occasionally into fresh water. Spawning occurs in shallow water of the low mesohaline zone (Lippson et al. 1979). Young and adults are strongly shore zone oriented, moving to deeper waters only to escape cold temperatures. Upstream the Atlantic silverside is replaced by the tidewater silverside, Menidia beryllina. Expansion of Atlantic silverside habitat indicates a contraction of tidewater silverside habitat and vice versa.

Impact Ratios and Categorization: The Atlantic silverside appears insensitive to the effects of low flows produced by consumptive loss. The Future Average did not show as much as a 1 percent increase in habitat. Low flows due to drought increased Atlantic silverside habitat by 5 percent, decreasing tidewater silverside habitat by a like amount. The Future Drought scenario increased Atlantic silverside habitat (and decreased tidewater silverside habitat) by 7 percent.

Morone americana - White perch

Description: These fish are freshwater spawners with adult range extended well into the estuary. They spawn in the spring in tidal fresh water. Their eggs are adhesive and generally spawned in shallow water. White perch have the same nursery areas as the striped bass but are in the nursery grounds earlier in the spring.

Impact Ratios and Categorization: Consumptive water losses in the Future Average cause a shift of the isohalines up into narrower positions of the Bay and tributaries. This results in a habitat area decrease to 82 percent of the Base Average for the early life stages of white perch. The Base Drought scenario indicates that under those conditions of inflow one could expect 70 percent of the Base Average habitat for early life stages to be available. The addition of consumptive losses to drought level flows (Future Drought) further reduces the early life stage habitat to 65 percent of the habitat area available under Base Average conditions.

An assumption of this assessment is that applicable water quality criteria will be met during all scenarios. Under present conditions a translocation of the spawning region up river of the magnitude occurring for white perch and other anadromous species would move the primary spawning area into a region where water quality would be an additional habitat limiting factor. Also, the small size of tributaries in these areas might further restrict usable habitat.

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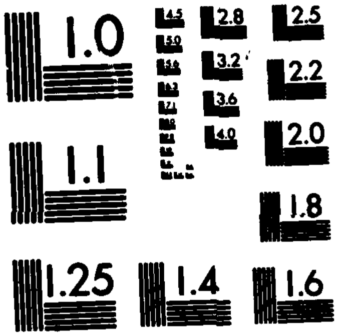

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

During Future Average the adult white perch would be able to occupy 93 percent of the habitat which they occupied under modal flow conditions. Base Drought inflows would force the white perch into an area 67 percent of their previous habitat area. Future Drought inflows would reduce their habitat area to 33 percent of the basic habitat, a very large negative impact.

Morone saxatilis - Striped bass

Description: Striped bass grow larger and live longer than their relative the white perch. In addition, the adult fish are not restricted to estuaries but range along the Atlantic coast. Chesapeake Bay is the principal Atlantic coast spawning area (Berggren and Liberman, 1978) for striped bass and conditions within the estuary can have a major impact on the landings of striped bass all along the Atlantic coast (Wise 1974). The striped bass use the same tidal fresh water spawning area as the white perch but later in the spring. The eggs of the striped bass are non-buoyant and non-adhesive. To prevent smothering of the eggs in silt, striped bass spawn in deeper channels where there is enough current flowing to keep the eggs in turbulent suspension. Survival of the larvae appears to depend on critical densities of the appropriate sized food organisms (Mihursky et al. 1976) which in turn are dependent on climatic factors, particularly the timing of the spring runoff pulse. Because of the complex interrelation of runoff and food sources for the larval fish the habitat measurements will probably underestimate the effects of consumptive losses.

Impact Ratios and Categorization: With respect to habitat area, striped bass are not sensitive to flow reductions of the magnitude of consumptive losses (Future Average). The spawning area habitat changed by less than 1 percent and the adult habitat also changed by the same amount. However, during Base Drought inflows striped bass spawning habitat area is reduced to 70 percent of the habitat available under Base Average. Consumptive water losses added to the drought condition (Future Drought) reduce the spawning habitat area to 56 percent of the extent of Base Average spawning habitat. The adult habitat is extended upstream during these low flow events by 6 percent during Base Drought conditions and by 10 percent during Future Drought conditions. However, adult striped bass are not restricted to Chesapeake Bay and the small increase of usable adult habitat is unlikely to have any offsetting effect to the decrease in essential spawning habitat.

Perca flavescens - Yellow perch

Description: Yellow perch are fresh water fish invading the estuary. Spawning occupies shallow still waters of the tidal fresh zone during the late winter. Adult yellow perch distribution extends down to 12 ppt in the summer, to somewhat lower salinities in winter.

Impact Ratios and Categorization: Spawning area of the yellow perch in the Future Average would be 82 percent of the spawning habitat area during Base Average. The historic drought would reduce the habitat for spawning to 23 percent. This is a very large reduction in habitat due in part to the late winter spawning season which is a very dry time of year in the historic hydrograph but not in the modal hydrographs (See Figure II-2). In addition to the winter time differences between modal and drought hydrographs the yellow perch spawning areas are farther up the rivers than those of the spring spawning fishes. The small size of the rivers at that point causes a larger change in percentage area than would be caused by an equal distance displacement up the wider portions of the river. Future Drought conditions constrict spawning habitat area even more to 12 percent of the habitat available under the Base Average conditions.

The yellow perch is one case where the consumptive loss occurring during a drought does cause a significant loss of habitat. Consumptive losses only reduced Base habitat by 18 percent. Consumptive losses during a drought reduced the Base Drought scenario habitat by half.

Adult yellow perch habitat fared only a little better during low flow events. Future Average conditions would produce 85 percent of habitat available under Base conditions. Historic drought reduces yellow perch to 59 percent of the habitat available under Base Average conditions. The drought with projected consumptive losses would leave 35 percent of the Base habitat available to adult yellow perch.

Aythya valisineria - Canvasback

Description: The canvasback is a formerly abundant wintering migrant duck. A diving duck, the canvasback is capable of feeding on submerged vegetation, fish and benthic invertegrates. The canvasback inhabits open water and deeper shorelines areas. Although the species formerly fed extensively on SAV it has recently switched to a reliance on the baltic clam, Macoma balthica. Areas of winter concentrations of the Canvasback coincide with highest densities of this bivalve. Although the vegetation on which the duck formerly fed has recovered in some areas, the bird continues to feed primarily on Macoma (M. Perry, pers. comm.). If stressed by lack of Macoma, the duck is physically capable of feeding on SAV, if sufficient vegetation is available. When and how quickly such switching would take place cannot be predicted.

Impact Ratios and Categorization: Macoma balthica habitat is reduced significantly in all scenarios, as are many important submerged aquatic vegetation on which Aythya once fed. This indicates that the Canvasback may face food stress in periods of reduced fresh water inflows. The Base Drought causes an increase of 5 percent in the total habitat area of the canvasback. However, during this drought scenario the feeding area is reduced to 72 percent of the modal area. The drought plus consumptive loss scenario does not cause an increase in habitat over Base Drought, yet the feeding area (duck concentration) is reduced to 48 percent of the duck concentration habitat under Base Average conditions. This is a very large impact on the canvasback. The duck would be faced with heavy competition for food and would either have to switch diets again or suffer reduced growth and migratory capabilities.

Summary for Fish: A compilation of the impact ratios for fish (Fig. III-32) indicates the relative sensitivity of study species fishes to impact by life stage. The horizontal axis scale is the impact ratio between Base Average and Base Drought. The vertical scale is impact ratio between Base and Future Average (consumptive loss) conditions. The diagonal line is the equal impact line. Species or life stage to the right of the equal impact line are more sensitive to consumptive water loss than to drought. Species or life stages to the left of the diagonal are relatively more sensitive to drought than to the projected consumptive water losses.

The triangles are early life stages, eggs or larvae. The squares are juveniles and the circles are adults. The subscript refers to the following species:

A.	American shad	*Alosa sapadissima*
B.	Alewife	*Alosa pseudoharengus*
C.	Menhaden	*Brevoortia tyrannus*
D.	Bay anchovy	*Anchoa mitchilli*
E.	Atl. croaker	*Micropogonias undulatus*
F.	Spot	*Leiostomus xanthurus*
G.	Atl. silverside	*Menidia menidia*
H.	White perch	*Morone americana*
I.	Striped bass	*Morone saxatilis*
J.	Yellow perch	*Perca flavescens*

All the life stages of fish which are more sensitive to consumptive losses than to drought are adults which range in from the ocean. The general pattern is for the early life stages to be more sensitive than the juveniles or adults. The closer a given life stage is to the lower left corner of the graph the stronger the negative impact to the life stage from either form of low fresh water inflows.

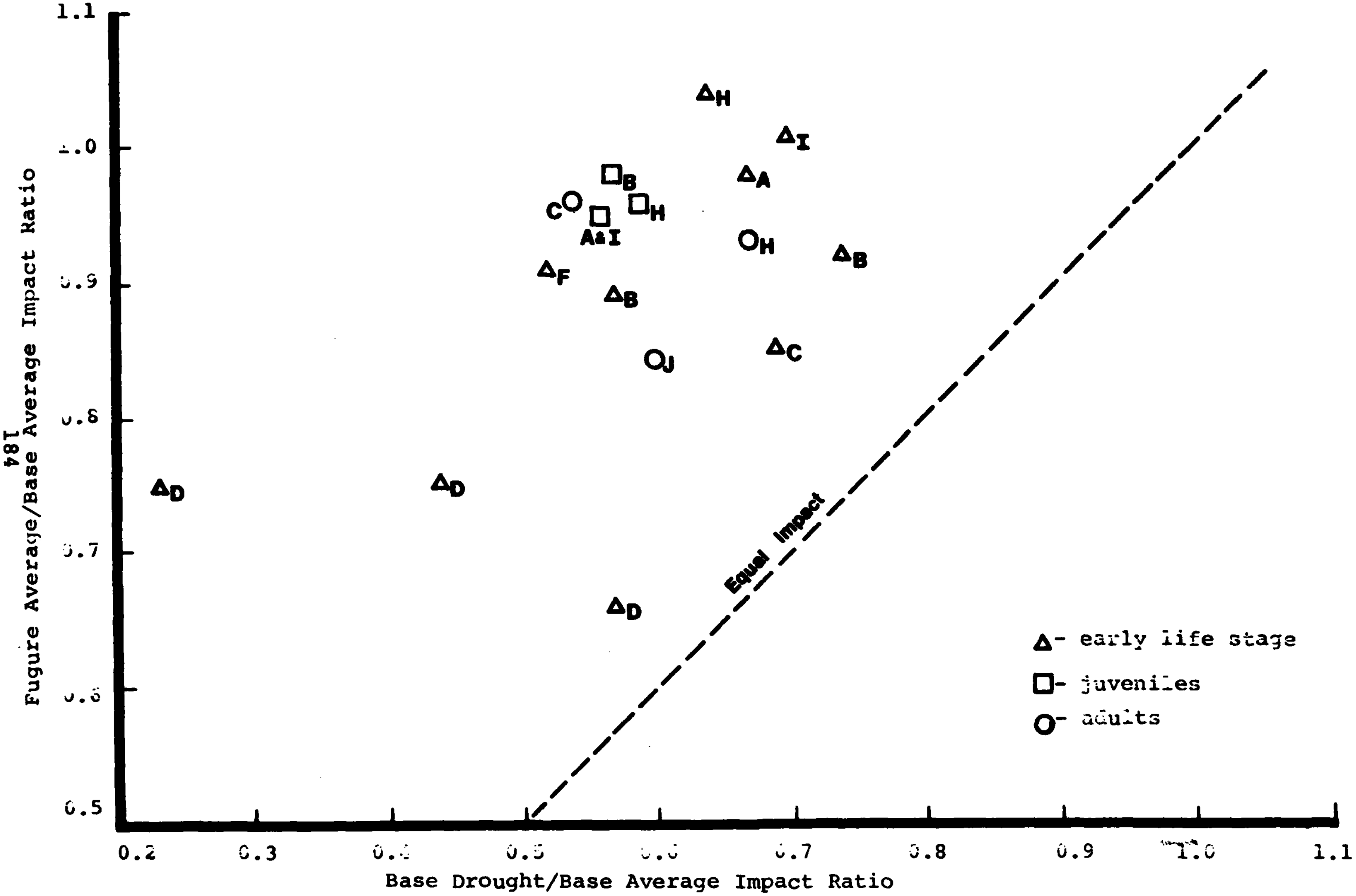

Figure III-32. Relative Sensitivity of Fish by Species and Life Stage

F. CONFIDENCE LIMITS

The determination of confidence limits to be placed on the results is the most difficult aspect of a study of this type. Data from many sources was used and each source had its own characteristics. The degree of confidence which can be placed in the recommendation of a study reflect the precision with which the work was done. The upper limit of precision is set by the accuracy of the data. There are three major headings for sources of error in the present study: 1. Physical, 2. Biological, and 3. Statistical.

1. Physical Data Source Confidence Intervals

Salinity data used in the low freshwater inflow biota impact assessment study come from two sources, 1) data files of institutions studying Chesapeake Bay and 2) Corps of Engineers Hydraulic Model. The model in turn relied on verification data obtained from source 1. Depending on the instrumentation used, Chesapeake Bay (Prototype) salinities were collected with accuracy between ± 0.5 ^{0}/00 to ± 0.02 ^{0}/00. Hydraulic model salinities were obtained with an accuracy of ± 0.5 ^{0}/00. From these data salinity maps were constructed to the nearest integer part per thousand. Bathymetry maps were constructed from most recent NOAA charts to contours every 3.05 meters (10 feet). For benthic habitat maps the assumption was made that the Bay bottom was planar between contours.

Habitat area from maps was planimetered with instruments having an accuracy of ± 2% of measured area. All areas were measured several times and the results averaged. Very small areas proved difficult to measure reliably. Therefore, for very small areas the number of measuring iterations was doubled.

2. Biological Data Source Confidence Intervals

Most of the information regarding species distribution and salinity tolerances was obtained from referenced literature. Some portion was obtained from the gray literature and the remainder by personal communication from Bay area researchers. Confidence in the accuracy of the biological data reflects the care and professional integrity of the research community. The thorough screening process for selection of the study species carefully considered the amount and quality of data available for each species before it was selected as a study species.

Restriction of the application of the results of this study are familiar to anyone involved in projection of future trends. Primary consideration must be given to the assumptions used in generating the experimental design:

1) the assumption on population growth and water use made in design of the Low Freshwater Inflow Hydraulic Model Test.
2) the existence of 3 new dams with flow regulating authority: Drought hydrographs were modified to reflect operating schedules of these dams which were constructed after 1965.
3) the existence of the 50 foot deep navigation channel to Baltimore
4) no significant changes in harvesting intensity or efficiency for any sport or commercial species
5) all water quality goals will be met, and that these goals are effective in preventing environmental deterioration
6) the 1960's drought is a representative one and can be used as a measure of the changes associated with drought conditions
7) no additional toxins or pathogens will occur in Chesapeake Bay to stress the biota other than those specifically mentioned in the report.

3. Statistical Sources

When a set of measurements are paired with one another, as in a set of measurements on the same species under control and experimental conditions, the standard error is no longer estimated by the weighted sum of the population variances. The standard error also includes covariance due to the correlation on the measurements. The standard error of two sets of proportions (the impact ratios) is given by the formula:

$$\delta^2_{\frac{A_2}{A_1}} = \delta^2_{A_1} + \delta^2_{A_2} - 2R\,\delta_{A_1}\,\delta_{A_2}$$

Where $\delta^2_{\frac{A_2}{A_1}}$ is the variance of the proportion between areas 1 and 2.

$\delta^2_{A_1}$ is the variance in areas of species measured under one condition,

A_2 is the area of species measured under the second condition.

R is the product moment correlation coefficient between the areas measured under the first and second conditions.

Confidence intervals for the distribution of impact ratios, corrected for covariance, is calculated on this standard error by the formula:

$$CI = \pm\, 1.95 \left. \frac{\delta^2_{\frac{A_2}{A_1}}}{N} \right)$$

Where N is the number of pairs

1.95 is the area of the normal distribution which falls between the probability boundaries +0.95 and -0.95.

Given the assumption that the distribution of proportions is normal the 95% confidence interval for the impact ratios

Base Average: Future Average is ± 0.01

Base Average: Base Drought is ± 0.06

Base Average: Future Drought is ± 0.10

The larger values for drought conditions are due to the larger divergence of the impact ratios from Base Average conditions.

Seasonal average salinities were calculated for each station and season for each of the four scenarios. The question arises of how much variability there is in salinity values at any one station over one season. A confidence interval was calculated for the 95% probability interval for seasonal salinity averages for the entire data set, including rivers and main bay and all scenarios. Given the assumption of normal distribution of salinities at any one station and season the 95% confidence interval for seasonal salinities is ± 0.80 $^{0}/00$. For example, given a seasonal average of 18.0 $^{0}/00$ one can be confident that the true value of salinity at that point for the given season will be between 18.8 $^{0}/00$ and 17.2 $^{0}/00$ for any station on the Bay.

Some departures from the assumption of normality do occur. Salinity exhibits a wider seasonal variance at the surface than at deeper depths. Salinity at the surface also exhibits a wider seasonal variance in the oligohaline regions of the Bay and tributaries. The range of seasonal variance at one station was a minimum of 0.05 $^{0}/00$ to a maximum of 6.90 $^{0}/00$ for the entire data set.

An addi[illegible] question of confidence limits concerns the probability of occurrence of a natural event such as drought. From Figure II-3 several periods can be identified which dip below 60,000 cfs (the high flow point during the 1960's drought period) although only the 1964-65 water years remained at or below the 60,000 cfs level for the entire water year. This is one drought in a 30 year span. However, the present year shows a sharp decline in average streamflow and projections (Figure III-27) from the Atmospheric Sciences Unit in Cornell (Paine, 1981) indicate a continuation of below average precipitation for the next year or so. If these projections are correct, a drought of the mid-1960's proportions could be anticipated to occur on approximately 20 year - 30 year

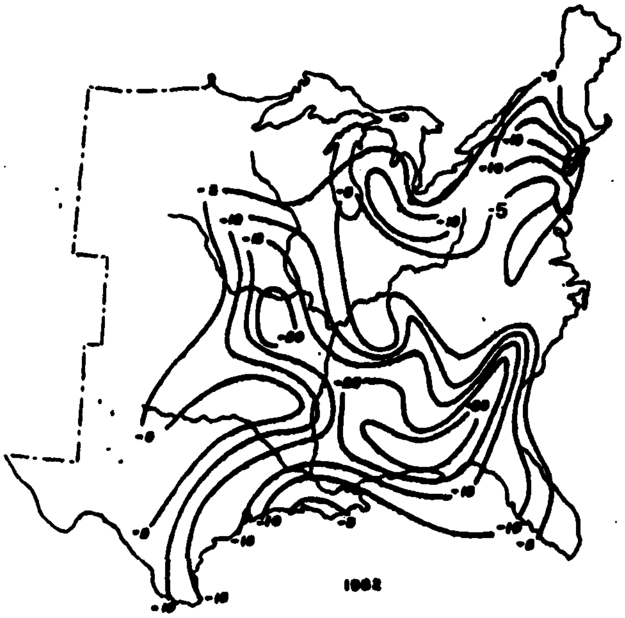

Figure III-33. Projected Annual Precipitation Deficits (Inches) from the 40-Year Mean for 1982.

(Source: Paine 1981)

intervals. This would agree with sun spot cycle periodicity and indicate that dry periods may be expected to occur between now and the year 2020. The existing flow records are not yet of sufficient duration to determine the likelihood of this possibility. Thus, the concern that the effects of consumptive water loss and co-occurring drought are reasonably likely events.

IV. SUMMARY AND CONCLUSIONS

In this chapter, we attempt to recapitulate the effects of reduced freshwater inflow on biota in a holistic manner, first by biota group and then by scenario. Particularly sensitive organisms or conditions are emphasized in these sections. Major gaps in research related to low flow effects on biota are then summarized.

A. EFFECTS OF LOW FLOW BY BIOTA GROUP

1. *Phytoplankton*: All phytoplankton associations save the polyhaline winter/spring and the high mesohaline-polyhaline summer/fall communities show habitat reduction with decreasing fresh water inflow; these two other associations show habitat increase. In general, reductio or increase in habitat is minimal from Base Average to Future Average scenario, with effects of drought large or very large. The exception occurs with winter/spring mesohaline and polyhaline associations, and *Prorocentrum minimum* winter occurrence, which show moderate or large changes from Base Average to Future Average.

Each phytoplankton species has an individual response to salinity. It can be hypothesized that not only will location of the phytoplankton associations themselves change as freshwater inflow is reduced, but the actual species making up the community may also be altered.

2. *Submerged Aquatic Vegetation*: Habitat for most of the SAV study species decreases with reduced flows; only *Zostera* and *Ruppia* show a habitat increase. Again, most changes in area were minimal in the consumptive loss scenario alone, but Base Drought and Future Drought events cause more serious impacts.

Rooted aquatic plants would be among the most seriously impacted by reduced flows. Unable to leave areas of unfavorable salinity, even a relatively short-term drought event could reduce or eliminate sensitive SAV species. Whether more salinity-tolerant species (such as *Zostera* or *Ruppia*) would colonize newly available habitat would depend on numerous other factors including means of dispersion. A positive effect, however, would be reduction of turbidity.

3. *Emergent Aquatic Vegetation*: Fresh water associations would be most seriously impacted by low flow conditions. As this is the most diverse marsh community, important to waterfowl and aquatic mammals, as well as to detrital-based food chains, reduction in available habitat could be serious to the Bay's ecosystem. Change in local drainage patterns, ground water, and tidal inundation due to low flow would also affect marsh habitat.

4. *Zooplankton*: As a generalization, species of low salinity affinities decrease and those of higher salinity areas increase. Changes are usually minimal under Future Average, but exceptions are *Eurytemora* (spring) and *Evadne*, as well as the predator species *Beroe ovata*. The two drought events produce more severe impacts in the study species. Examination of Future Drought: Base Drought impact ratios indicate that the change between these scenarios is significant for *Eurytemora* (summer), *Scottolana*, *Bosmina*, and *Evadne*.

An expected effect of reduced flows would be retreat of tidal fresh water and oligohaline species upestuary, and greater penetration into the Bay of polyhaline and neritic species. This has been observed in past drought events.

5. Benthic Invertebrates: Again, species of tidal fresh and oligohaline affinities are reduced in habitat, while those of higher salinities are increased. Although most changes are minimal between Base Average and Future Average scenarios, exceptions are Scolecolepides, the oyster parasite Minchinia, Macoma balthica, Mercenaria, Rangia, Ampelisca abdita, Callinectes summer males, spawning area, and winter females, and Leptocheirus plumulosus. Comparison of Future Drought to Base Drought shows this change is significant to Scolecolepides, Minchinia, M. balthica, Rangia, Callinectes summer males, spawning area, winter males and females, Cyathura polita and Gammarus daiberi.

Sessile benthic species would be most severely affected by low flow; sensitive taxa could be significantly impacted by even relatively short-term events. Species lacking planktonic larval stages will be least able to recolonize habitat, or expand into newly available areas. In addition, alteration of estuarine circulation patterns could affect ability of other species to reach nursery areas, or favorable habitat upestuary. Reduction of detrital input will also affect food supply for benthic detritivores.

6. Fish: In general, the major effect of low flows on fish involves sensitive life stages, particularly spawning and nursery areas. Only one species, Perca flavescens, shows a significant change in available adult habitat from Base Average to Future Average. Reduction in habitat for juveniles of the ocean-spawning Brevoortia , and early life stages of Anchoa and Perca, both Bay-spawners, occurs in the Future Average. Changes in available habitat are more marked in Base Drought and Future Drought scenarios. In general, adults of most species show little impact from reduced freshwater inflows, even during drought events. Exceptions are those oriented toward tidal fresh water and oligohaline habitats: Morone americana and Perca flavescens. However spawning areas for anadromous species are significantly reduced, as are nursery areas for juveniles of these and ocean spawning fish (eg. sciaenids, Brevoortia).

Compression of available habitat for early life stages - particularly during drought events - is the most obvious effect of reduced flows on fish. Simultaneous reduction in habitat for important food organisms for larval and juvenile fish will also exert a negative impact. Changes in current structure and velocity can cause disruptions, as many species utilize upstream flow of water at depth to reach their low salinity nursery areas.

B. EFFECTS OF LOW FLOW BY SCENARIO

Impact ratios for the three low-flow scenarios generally show a greater change (deviation from 1.0) as one proceeds from Future Average to Base Drought to Future-Drought. Thus, the Future Average consistutes the most mild change from Base Average conditions (although it is a permanent change). The Base Drought scenario has considerable change for most organisms and is fairly close in severity to the Future Drought which is most extreme. Table IV-1 shows the percentage of impact ratios within each category defined in Chapter II (for all life stages, densities, etc., including totals). These are discussed by scenario below.

[illegible] of [illegible] the Future Average scenario are within [illegible] and therefore fall within the minimal category. Most of [illegible] habitat losses. Another quarter of the ratios fall between 4[illegible] of the present habitat as defined by the moderate [illegible] again, [illegible], 85 percent are affected at moderate levels or less. It should be noted, however, that even moderate category changes may be very important for some organisms or [illegible]. These categories of severity were developed to permit [illegible] an overall basis and do not necessarily reflect actual impact on any given species.

Table IV-1. Percentage of Impact Ratios by Severity Rating

Impact Severity / Scenarios	Future Average		Base Drought		Future Drought	
	Base Average		Base Average		Base Average	
	Incr.	Decr.	Incr.	Decr.	Incr.	Decr.
Minimal	22	36	15	4	12	3
Moderate	9	18	10	7	12	3
Large	5	4	10	41	9	31
Very Large	1	1	5	4	6	19
Extreme	1	0	1	1	3	2

The large impact category constitutes only 9 percent; however, this category represents a significant change for the organisms included. At the far ends of this category an organism's potential habitat may be doubled of halved. Very large and extreme changes total only 3 percent, affecting two species of zooplankton and spawning area for crabs (which is increased).

2. Base Drought

The Base Drought scenario represents a considerable change from the Future Average. The Future Average is predominantly minimal impact, while Base Drought is predominantly large, two impact categories more severe than the Future Average. The Base Drought contains roughly equal amounts between 15 and 20 percent of minimal and moderate impacts with over half of the impacts in the large range, most of these being habitat decrease. Thus, over 50 percent of the organisms have their habitat multiplied or divided by nearly a *factor or two.*

The very large category during Base Drought composes nine percent of the organisms, nearly five times the number subjected to this change in the Future Average. The extreme category nearly triples to 3 percent with a zooplankton and a larval fish falling into this category as well as spawning area for crabs. Of these three, the fish larvae is the only organism lifestage which is decreased by the drought.

3. Future Drought

The Future Drought scenario is quite similar to the drought in the minimal and moderate impact categories, with roughly 15 percent in each category. The dominant category is again large habitat change although this is no longer a majority of the species.

In this scenario, more species have been shifted to very large and extreme impact. Eight of the ten fish study species are affected in these impact categories, usually in the egg or larval portions of their life cycle. There are also large decreases in clams and other benthic organisms, several zooplankton and the canvasback. Submerged and emergent vegetation seem to be buffered from these very large and extreme effects, although many of the species fall into the large change category.

4. Summary

Of the three scenarios,the Future Average presents the least actual change while drought events are considerably more severe. There is,however, a fundamental danger in comparing consumptive losses and drought on the basis of salinity change alone. There is a basic difference in timescales of the two changes; consumptive losses are projected to be relatively permanent whereas a drought condition would normally last only a few years. The long-term effects of consumptive losses may be more significant than indicated in this analysis. Such effects might involve cumulative stresses on organisms or changes in interaction patterns in the biological communities producing totally unexpected results.

The most severe scenario is the Future Drought. It is the most important scenario since, with consumptive losses, it can be confidently expected that natural cycles will result in periodic drought conditions. The occurrence of a Future Drought of the severity predicted in this study would make fundamental and intense changes in the dominant fish and shellfish species of the Bay both directly through action on sensitive life stages and indirectly by drastic effects on certain food organisms.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

The research conducted during this Biota Assessment have revealed numerous areas of the bay and its organisms that require significant future research. The purpose of this research should be to integrate our understanding of the bay and its resources, treating it as a whole dynamic system in which both commercial species and the organisms which provide their food and other needs are important.

First and foremost, standardized baywide research is needed on limiting factors and organism tolerance. In this study we have very broadly used salinity,depth and substrate to classify potential habitat. There are numerous other critical parameters including water quality, nutrients, transport (velocity phenomena) which partially define organism habitat. These need to be understood for a broad class of organisms throughout the bay before accurate baywide quanitification of impacts from human encroachment or management can be made.

Secondly, a better understanding of food and non-food relationships (competition, etc.) between organisms needs to be developed. The food webs in this report are state-of-the-art as far as present research goes. However, the quantitative aspects of most organism feeding paths are practically unknown, as are the capabilities of organisms to switch to alternate food sources. Analyses such as these could lead to better understanding of natural population cycles of major commercial species. Physical transport and migration of organisms which tie into these natural cycles are poorly understood and are of vital importance in creating a clear picture of organism interactions.

Bay research needs to be approached on a wider geographical scale encompassing major portions of the system, rather than only small scale studies specific to one bay location or tributary reach. Such study would entail inter-agency and inter-institution cooperation.

Finally, the effect of long-term versus short-term stress effects needs to be investigated through continuous research studies. Such items as recolonization rates following high or low flow periods, changes in interactions between organisms and rates of return to stable populations should be studied. Only with this knowledge can the results of the present study be applied to baywide management with any certainty of advance prediction.

GLOSSARY

The terms below are in most cases specific to the biota assessment study. Numerous other scientific terms relating to species are used throughout the report. Readers unfamiliar to these are referred to the Dictionary of Scientific and Technical Terms, second edition, Daniel N. Lapedes, editor, McGraw-Hill Company, New York.

BASE TEST - one of a set of two tests conducted on the U.S. Army Corps of Engineers Chesapeake Bay Hydraulic Model which characterized inflow conditions corresponding to present average inflows and those of the 1960's drought.

BASE AVERAGE - one of four inflow scenarios, this scenario characterizing present average inflow conditions.

BASE DROUGHT - one of four inflow scenarios, this scenario characterizing inflows during the 1960's drought.

BIOTA EVALUATION PANEL - a committee of distinguished Chesapeake Bay scientists convened by the U.S. Fish and Wildlife Service and the U.S. Army Corps of Engineers to evaluate effects of reduced freshwater inflow on health and productivity of key Chesapeake Bay organisms.

DIRECT IMPACT (OR EFFECT) - a change in the basic physical, chemical, or biological factors which govern an organism's habitat.

DROUGHT HYDROGRAPH - a simulation of flows into Chesapeake Bay during the 1960's drought on the Corps hydraulic model.

FOOD WEB - a diagrammatic representation of predator-prey or similar food relationships between organisms in an ecosystem.

FUTURES TEST - one of a set of two tests conducted on the U.S. Army Corps of Engineers Chesapeake Bay Hydraulic Model which characterized flow conditions corresponding to inflows in the future (year 2020) reflecting the base test as reduced by increased consumptive water losses predicted for that year.

FUTURE AVERAGE - one of four inflow scenarios, this scenario characterizing present (base) average conditions as reduced by consumptive losses predicted for the year 2020.

FUTURE DROUGHT - one of four inflow scenarios. This scenario characterizing the 1960's drought reduced by consumptive losses predicted for the year 2020.

HABITAT - a geographical area defined by the physical, chemical, and biological conditions which are favorable to the survival, growth, and reproduction of a given organism.

HABITAT CHANGE - an alteration in habitat size or distribution caused by a change in a physical, chemical or biological factor which defines that habitat.

HABITAT MAPS - a set of maps which define habitat for the study species based on salinity, substrate, depth, season, lifestage and sometimes other organisms. These maps were completed for each of the four scenarios.

HYDRAULIC MODEL - a physical scale model of Chesapeake Bay located on Kent Island, Maryland used by the U.S. Army Corps of Engineers to simulate conditions of tides, inflow, salinity, and other variables of interest.

IMPACT RATIO - a ratio of the habitat change, usually between the base average scenario and one of the three low flow scenarios.

INDIRECT IMPACT (OR EFFECT) - a change in organism habitat, abundance, or survivability induced through another organism (i.e., lower or higher in the food web) or through some other indirect mechanism.

ISOHALINE - a mapped line of equal salinity concentration, usually at a given depth and averaged over some time period (i.e. season)

LOW FLOW SCENARIO - one of three scenarios 1) Base Drought, 2) Future Average or 3) Future Drought characterized by inflows reduced from those of the Base Average scenario.

MODAL HYDROGRAPH - a graphical summary of inflows used in the hydraulic model for the base average scenario.

PLANIMETRY - a technique used for measurement of mapped habitat areas using a perimeter measuring integrator instrument called a planimeter.

POTENTIAL HABITAT - the area favorable to an organism (or lifestage) survival, growth and development or reproduction governed by the factors of salinity, substrate, depth, and other organisms.

SALINITY EXTREME - a salinity variation divergent from the seasonal average which lasts a given period of time (i.e. two weeks).

SALINITY MAPS - a set of maps of salinity isohaline by season, depth and scenario as preducted by the Corps hydraulic model and subsequent linear interpolation.

SEASONAL SALINITY - a seasonally averaged salinity at a given point or along an isohaline as interpolated at a certain depth from hydraulic model data.

SECONDARY IMPACT (OR EFFECT) - an impact or effect resulting from a cause not directly related to seasonal habitat change, such as effects of salinity extremes.

STUDY SPECIES - a group of 54 species selected during Phase I as indicative of typical organisms responsive to low flow environmental changes.

SUBSTRATE - soil or sediments comprising the bottom of the bay or bayshore areas.

TIME-HISTORY PLOT - a graphical presentation of salinity changes with time at a given hydraulic model sampling station.

TRANSECT - a linear series of hydraulic model stations, usually extending across the bay or tributary channel.

TROPHIC - of or pertaining to food relationships between organisms.

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