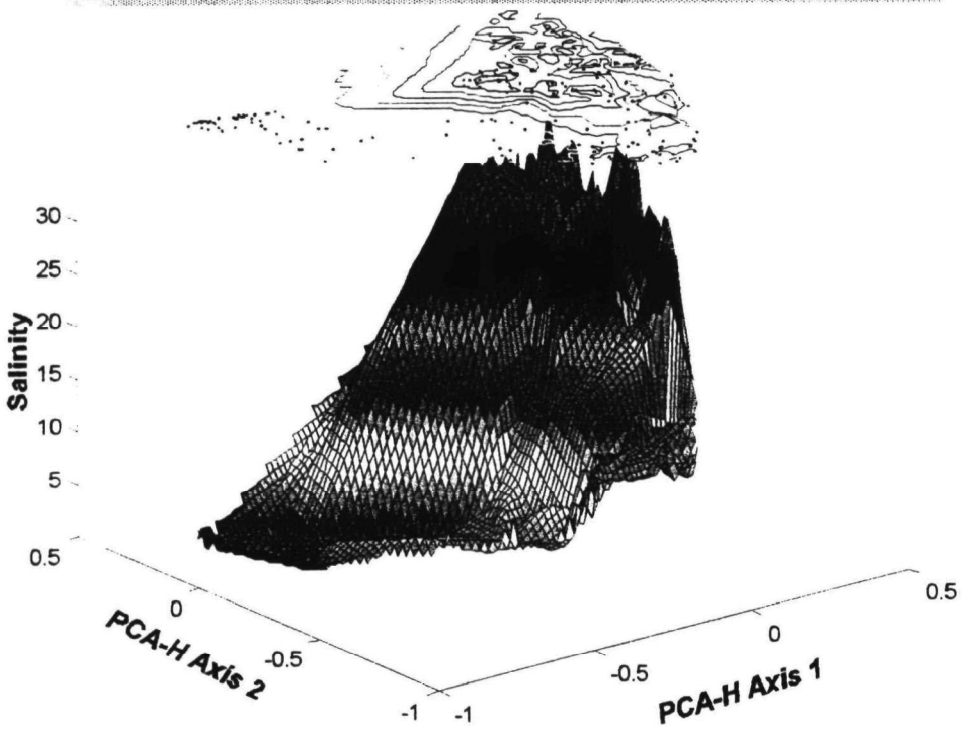
Virginian Province Macroinfaunal Community Structure: PCA-H Analyses and an Assessment of Pollution Degradation Indices

Eugene D. Gallagher
Environmental, Coastal, and Ocean Sciences
100 Morrissey Boulevard
University of Massachusetts Boston
Boston MA 02125-3393

J. Frederick Grassle
Institute of Marine and Coastal Sciences
Rutgers University
New Brunswick NJ 08903-0231



Final Report Submitted to the
United States Environmental Protection Agency
Atlantic Ecology Division (AED)
Narragansett, RI 02882
EPA PROJECT OFFICER: **Brian D. Melzian**

Virginian Province Macroinfaunal Community Structure: PCA-H Analyses and an Assessment of Pollution Degradation Indices

Eugene D. Gallagher

Associate Professor
Department of Environmental, Coastal, and Ocean Sciences

University of Massachusetts at Boston

Boston MA 02125

(World Wide Web URL: http://www.es.umb.edu/edgwebp.htm)

J. Frederick Grassle

Professor and Director
Institute of Marine and Coastal Science

Rutgers University

PO Box 231

New Brunswick NJ 08903-0231

A final report submitted to the

United States Environmental Protection Agency (EPA)

Atlantic Ecology Division (AED)

Narragansett, Rhode Island 02882

EPA PROJECT OFFICER: **Brian D. Melzian**

February 11, 1997

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

INTRODUCTION 2

STATISTICAL METHODS USED IN THIS STUDY 4

How the EMAP-E VP benthic data were collected 4
Preparing the EMAP-E Virginian Province data for community analysis 4
Methods to analyze community structure 7

RESULTS & DISCUSSION 8

The What, Why and Where of benthic monitoring 8
Analysis of the EMAP-E VP Benthic Degradation Indices 12
Community Structure Analyses of Virginian Province 23

CONCLUSIONS 37

On the central role of salinity 37
Suggestions for improving EMAP-E VP 37
Have the EMAP Goals and Objectives Been Met? 43

REFERENCES 44

APPENDIX I METHODS FOR ANALYZING COMMUNITY STRUCTURE 54

Diversity indices 54
Rarefaction, CNESS and Principal Components Analysis of Hypergeometric probabilities (PCA-H) 56

APPENDIX II TERMS AND DEFINITIONS 66

APPENDIX III FULL EMAP-E VIRGINIAN PROVINCE MODIFIED FAUNAL LIST 70

APPENDIX IV SAMPLE CLUSTER ANALYSIS 90

APPENDIX V SPECIES CLUSTERS FOR ALL 551 EMAP-E VP TAXA 107

EXECUTIVE SUMMARY

This report describes research done under a cooperative agreement between the EPA and the University of Rhode Island and Rutgers University. The lead author performed this work while on sabbatical leave at Rutgers University in the 1994-1995 academic year. Dr. J. Fred Grassle hosted and assisted Dr. Gallagher in the analysis of the EPA's "Environmental Monitoring and Assessment Program-Estuaries Virginian Province " (EMAP-E VP) data.

The EMAP program set as a goal the identification of degraded biological conditions in the nation's ecosystems. Biotic indicators of degraded conditions were to be developed rather than focusing on the concentrations of pollutants (Messer *et al.* 1991, p. 70-81). Each EMAP program was to design biotic indices to determine the extent of impacted biological conditions. Then, the assessment portion of the EMAP program was to determine whether these adverse effects could be attributed to the effects of pollution. The EMAP program was designed as a multi-decade program. The EMAP-Estuaries program was to assess the status of our nation's near-shore coastal zone, including estuaries. The Virginian and Louisianian Provinces were chosen to be the demonstrations for the EMAP-E program. The EMAP-E Virginian Province (EMAP-E VP) program developed four different indices of benthic degradation. We review each of these indices and offer our assessment of their adequacy as descriptions of impacted benthic communities. The first three benthic indices are no longer used in the EMAP-E VP program. We provide additional reasons to reject these indices. We provide an analysis of the latest EMAP-E VP index, the 1990-1993 index. This index may discriminate between a subset of stations regarded as degraded and non-degraded, but it should not be used as a general index of degraded marine benthos. When reduced to simple terms, this index states that roughly 7000 spionid polychaetes or 17000 oligochaetes per square meter indicates benthic degradation. This index will classify large portions of pristine benthic areas in the Virginian Province and throughout the world as degraded.

We review one of the central assumptions of the development of EMAP-E VP benthic degradation indices: that sediment pollutant concentrations, overlying dissolved oxygen concentrations, and amphipod toxicity are necessary and sufficient conditions for creating test data sets of degraded and reference stations. We do not agree with this assumption. It is possible to have relatively unimpacted benthic sites be classified as degraded using the EMAP-E VP criteria for degradation. Conversely, many impacted sites would fit the EMAP-E VP criteria that define natural or reference sites. The EMAP-E program is based on circular logic. Instead of devising independent criteria to assess the effects of contaminants and low dissolved oxygen on benthic communities, the EMAP-E program has *a priori* assumed that sites having concentrations of contaminants in excess of published thresholds, amphipod survival less than a threshold or low dissolved oxygen in the overlying water must be degraded. Once these criteria were established, two test data sets were created and an equation derived which would separate these two groups. All other EMAP-E VP sites are scored using this function. The EMAP-E VP program did not evaluate whether any of these sites really showed biological impacts indicative of degradation.

We present new analyses of the patterns of benthic community structure in the Virginian Province. The effects of pollution on benthic communities must be assessed relative to natural patterns of variation in community structure. We use both classification and ordination analysis to describe the major patterns in community structure in the EPA's EMAP-E VP benthic data. These analyses use the metric faunal distance metric CNESS, short for Chord-normalized expected species shared (Trueblood *et al.* 1994). This index is a metric version of Grassle and Smith's (1976) NESS or Normalized Expected Species Shared faunal similarity index. The ordination method based on CNESS is called PCA-H, short for principal components analysis of hypergeometric probabilities. We conclude that salinity is the overriding factor controlling natural patterns of Virginian Province community structure. It is the major factor controlling the maximum number and type of

species that occur in an area. Species richness in the Virginian Province is a strong function of salinity, with very low salinity habitats having roughly eight species in three replicate samples and high salinity areas having over forty species.

The EMAP-E VP benthic degradation indices have attempted to account for this habitat factor. Salinity strongly affects degradation indices based on species richness and the abundance of opportunistic taxa, variables which strongly covary with salinity. The use of opportunistic or pollution-indicating taxa is problematic because almost all opportunistic taxa used in marine ecology are natural components of medium and low salinity habitats.

The existing EMAP-E indices indicate that tidal-river habitats have the highest percentage of degraded area, approximately 40%. Tidal river systems, often near urban sources of pollution, are more likely to have degraded benthic communities than large and s mall estuaries. However, these sites are also the ones most likely to be misclassified as degraded if the effects of salinity are not properly taken into account.

We review the extensive literature on benthic pollution indices. Much of this literature has attempted to find an index to classify pollution-affected *vs.* natural benthic communities. The Chesapeake Bays Program developed a Restoration Goals Index for the Chesapeake Bay. This index is different from the EMAP-E index. An index similar to the Chesapeake Bay Restorations Goals Index was developed for the Regional EMAP program in the New York/New Jersey harbor system.

INTRODUCTION

The Environmental Monitoring and Assessment-Estuaries (EMAP-E) program was designed to be a long-term, multi-decade monitoring plan for the nation's estuaries. EMAP-E is a subset of the nationwide EMAP program, which was to provide answers to the following questions (Weisberg *et al.* 1993):

- What is the status, extent, and geographical distribution of the nation's ecological resources?
- What proportion of these resources is declining or improving? Where? At what rate?
- What factors are likely to be contributing to declining conditions?
- Are pollution control, reduction, mitigation, and prevention programs achieving overall improvement in ecological condition?

The Virginian Province was selected as the demonstration area to implement the sampling and analytic procedures for the EMAP-E program. As a result, it has been sampled over four different years (1990-1993). The Louisianian Province was sampled in 1991. These provinces are shown in Figures 1 and 2.

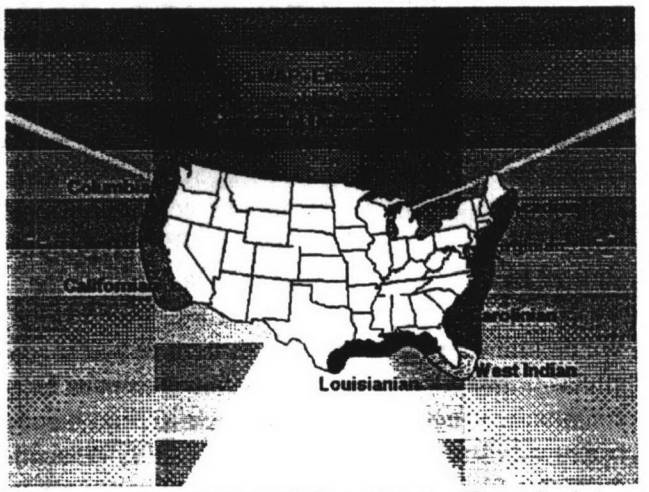


***Figure 1.** The EMAP-E Provinces. The Virginian Province was sampled each year from 1990-1993 and the Louisianian Province was first sampled in 1991. [Figure from the EMAP-E World-Wide Web page.]*

EMAP-E sampling stations (sites) were chosen using Overton *et al.*'s (1990) probability-based

sampling procedure. Probability sampling was applied to three strata in the Virginian Province: large estuaries, small estuaries and tidal rivers. A random selection of small estuaries was selected for probability-based sampling, and all large tidal rivers and large estuaries were sampled. Approximately two thousand benthic grab samples were processed during the four-year duration of EMAP-E VP.

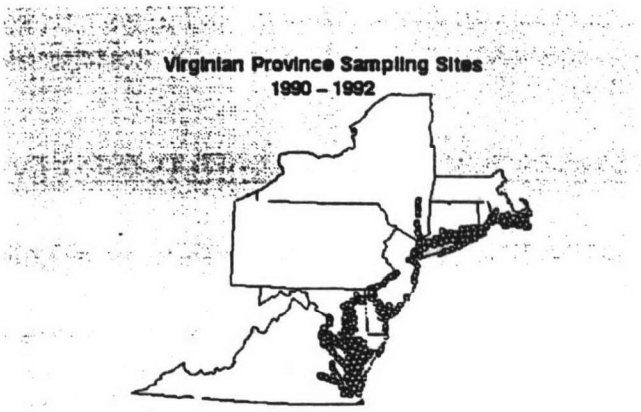


Figure 2. Virginian Province EMAP-E sample locations from 1990-1992 [1993 sample locations not shown, Figure downloaded from the EMAP-E web page]

The EMAP-E VP program used patterns of benthic community structure to assess the status of the Virginian Province's near-shore coastal zone. Benthic ecologists throughout the world use benthic community structure to assess the effects of anthropogenic pollution (*e.g.*, Boesch and Rosenberg 1981, Bloom 1980, Chapman *et al.* 1987, Field *et al.* 1982, Gray 1976, 1979a & b, 1989, Jumars 1981, Warwick 1993). Some reasons for the efficacy of monitoring changes in benthic community structure are that benthic populations are relatively sedentary (*i.e.*, they can't migrate away from a pollution source or source of disturbance), and their typical monthly to annual generation times are such that the populations are adapted to short-term fluctuations in environmental variables but are capable of a strong numerical response to significant long-term environmental changes. Moreover, the populations are sensitive enough to respond to relatively low levels of toxic substances. For example, Grassle *et al.* 1981 observed pronounced community responses to 90 ng/g of #2 diesel oil in the MERL ecosystem tanks). The recovery time of benthic populations is short enough that changes in community structure can be detected in a matter of months, but long enough that the community structure is to some extent a response to the integrated habitat quality over the previous months or even years.

The EMAP-E VP program developed benthic degradation indices to determine the proportion of the Virginian Province with degraded benthic communities. The EMAP-E VP program selected a set of degraded stations and a set of undegraded, or "reference" stations, and then produced an equation based on biological variables that discriminated between these two groups. The Chesapeake Bay Restorations Goals Index [RGI] (Ranasinghe *et al.* 1993) used a similar approach. The EMAP-E VP and RGI indices differ in the statistical methods used to classify samples into degraded and undegraded classes. The EMAP-E VP uses a parametric linear discriminant function. The RGI index is based on an ordinal ranking of biological variables into the groupings 1 (below expected), 2 (expected), and 3 (greater than expected). A degraded station in the RGI index is one that has an average ranking across biological variables of less than 2.

To demonstrate the utility of alternate methods for assessing the effects of pollution on benthic communities, this report contains detailed analyses of patterns of community structure in the four-year Virginian Province data. These analyses are performed using methods based on CNESS and PCA-H (Gallagher *et al.* 1992, Trueblood *et al.* 1994). CNESS or the chord-normalized expected species shared, is a metric for assessing the faunal similarity among samples. PCA-H, short for principal components analysis of hypergeometric probabilities, is an ordination technique based on CNESS. CNESS is the metric equivalent of Grassle and Smith's (1976) Normalized Expected Species Shared or NESS index. Using either NESS or CNESS, the entire 1918-sample EMAP-E VP data can be clustered using COMPAH96 in about 10 minutes using a desktop PC. COMPAH96 is the latest version of Boesch's (1977a) clustering program. It is available for

download with documentation on the lead author's World Wide Web page. Boesch's (1977a) EPA report describes many of the methods available in COMPAH and applies them to benthic data from Chesapeake Bay.

STATISTICAL METHODS USED IN THIS STUDY

How the EMAP-E VP benthic data were collected

Samples are taken within the Virginian Province using a probability-based sampling design within pre-defined strata. Weisberg *et al.* (1993, p. 2-4 to 2-5) describe the strata: Large estuaries, Large Tidal Rivers, and Small Estuarine Systems. The specific application of probability sampling to each strata was different. A systematic random two-dimensional grid was applied to the large estuaries. Overton's (1989) sampling grid, designed for the nationwide EMAP program, was scaled down to make these grids. The sampling points were the centers of the hexagonal grids. The five large tidal rivers (*i.e.*, Hudson, Potomac, James, Delaware, and Rappahnannock) were sampled using a one-dimensional analog of the two-dimensional grid used for the large estuaries. A list frame was used to select 32 (23%) of the 137 small estuarine systems during the 1990 sampling. All small estuaries were ranked by latitude and grouped into groups of four. One small estuary out of each group was randomly chosen. In the 1990 sampling, Delaware Bay and the Delaware River were sampled more intensively. Subsequent EMAP-E VP sampling used the same basic approach. Strobel *et al.* (1995, p. A-2) summarize all four years of EMAP-E VP sampling. There were 446 sites sampled with probability-based sampling. Several EMAP-E VP sampling sites were sampled repeatedly over the four-year period (*e.g.*, twenty samples from Indian River Bay site No. 150, and eighteen benthic samples from the Potomac River site No. 188). Most sites were sampled only once, with three replicate grabs. A subset of sampling sites from the 1990 sampling, called Index sites, were chosen because they are 'located in depositional environments, where there is a high probability of sediment contamination or low dissolved oxygen conditions.' There were 86 index sites in the EMAP-E VP database. There were a select number of 1990 sampling sites chosen for long-term sampling, the Long-term trend sites. There were twelve Long-term trend (LTT) sites. Strobel *et al.* (1995) describe additional sites that were sampled repeatedly during the EMAP-E VP program.

Typically three Ted Young modified van Veen grab samples (0.044 m^2) were collected at each sampling station (site) from the Virginian Province (Figure 2). Additional grabs were taken and composited for sediment chemistry, grain size, and amphipod toxicity tests. The benthic infauna retained a 500-μm mesh sieve were identified. Most of the sorting and identification in the EMAP-E VP program was done by Cove Associates. Most of the individuals were identified to species. The taxonomy of samples collected in areas with bottom water salinity less than 5 psu (short for practical salinity units, formerly called parts per thousand or abbreviated ‰) is handled differently than the remaining samples. Oligochaetes and chironomids were classified to levels finer than the taxonomic level Class. Many of the oligochaetes and chironomids collected from sites with bottom salinities less than 5 psu were identified to species. The chironomids and oligochaetes from samples collected in areas with salinities above 5 psu were lumped at the level of Family and Class, respectively.

Preparing the EMAP-E Virginian Province data for community analysis

The unedited EMAP-E VP data cannot be used for traditional community structure analysis. There are 868 taxonomic categories in the full EMAP database. We dropped many taxa and merged others to form a much smaller set of valid taxonomic categories. Some of the EMAP taxa are invalid, some are redundant, and many refer to epifaunal taxa. We arrived at a final list of 551 taxa. We discuss the reasons for dropping and merging categories below. This provide the full and edited list of EMAP-E VP taxa in Appendix II.

Drop and Merge Rules

There are over 868 taxonomic designations listed in the four-year Virginian Province data set. Two of these 'taxa' include:

NOORGPRS	No Organisms Present
POLYCHAE	Polychaeta: Other - Unidentified & fragments

Of the remaining 866 species codes in the EMAP-E VP database, more than three hundred must be dropped or merged for community structure analyses. We use 551 taxonomic designations (most are species) for our analyses. For more detailed analyses of community structure, we would probably drop many or merge many additional EMAP-E VP taxa. For example, much of the break in community structure at the 5 psu mark is because chironomids and oligochaetes were sorted to levels finer than family and class in the low salinity habitats, but not in the higher salinity habitats. To assess whether 5 psu really marks a key transition in community structure, these taxa would have to be merged or dropped. The existing EMAP-E VP data set flags only a subset of the invalid taxa with the database flag SPEC_IGN (Ignore this species in calculating total species per event).

The authors of this study developed the first list of "valid EMAP taxa" using two DROP rules and three MERGE rules:

The drop rules

Drop Rule 1. Drop all strictly epifaunal, meiofaunal, and pelagic taxa.

Drop Rule 2. Drop all general taxonomic designations at the generic, familial and higher taxonomic levels if there are more than two valid lower-level designations for that group. For example, there are many species of the family Spionidae identified in the EMAP data and three species of the genus *Spio*. Therefore, both the familial level EMAP taxon SPIONIDA and the generic level taxonomic category SPIO must be dropped. Failure to implement this "drop" rule would have the unfortunate effect of greatly enhancing the faunal similarity of samples along environmental gradients. Samples would appear more similar than they really are.

Only a limited number of non-specific designations escaped the drop rule. These are listed below. Several of these higher level taxonomic designations should be dropped in future analyses designed to assess biogeographic patterns (*e.g.*, oligochaetes, Tubificidae with capiliform chaetae, Tubificidae without capiliform chaetae).

Acanthohaustorius spp.
Amphitritinae
Aphelochaeta spp.
Bezzia spp.
Buccinidae
Capitella spp.
Chironomidae
Chironomus spp.
Cladotanytarsus spp.
Coelotanypus spp.
Cryptochironomus spp.
Demicryptochironomus spp.
Dicrotendipes spp.
Diptera
Dolichopodidae
Flabelligeridae
Laonice spp.
Magelona spp.
Microchironomus spp
Nemertinea
Oligochaeta
Ophryotrocha spp.
Owenia spp.
Palpomyia spp.
Phoronis spp.
Pisidium spp.
Polygordius spp.
Polypedilum spp.

Procladius spp.
Procladius (Holotanypus) spp.
Protodrilus spp.
Protohaustorius spp.
Pseudochironomus spp.
Sipuncula
Solecurtidae
Sphaerodoropsis spp.
Sphaeromias spp.
Stictochironomus spp.
Tanypus spp.
Tanytarsus spp.
Thalassinidea
Tubificidae without capiliform chaetae
Tubificidae with capiliform chaetae

The merge rules

Merge Rule 1. Merge all taxa that can not be adequately distinguished taxonomically. The EMAP-E VP data set contains hundreds of taxonomic designations at taxonomic levels higher than the species. For example, in the full EMAP species list, the following eight ampeliscid amphipod categories are found:

AMPEABDI	*Ampelisca abdita*
AMPEABVA	*Ampelisca abdita-vadorum* complex
AMPELISC	*Ampelisca* spp.
AMPEVADO	*Ampelisca vadorum*
AMPEAGAS	*Ampelisca agassizi*
AMPEVERR	*Ampelisca verrilli*
AMPHIPOD	Amphipoda: Other

We consulted with the taxonomists at Cove Associates (Tim Morris and Nancy Mountford) to determine whether *Ampelisca* spp. and 'Amphipoda: Other' were indeed different from the juvenile stages of *Ampelisca abdita* and *A. vadorum*, which can not be identified to species. They stated these categories did not refer to either *A. abdita* or *A. vadorum*, therefore both higher level taxa were dropped using DROP RULE 2 (above). Using Merge Rule 1, the AMPEABDI, AMPEABVA, and AMPEVADO designations were fused, reducing the original seven taxonomic categories used to describe ampeliscid amphipods to three:

AMPEABVA	*Ampelisca abdita-vadorum* complex
AMPEAGAS	*Ampelisca agassizi*
AMPEVERR	*Ampelisca verrilli*

Merge Rule 2. If there are a pair of taxonomic designations indicated by *Genus A species x* and *Genus A spp.*, and there is a high probability that the individuals identified only as *Genus A spp.* are indeed *Genus A species x*, then merge the two taxa. This merge usually occurs when there is only one species in addition to the higher level taxonomic designation. Note that Drop Rule 2 would force the deletion of *Genus A spp.* if there were more than one species of *Genus A* in the data set. Our main justification for merging these taxa is that the taxonomists were better able to distinguish species in the later years of the EMAP-E VP sampling.

The following groups of EMAP taxa refer to single species and should be merged:

LUMBHEBE	*Scoletoma hebes*	(These refer to the same species, but
SCOLHEBE	*Scoletoma hebes*	were listed as separate species in the EMAP data)

MELINNA	*Melinna* spp.	MICRATRA	*Microphiopholis atra*
MELIMACU	*Melinna maculata*	OPHIUROI	Ophiuroidea
NOTOMAST	*Notomastus* spp.		
NOTOSPA	*Notomastus* sp. A Ewing	MUSCTRAN	*Musculium transversum*
		MUSCULIU	*Musculium* spp.
OWENFUSI	*Owenia fusiiformis*		
OWENIA	*Owenia* spp.	ORCHMINU	*Orchomenella minuta*
PECTGOUL	*Pectinaria gouldii*	ORCHOMEN	*Orchomenella* spp.
PECTINAR	*Pectinaria* spp.		
		PANDGOUL	*Pandora gouldiana*
PHERAFFI	*Pherusa affinis*	PANDORA	*Pandora* spp.
PHERUSA	*Pherusa* spp.	PANDORID	Pandoridae
ASYCELON	*Sabaco elongatus*		
ASYCHIS		SOLEMYA	*Solemya* spp.
SABAELON	*Sabaco elongatus*	SOLEMYID	Solemyidae
(All 3 designations refer to the same maldanid polychaete species, but different codes were used in different years in the EMAP database [The genus name had changed from *Asychis* to *Sabaco*])		SOLEVELU	*Solemya velum*
		TELLAGIL	*Tellina agilis*
		TELLINA	*Tellina* spp.
		(Note: the EMAP taxon TELLINID Tellinidae is dropped)	
EUDOPUSI	*Eudorella pusilla*	YOLDIA	*Yoldia* spp.
EUDORELL	*Eudorella* spp.	YOLDLIMA	*Yoldia limatula*

Merge Rule 3. On occasion, a merge could occur between a higher level category and a species, even if more than one species in a genus were present. If the taxonomists at Cove Associates were reasonably certain that individuals identified as *Genus spp.* belonged to a valid species designation, these taxa were fused rather than dropping the higher level designation.

For example, the EMAP species list contains the following three taxa:

LEITFRAG	*Leitoscoloplos fragilis*
LEITOSCO	*Leitoscoloplos* spp.
LEITROBU	*Leitoscoloplos robustus*

DROP Rule 2 would dictate that LEITOSCO (*Leitoscoloplos* spp.) should be dropped. However, Cove Associates is reasonably certain that the individuals identified as LEITOSCO are *Leitoscoloplos robustus*, so these two categories are merged, forming 2 valid taxa:

LEITFRAG	*Leitoscoloplos fragilis*
LEITROBU	*Leitoscoloplos robustus*

Methods to analyze community structure

Converting EMAP-E VP data from SAS™ to Matlab™

The EMAP-E VP data are stored in a SAS database. We adapted a SAS program, provided by S. Weisberg and A. Ranasinghe (VERSAR, Columbia MD) to convert the SAS EMAP-E VP database to

COMPAH input format. COMPAH reads data in a number of accepted formats and will convert to other formats, including the binary form used by MATLAB™.

Most of the analyses performed in this report were done with MATLAB™ programs written by the lead author. Many of these programs are available on the lead author's World-Wide Web page.

Diversity analyses

We used the following diversity indices to analyze the EMAP-E VP data: Brillouin's H, Shannon's H', Hurlbert's $E(S_n)$, Pielou's J' Evenness , Simpson's diversity, total number of species, and Gleason's D. The first six indices are described in Pielou (1969, 1975, 1977), Peet (1974) and Magurran (1988). Smith and Grassle (1977) describe the statistical properties of Hurlbert's (1971) $E(S_n)$ and Simpson's unbiased diversity indices. Hurlbert's (1971) $E(S_n)$ is based on Sanders' (1968) rarefaction method for analyzing species diversity. Gleason's D diversity index, the number of species divided by the logarithm of number of individuals, is described in Washington (1984).

Cluster analysis

COMPAH was used to cluster samples and species. Both the sample and species cluster analyses follow methods described in Trueblood *et al.* (1994). Sample clustering uses CNESS (m=25) as the distance measure and unweighted pair group (UPGMA) sorting. For clustering species, we used Pearson's r of the normalized hypergeometric probability matrix with single-linkage clustering. The lead author distributes full documentation, source, and executable codes for COMPAH on his web page.

PCA-H Analysis

Trueblood *et al.* (1994) describes the methods used to perform an ordination using CNESS faunal distances. This ordination uses a principal components analysis of hypergeometric probabilities, which is abbreviated as PCA-H. Programs to perform PCA-H are available on the lead author's web page. Appendix I provides background information on CNESS and PCA-H.

RESULTS & DISCUSSION

The What, Why and Where of benthic monitoring

What is monitoring and assessment?

Chapman *et al.* (1987a) provided this definition of monitoring:

> *"Monitoring consists of repetitive data collection for the purpose of determining trends in the parameters [sic] monitored."*

According to Chapman *et al.* (1987a), monitoring must be based on three questions:

- What beneficial uses should be protected?
- What water-quality problems have been identified in the past or at present that need to be monitored?

- What major natural and anthropogenic factors affect the ecosystem?

The first question is difficult to answer. Chapman *et al.* (1987a) urge ecologists to consider which changes are meaningful ecologically or for regulatory purposes. O'Connor and Dewling (1986) argued that ecological significance is different from statistical significance. An ecologically significant, or perhaps environmentally significant, result is one that is important enough for ecologists to warn regulators about and important enough for environmental regulators to consider regulatory action. Using O'Connor and Dewling's (1986) criteria, we might assess whether the EMAP-E VP benthic degradation indices be used now to assess whether estuarine sediments are sufficiently 'clean' for oceanic dredge disposal.

Green (1979, p. 68) divides the broad field of ecological survey sampling into three categories: baseline studies, monitoring studies, and impact studies. A baseline study is a sampling program that determines the present state of the system (*e.g.*, estimates of biological and chemical variables). An impact study assesses the effects of an impact such as an oil spill. In a monitoring study, the goal is merely to detect change from the present state. Baseline data must be available in an impact study to provide a standard against which to detect a change.

One of the goals of the EMAP-E VP program is not only to establish baseline monitoring data, but also to measure a wide variety of habitat and sediment pollutant variables. The habitat factors include water depth, temperature, salinity, pH, stratification, total suspended solids, water clarity, and sediment grain size. The pollutant variables include most of the EPA priority pollutants including heavy metals, pesticides, PCB's, PAH's and pesticides. The assessment portion of the EMAP-E VP program, based on analyses of the covariation of physical and biological variables, should allow the assessment of which factors might be responsible for changes in community structure.

Statistics and sampling designs

A monitoring plan should be based on established principles of statistics. All variables, hypotheses and statistical models should be specified in advance. The use of sample statistics in the broad sense should be an essential part of almost all monitoring plans. Unfortunately, despite token references to the contrary, hypothesis testing using valid sampling designs is rarely incorporated in most monitoring studies. A strong case could be made for the view that hypothesis testing need not be an essential feature of monitoring. Just as museum collections of bird shells provided essential baseline data for documenting the effects of DDT in the 1960s, some might feel that data collection *per se* has intrinsic value. However, when funds for monitoring are scarce and the potential array of variables that might be monitored is large, data collection without a rigorous sampling design can no longer be justified. A monitoring program should attempt to link changes in the environment with the variables that account for that change.

There are three types of error involved in an experimental or survey design. The first two are well known: Type I and Type II error. These well-known statistical errors in a monitoring program involve finding change when there is none and not detecting a change in the environment. Underwood (1981) called a third major source of error model misspecification. Model misspecification is caused by using an inappropriate statistical model to perform the analyses. Model misspecification can result in either failing to detect important patterns in the data, or detecting patterns and attributing the result to the wrong cause. This third source of error subsumes much of what Hurlbert (1984) has called pseudoreplication. Monitoring should attempt to minimize this third source of error by insuring that the assumptions of the tests being used are met, and that the appropriate covariates are either measured or randomized out of the design.

Type I & II error and model misspecification

The following table shows the relationship between Type I and Type II error:

		Null Hypothesis	
		True	False
Decision Based on Statistical Test	Reject H_o	Type I error	Correct decision *"Science Advances"*
	Accept H_o	Correct Decision *"No Advance"*	Type II error

In environmental monitoring, the traditional null hypothesis is that of 'no change' (*e.g.*, H_o: $\mu_1 = \mu_2$). The probability of **Type I error**, symbolized as I, is the probability of rejecting a true null hypothesis; its magnitude is set through the choice of the critical value of the underlying statistical distribution against which the value of the test statistic is to be judged. Conventionally, the probability of Type I error is set at 0.05 or 0.01, so that the odds of rejecting a true null hypothesis are only 1 in 20 or 1 in 100. The choice of a significance level is merely convention, and there is justification for choosing a relatively large α-level (*e.g.*, Probability (Type I error)≈0.10) for environmental monitoring studies. Committing a Type II error by accepting a false null hypothesis of no change in the environment may have serious regulatory consequences. For example, the depletion of atmospheric ozone is of such immediate world-wide concern that sampling programs for Antarctic ozone levels should be designed to minimize the probability of Type II error. If the null hypothesis is 'the percentage of benthic area containing few animals, *e.g.*, less than 1000 per square meter) is not changing, the environmental consequences of a large Type II error could be extremely serious. For a given sample size, increasing the probability of Type I error (*e.g.*, testing at the α=0.10 rather than α=0.05 level) leads to a decrease in the probability of Type II error. Increasing sample size reduces the probabilities of both Type I and Type II error. However, if sample size can not be increased, then many scientists would argue for α-levels larger than the conventional 0.05 level to reduce the probability of Type II error.

The EMAP-E VP program is one of the few benthic monitoring programs that has included explicit power analyses in its statistical summaries. The EMAP-E VP program is designed so that a 2% annual change in the percentage of area classified as degraded can be detected with high statistical power over a 10-year period.

Trend analysis

Chapman *et al.* (1987) state that the goal of monitoring is not merely to detect **a change** in environmental variables, but **a trend**. '**Trend**' usually implies a non-random temporal pattern in the data. It would be possible to take enough samples so that a change in an environmental variable could be detected between each and every sampling period; roughly half of these changes would be positive and half negative. It is not sufficient to merely find significant results in a monitoring program. If that was the goal, by increasing the sample size and program cost, a monitoring program could detect even slight changes in variables. If there was no long-term trend in the variable, half of these significant changes would be positive and half negative.

As O'Connor and Dewling stress, applied ecologists must move beyond minimizing Type I and Type II error and determine what magnitude of change is significant ecologically. Year-to-year fluctuations about the mean can be detected with a large enough sample size (*i.e.*, more replicate samples), but these fluctuations are not good indicators of the long-term changes in the ecosystem. However, the demonstration of a significant trend in an environmental variable cannot be achieved by simply increasing the number of samples and solves this dilemma. Increasing the number of replicates will not produce a trend if none exists.

The EMAP-E VP program is designed to detect trends in environmental degradation over the decade time scale. The EMAP-E VP sampling program has been curtailed after only four sampling periods. The detection of a significant temporal trend in a variable (at an α-level of 0.05) requires at least six sampling periods. The probability of observing five straight increases (or decreases) in an environmental variable sampled six times is $(0.5)^5$ or 0.03125. In order to be assured of detecting a trend, far more sampling periods are needed. In trend analyses there is one null hypothesis, 'No trend', but there are many alternate hypotheses:

- A short-period cycle plus a unidirectional trend.
- Unidirectional trend.
- Unidirectional trend confounded with a long-term cyclic trend.
- Cyclic trend.

Distinguising between increasing or decreasing trends and cycles requires long time series. Nichols (1988) discovery of a long-term cyclic trend with an apparent twenty-year period in the benthic infaunal community structure of the 200-m main basin of Puget Sound should give pause to any benthic ecologist who assumes that a 4-year trend is due to a degradation of the marine environment. The deepest part of Puget Sound, at 200-m depth in Elliot Bay was first sampled by Ulf Lie in the early 1960s (Lie 1968, Lie and Evans 1973). Fred Nichols sampled this station in the late 1960s for his masters and doctoral dissertations (Nichols 1975). During the 1960s and 1970s, this site ("the 100-fathom hole") was dominated by a subsurface deposit-feeding polychaete *Pectinaria californiensis*. Nichols continued to monitor this area every year throughout the 1970s and 1980s. The *Pectinaria* population, which had reached abundances of 1000 per m^2 1969, had nearly disappeared from the main Basin of Puget Sound by 1976. The new numerical and biomass dominants were surface deposit feeding bivalves and polychaetes. Nichols (1985) thought that the changes he observed in benthic community structure at his 200-m station were due to degradation of the Sound environment due to anthropogenic pollutants (Seattle METRO's West Point Sewer Outfall). The pattern fit Pearson and Rosenberg's (1978) paradigm which predicts that organic enrichment will lead to the replacement of subsurface feeders by surface deposit feeders. Shortly after Nichols published his 20-year data set in 1985, *P. californiensis* returned to the main basin of Puget Sound. Annual monitoring shows that *Pectinaria* abundances are now as high as they were in the early 1960s. Nichols (1988) rejected his hypothesis of a long-term unidirectional trend (alternate 2 above) in favor of 20-year cyclic trend driven by long-term hydrographic changes in the Sound. The flushing charactersitics of the deep portion of Puget Sound change on a twenty-year time scale, and this pattern may have led to changes in larval recruitment to the site. Gray and Christie (1983) document other long-term trends in benthic populations, driven presumably by allogenic trends, especially hydrography.

Mistaking long-term trends and cycles in benthic communities for changes in pollutant loading is an example of model misspecification. Detecting significant ecological changes in benthic communities is not the problem. The major problem is connecting those changes to changes in pollutant loading.

Analysis of the EMAP-E VP Benthic Degradation Indices

The 1990, 1991-1992, and 1990-1993 Benthic Degradation Indices

To date, there have been at least four different benthic degradation indices applied to EMAP-E VP benthic community structure data: the 1990 index (Weisberg *et al.* 1993), the 1991 Louisianian Index: (Summers *et al.* 1992), the 1991 Virginian Province index (Schimmel *et al.* 1994), and the 1990-1993 Index (Strobel *et al.* 1995). Strobel *et al.* (1994) used the 1991 Index to summarize the 1992 EMAP-E VP Virginian Province data. All of these indices are based on a one-dimensional discriminant function, developed to distinguish between a selected group of degraded and non-degraded stations.

The abiotic data from the EMAP-E VP program are used to classify benthic samples into degraded and non-degraded "reference" groups. Weisberg *et al.* (1993), Summers *et al.* (1992), Schimmel *et al.* (1994), Strobel *et al.* (1994), and Strobel *et al.* (1995) describe the protocol for the creation of these indices. A set of degraded stations is chosen based on low dissolved oxygen, sediment contaminant concentrations, and amphipod survival. The absolute values of these thresholds have changed from year to year. For example, in 1990, to be classified as "degraded" due to low dissolved oxygen, oxygen concentrations had to be less than 0.3 mg/L at any time, or 10% of measurements less than 1 mg/L or 20% of continuous measurements < 2 mg/L or less than 2 mg/L for 24 consecutive hours. Strobel *et al.* (1995, p. A-12) state that a site could be classified as a degraded test site if the bottom dissolved oxygen was less than 2 mg/L. The 1990-1993 index used the recent Long *et al.* (1995) ER-L and ER-M values to divide samples into degraded and reference data sets. These stations were selected from three salinity regimes (<5 psu, 5-18 psu, and >18 psu).

Reference, or non-degraded, stations were also selected. None of these stations could have significant *Ampelisca* mortality, DO less than 1 mg/l, and no pollutants could exceed Long and Morgan's (1990) ER-M value. Strobel *et al.* (1995) used the newer Long *et al.* (1995) ER-L and ER-M contaminant thresholds. In the latest 1990-1993 index, to be considered a "reference" site, no more than three sediment contaminant concentrations could exceed the Long *et al.* (1995) ER-L value and none could exceed the ER-M concentration.

Once these two groups of test stations were chosen, Student's t-tests were used to find variables that significantly differed between groups. In all years, the effects of habitat factors on species richnes were evaluated. In the 1990 index, the EMAP-E VP diversity measure, Total Species per Event, was calculated relative to the expected species richness at each salinity. A similar analysis was performed for the 1991 index, including organic carbon as well, but salinity was not included in the final 1991 index, becasue the "salinity-normalized" variable was poorer at discriminanting degraded and undegraded sites than the unnormalized species number. These variables, including those adjusted for salinity, are then entered into a set of step-wise discriminant analyses to find the linear combination of variables that best discriminates between groups. The 1990 Benthic Index from Weisberg *et al.* (1993) is shown below:

1990 *Benthic Index*

Weisberg et al. (1993)

$$BI =$$

$+ 0.011 * \textit{Percent Expected Species (mean number)}$
$+ 0.817 * \textit{Number of amphipods per } 0.044\text{-}m^2 \textit{ grab}$
$+ 0.671 * \textit{Percent of total abundance as bivalves}$
$+ 0.465 * \textit{Number of capitellidsper } 0.044\text{-}m^2 \textit{ grab}$
$+ 0.577 * \textit{Average weight per individual polychaete.}$

$BI < 3.40$ *INDICATES DEGRADED.*

This 1990 Benthic Index was based on only the first year of EMAP-E VP sampling. The expected species included normalization for salinity. Weisberg *et al.* (1993) found a very strong positive correlation between the number of species collected in a grab and salinity. At the lowest salinities in estuaries, only about eight to ten species will be found per grab (Figure 3). With each additional psu salinity, about one additional species is added. Weisberg *et al.* (1993) used a three-point running average to fit a polynomial curve to the top of the cluster of points in a plot of total species sampled *vs.* salinity.

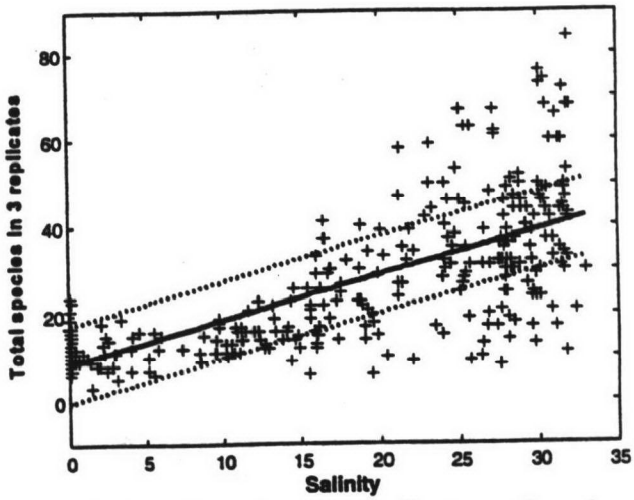


Figure 3. Total species per sampling event (species in all 3 replicate grabs) is strongly correlated with salinity. At 0 psu salinity, 8.5 species are expected and roughly 1 species is added for every psu of salinity. The variance increases at salinities greater than 15 psu. This plot is similar to Weisberg et al. (1993, Fig. 4-2) but is based on an additional three years of data and a much reduced list of valid taxa. The R^2 is 48.3%. 95% Confidence limits for the mean value of the dependent variable are based on three replicates.

Weisberg *et al.* (1993) compared their 1990 Benthic Index with Rhoads & Germano's (1986) Organism-Sediment Index. The OSI™ is based on the photographs of the sediment-water interface. Figure 4 shows the values of the 1990 Benthic Index and the OSI™ for a subset of the 1990 samples. The two indices are weakly correlated. However, if the indices are converted to their binary "degraded-nondegraded" form, the statistical association is no greater than one might expect by chance alone.

Schimmel *et al.* (1994) tested the 1990 Biotic Index on the EMAP-E VP data collected in 1991. Following the procedures developed by Weisberg *et al.* (1993), they identified a set of degraded and "reference" sites based on pollutant concentration (pollutants > Long & Morgan's ER-M), amphipod toxicity, and dissolved oxygen concentration. New reference and degraded stations were added to the list of stations used in 1990. Schimmel *et al.* (1994) identified thirteen new stations in the 1991 dataset as being degraded using their established criteria. The 1990 index classifed 7 of these 13 (54%) as degraded and 6 (46%) as non-degraded. Based on this high rate of misclassification of presumably degraded stations, Schimmel *et al.* (1994) developed the 1991 index (shown below). In

developing the 1991 index, Schimmel *et al.* (1994) analyzed the effect of salinity on species richness. They performed their discriminant analyses using both unnormalized species number and species number normalized by both organic carbon and salinity. Figure 5 plots the second order polynomial equation, used to normalize simultaneously for organic carbon and salinity (2 minor typographic errors in the original equation on Page B-3 of Schimmel *et al.* 1993 have been corrected):

$$\textit{Expected number of species} = 8.25 + 3.87\times10^{-4}\,(TOC) - 1.9\times10^{-8}\,(TOC)^2 + 0.784\,(salinity) - 0.00125\,(salinity)^2 - 2.031x10^{-5}\,(TOC)\,(salinity).$$

Schimmel *et al.* (1993, B-3) divided the observed number of species by the expected number of species predicted by this equation.

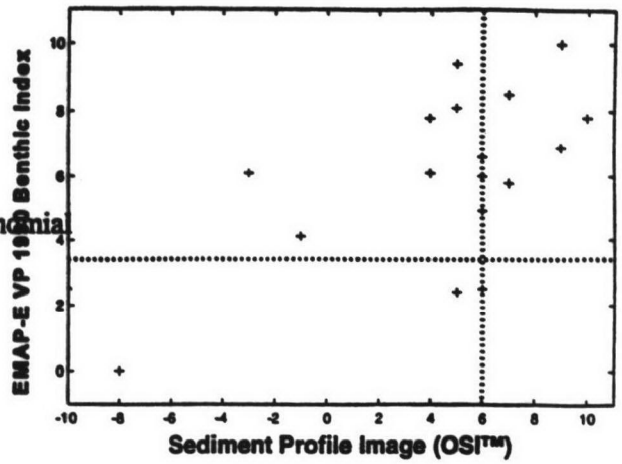


Figure 4. The value of the 1990 EMAP-E VP benthic index vs. *that calculated using Rhoads and Germano's (1986) Sediment-Profile-Image Organism-Sediment Index. The thresholds between degraded and non-degraded are indicated. The two indices are correlated (Kendall's τ=0.326, prob<0.044). However, when these ordinal data are converted to nominal "good-bad", or "degraded-nondegraded" classes, the concordance between indices is non-significant.*

Schimmel *et al.* (1994) created a test data set and ran a series of discriminant analyses. The TOC/salinity adjusted species richness measure was less effective at discriminating between degraded and reference conditions than unadjusted species number.

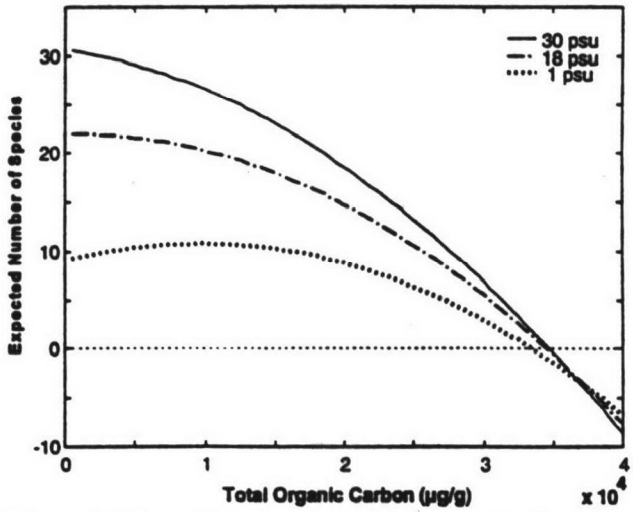


Figure 5 The salinity and Total Organic Carbon normalization used by Schimmel et al. (1994) in developing the 1991 EMAP-E biotic index is plotted. The expected number of species continues to decline, reaching about -150 expected species at 8 x 10^4 µg/g (8%) Total Organic Carbon.

Schimmel *et al.* 's (1994) EMAP-E VP 1991 benthic degradation index is shown below. The only negative term in the 1991 benthic index is the abundance of a set of opportunistic species. The list of opportunistic species is not provided.

1991 Benthic Index
Schimmel et al. (1994)

$$BI =$$
$$- 0.68 * \textit{Mean Abundance of Opportunistic Species}$$
$$+ 0.36 * \textit{Biomass / Abundance Ratio for all Species}$$
$$+ 1.14 * \textit{Mean Number Infaunal Species per Grab.}$$

BI < -0.5 INDICATES DEGRADED

Strobel *et al.* (1994) used the 1991 Benthic Index to analyze analyze the 1992 EMAP-E VP data. The only change made in the 1992 Benthic Index was to add 0.5 so that a BI score less than 0 indicated degraded.

Summers *et al.* (1993) developed a benthic index for the EMAP-E Louisianian Province (EMAP-E LP). Their index included a correction for the effects of salinity on species richness

EMAP-LP's* 1992 *Benthic Index
$$BI = + 2.3841 * \textit{Proportion of Expected Diversity}$$
$$- 1.6728 * \textit{Percent of Tubificid Abundance}$$
$$+ 0.6683 * \textit{Percent of Bivalve Abundance.}$$

BI < 4.1 INDICATES DEGRADED.

Strobel *et al.* (1995) reevaluated Schimmel *et al.*'s (1994) 1991 Index in their statistical analysis of all four years of EMAP-E VP benthic data. Strobel *et al.*'s (1995) rejected the Schimmel *et al.* (1994) benthic index. Their new 1990-1993 Index, shown at the right is based on all four years of EMAP-E VP sampling. It is based on a set of thirty degraded and thirty reference sites. They do not list these sites in their report. Presumably, many of these degraded and reference sites are the same as those listed in Schimmel *et al.* (1994).

1990-1993 *Benthic Index*
Strobel et al.(1995)

$$BI =$$
$$+ 1.389 * \frac{\textit{\% Expected Gleason's D} - 51.5}{28.4}$$
$$- 0.651 * \frac{\textit{Normalized tubificid abundance} - 28.2}{119.5}$$
$$- 0.375 * \frac{\textit{Spionid abundance} - 20.0}{45.4}.$$

where,

$$\textit{\% expected Gleason's D} = \frac{\textit{Gleason's D}}{(4.283 - 0.498 * \textit{salinity} + 0.0542 * \textit{salinity}^2 - 0.00103 * \textit{salinity}^3) * 100.}$$

$$\textit{Gleason's D} = \frac{S}{\ln N}.$$

S = Number of species.
N = Number of individuals.
$$\textit{Normalized tubificid abundance} = \textit{Tubificids} - 500 * e^{-15 * \textit{salinity}}.$$

BI < 0 INDICATES DEGRADED.

The 1990-1993 index includes two forms of salinity normalization. Salinity must be entered in psu for the polynomial fit (*e.g.*, 0 to 30 psu) and must be entered in decimal form for the tubificid normalization (0 to 0.030). Gleason's D diversity is

fit to a polynomial equation. Figure 6 shows a display of the Gleason's D diversity per three grabs *vs.* salinity. The lack of fit isn't too surprising. We deleted hundreds of invalid taxa from the EMAP-E VP data set, including perhaps one hundred taxa included in the EMAP-E VP analyses. Also, it is not clear from Strobel *et al.* (1995) how they were calculating Gleason's D. Gleason's D can be calculated several different ways.

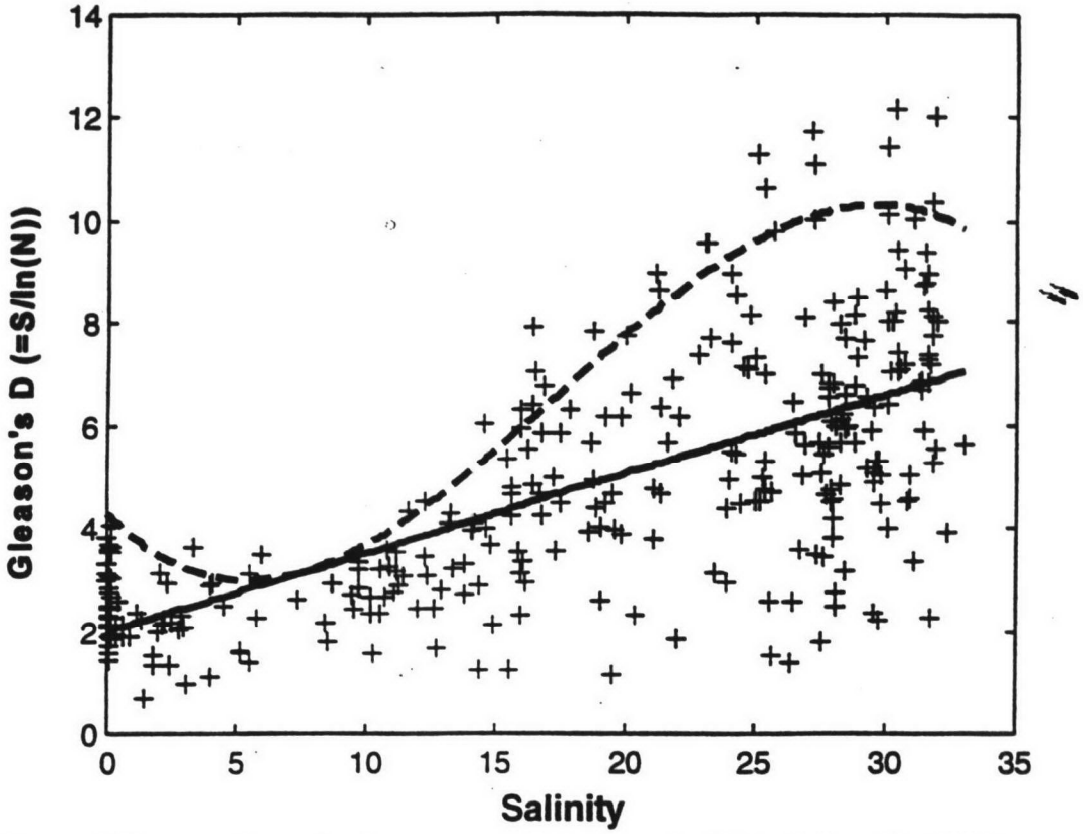


***Figure 6** Gleason's D species diversity* vs. *salinity plotted with Strobel et al.'s (1995) salinity normalization used in the 1990-1993 EMAP-E VP degradation index. The solid line is a linear regression fit; the dotted line is the 2nd order polynomianl fit from Strobel et* al. (1995). The R^2 for the linear regression is 47.2%. Note *that we use only a subset of species used by Strobel* et al. *(1995) and we deleted many individuals used by Strobel et al.* (1995).

Are these benthic indices adequate?

Are the benthic communities of the Virginian Province being properly assessed by the EMAP-E VP degradation indices? In the four major statistical summaries of the EMAP-E VP data, there are statistical summaries of the percentage of the area in the province that is degraded. Table 1 shows these values with 95% confidence limits

Table 1. Percentage of the Virginian Province classfied as "degraded" using biotic indices. Also shown for the 1990-1993 data are percentages of the Province with low bottom dissolved oxygen (≤2 mg/L), toxicity (amphipod survival less than 80% of controls), and sediment contaminant levels (any inorganic or organic contaminant >ER-M, using Long *et al.* 1995).

INDEX		LARGE ESTUARIES	LARGE TIDAL RIVERS	SMALL ESTUARINE SYSTEMS	OVERALL
1990 Index Weisberg *et al.* (1993, p. 5-16)		20 ± 8	46 ± 32	23 ± 14	23 ± 7
1991Index (Combined 1990-1991 data) Schimmel *et al.* (1994, p. 18, 71)		**6 ± 7**	27 ± 14	32 ± 17	**14 ± 6**
1992 Index Strobel *et al.* (1994, p. 59)		10 ± 10	37 ± 22	23 ± 12	14 ± 6
1990-1993 Summary Strobel *et al.* (1995)	**Biotic Index < 0**	**18 ± 4**	**33 ± 14**	**35 ± 6**	**23 ± 3**
	Bottom DO≤2 mg/L	6 ± 2	10 ± 6	0.2 ± 1.3	5 ± 2
	Toxicity (<80% control)	10 ± 3	3 ± 4	12 ± 6	10 ± 2
	Any analyte (organic or inorganic) > ER-M	5 ± 2	14 ± 6	5 ± 2	6 ± 2

How are we to interpret the results in Table 1? First, a comparison of the final four rows indicates that the biotic condition index is identifying degraded conditions in a much higher percentage of the Province than the abiotic condition indicators (DO, toxicity, and sediment contaminants). Also, the major biotic condition indices have produced significantly different estimates of the proportion of the Province that has degraded benthos. For example, Schimmel *et al.* (1994) concluded using the first two years of EMAP-E VP data that 14 ± 6% of the Virginian Province was degraded. Strobel *et al.* (1995) used the same data plus two additional years of data to conclude that 23 ± 3 % of the Virginian Province was degraded. What could account for this large, significant increase in degradation in such a short period? As noted by Strobel *et al.* (1995), the indices used to evaluate the 1990-1991 data are very different from those used to evaluate the 1990-1993 data set. The definition of 'degradation' hasn't changed much in any of the EMAP-E VP indices. Strobel *et al.* (1995) used the newer Long *et al.* (1995) ER-M levels to define degradaded stations for the test data set and noted that the new ER-M values were higher for metals resulting in a significant reduction in the percent area of the Province in exceedence. The differences in the estimates must be based on the differences in the equations used to determine degradation. The success of the EMAP-E program must be judged, in part, on the accuracy of the biotic indices. Is nearly one quarter of the Province's benthos degraded, even though no more than 8% of the Province has contaminant levels in excess of Long *et al.'s* (1995) ER-M values? There are major problems with the three major benthic indices developed in the EMAP-E VP program. We list the problems and discuss them in the following subsections. These problems are:

- **The validation problem.** The indices appear to work with the test data sets on which they are based, but fail when new sets of degraded and reference stations are added.
- **The "good-bad" dichotomy.** The degradation indices are based on a linear discriminant function derived from test data sets that are supposed to represent degraded and reference benthic communities. Some of the degraded benthic stations may not be degraded and some of the reference benthic stations may be impacted. The EMAP-E VP benthic degradation indices begs one of the major questions that the entire EMAP program was designed to assess: Is impacted benthic community structure a result of pollution?
- **Inconsitencies with basic benthic ecology.** Many of the variables used in the EMAP-E VP degradation indices are inconsistent with basic principles of benthic ecology.
- **Inadequate data and documentation.** All but the 1990 benthic index are inadequately documented. The list of opportunistic taxa used in the 1991 and 1992 biotic indices is not provided. One of the three terms in the 1990-1993 biotic index is based on a taxon which was not identified in most of the EMAP-E VP data.

The validation problem

The first problem, noted in EMAP-E VP reports, is that the indices developed for one year of data misclassify too high a percentage of new stations that are added in subsequent years. The 1990 index failed to discriminate between reference and degraded sites sampled in 1991. The 1991-1992 indices failed to successfully discriminate between reference and degraded sites identified in the full four-year EMAP-E VP data. The only EMAP-E VP index that was used in more than one annual statistical report was the 1991 EMAP-E VP biotic index (Schimmel *et al.* 1993). This index was used by Strobel *et al.* (1994) to describe the 1992 EMAP-E VP data. Strobel *et al.* (1995) rejected the 1991 index in their analysis of all four years of EMAP-E VP data. The only index that has not been rejected within the EMAP-E VP program is the Strobel *et al.* (1995) 1990-1993 biotic index.

The "good-bad" dichotomy.

The major weakness in the EMAP-E VP macroinfaunal analyses is the reliance on the assumption that benthic samples can be unambiguously classified using only two classes: degraded and reference. A review panel, convened by the Estuarine Research Foundation (Schubel *et al.* 1992, p. 5), raised this concern at an early stage of the EMAP-E program, stating that the EMAP-E program needed to modifiy "the 'black' and 'white', 'good' and 'bad', binary characterization of ecological/environmental conditions." This review panel concluded:

> *"We are concerned that EMAP-E may have unecessarily compromised its ability to achieve its goals by an overly simplistic (binary) approach to defining environmental quality as either "good" or "bad." Environmental quality is a continuum and society's definitions of "good" and "bad", "acceptable" and "unacceptable", "nominal" and "subnominal" may -- and indeed do -- change as knowledge of natural conditions increases, as management approaches and philosophies become more sophisticated and as society's priorities change."* Schubel *et al.* (1992, p. 28)

The EMAP-E VP degraded *vs.* reference dichotomy is poorly defined. An EMAP-E VP site is degraded if it is more similar to a set of degraded sites than it is to a set of reference sites. This similarity is based on the value of three variables in the latest 1990-1993 benthic index.. The EMAP-E VP program selected degraded and non-degraded reference sites using three criteria: dissolved oxygen concentration, sediment contaminant level, and short-term amphipod survival. As Table 1 shows, even

though abiotic indices (ER-M, DO, and amphipod survival) were used to define the "degraded" test data set, the biotic indices identified a much larger percentage of the Virginian Province as being degraded than the abiotic indices. The major reason for this is the black-white dichotomy inherent in the linear discriminant function. The 1990-1993 index chose an equal number of impacted and reference sites for the test data set (Strobel *et al.* 1995, p. A-12) and the classification of other sites was based on their 'nearness' to one of these two endpoints. If only 10% of the Virginian Province had pollutant concentrations or low dissolved oxygen that could impact benthic communities, and yet 50% of the test data set was composed of these stations, then the discriminant function would tend to classify too many sites as being degraded even if the assumptions of the discriminant analysis were set. For example, a discriminant analysis could be performed with one group consisting of thirty NBA All-Stars, and another group of equal size drawn randomly from the general population. The EMAP-E VP discriminant function was based on twenty-eight variables measured from the two groups (Weisberg *et al.* 1993, p. 4-17; Schimmel *et al.* 1994, p. B-3). If a similar number of variables were measured on the NBA All-Stars and on the general public, a linear discriminant function would undoubtedly identify some of the properties necessary to play in the NBA (*e.g.*, height, jumping ability, reflexes, and big hands). This discriminant function could then be used to divide the US population into two groups: NBA caliber, and not-NBA caliber. It is obvious that such a good-bad approach would produce a tremendous overestimate of the percentage of the US population that might be of NBA caliber. A similar problem may exist in the EMAP-E VP linear discriminant function. If the degraded stations are greatly overrepresented in the test data sets, then the function will overestimate the percentage of area that is impacted. The EMAP-E VP investigators can set the *a priori* Bayesian expectations for the classification frequencies expected from the discriminant analysis to reduce the probability of misclassification, but there is no documentation that they have done so.

The major assumption of discriminant analysis is the equality of variance-covariance matrices. What does this mean? It means that the variables used in the discriminant analysis should have the same scale of variation in the groups being discriminated. Discriminant analysis is designed to classify by differences in the mean values of discriminating variables, not their variance. Many of the variables used in the EMAP-E VP indices clearly violate this assumption. In the 1990-1993 index the first term is expected Gleason's D, adjusted for salinity. As shown in Figure 6, the variance in this species richness index will be much higher in the high salinity areas of the EMAP-E VP province.

There is another serious problem with the existing EMAP-E VP indices. There is no independent evidence that the degraded and reference groups in the EMAP-E VP data are really degraded or non-degraded. Sediment contaminant level is judged by ER-M and ER-L concentrations (Long & Morgan 1990, Long *et al.* 1995). These ER-M concentrations, which represent the concentrations at which 50% of the studies demonstrated some adverse biological effect are tabulated for a wide variety of organic and inorganic pollutants. There was little theoretical justification for these ER-M and ER-L concentrations. Long and Morgan (1990) and Long *et al.* (1995) determine their ER-M values by simply sorting existing environmental and biological data to find the median pollutant concentration at which any biological effect was observed. They considered a number of biological effects, including changes in benthic community structure. Thus, only half the samples containing a given pollutant at or above the ER-M level showed some kind of biological effect indicative of degradation. Long and Morgan (1990) did not assess the covariation among environmental variables or formally analyze the causal connection between a given pollutant variable and the biological effect observed. Other branches of the EPA and state agencies have been reluctant to codify the ER-M levels into regulations. DiToro *et al.* (1990, 1991, 1992) review alternate approaches for establishing sediment pollutant criteria. Strobel *et al.* (1995, p. 48-51) provide a nice summary of alternate approaches to estimated sediment contaminant levels. If the sediment acid volatile sulfide concentrations or organic carbon concentrations are high, a metal in excess of the ER-M level may have little significant biological

effect. Thus, only about 50% of the sites in the Virginian Province with pollutant concentrations in excess of ER-M are predicted to have significant biological effects, and this percentage might be lower if the SEM/AVS ratios are used (Strobel *et al.* 1995, p. 48).

The EMAP-E VP program does not provide an assessment of degraded community structure due to pollutants independent of the abiotic indicators. One of the stated goals of the EMAP program in all ecosystems was to develop indices of impacted community structure or biological effects independent of toxic loads or abiotic stressors. Ecologists were to identify samples or areas showing impacted patterns of community structure, and the assessment portion of the EMAP program was to determine whether these impacts could be due to pollution. The EMAP-E VP program begged this vital question, by assuming that sites with sediment contaminants in excess of ER-M, low dissolved oxygen, or significant amphipod toxicity, must have degraded benthic communities. The EMAP-E VP program did not develop an independent set of criteria to determine whether the patterns of community structure in the degraded sites were indeed degraded. It is entirely possible, and likely, that sites in the Virginian Province could have multiple sediment contaminants in excess of the ER-M thresholds and yet have no significant departures from 'reference' patterns of benthic community structure. The contaminants might be unavailable (*e.g.*, bound to sulfides or organic carbon), and dissolved oxygen concentrations of 2 mg/L in the overlying water might be more than adequate for benthic respiration.

More importantly the EMAP-E VP investigators chose "reference" sites using dissolved oxygen concentration, ER-L concnetrations and amphipod toxicity. Again, toxicologists and environmental regulators, including the EPA have been reluctant to embrace the Long and Morgan ER-L levels as indicators of 'clean' sediments. The dissolved oxygen concentration one meter above the bottom does not mean that the sediments are adequately oxygenated. In fact, due to the physics of the benthic boundary layer, anoxic sediments can be associated with very high oxygen levels even centimeters above the bed. Finally, benthic communities with adequate dissolved oxygen one meter above the bed and low pollutant concentrations can still have patterns of community structure indicating recent disturbance or impact. Physical disturbance by other processes — storms, predators, disruption by fishing nets, and red tides, drifting macroalgae — can all produce patterns in community structure that indicate recent disturbance. Many of these patterns of disturbance mimic the effects of pollution. For example, the frequencies of opportunistic taxa increase, species richness declines, species evenness declines, and infaunal abundance levels change. The EMAP-E VP program developed no independent criteria to detect these 'natural' impacts.

Inconsitencies with basic benthic ecology

The third problem with the indices is that they are inconsistent with basic benthic community ecology. The 1990 index (Weisberg *et al.* 1993) predicts that the more capitellid polychaetes, the more likely a site is to be classified as non-degraded. Members of the genus *Capitella* spp. are generally regarded as pollution indicators (*e.g.*, Grassle & Grassle 1974, Pearson and Rosenberg 1978, Grassle and Grassle 1985). Grassle and Grassle (1976) showed that the species formerly known as *Capitella capitata* is a sibling species complex. Most if not all of these sibling species are found in areas high concentrations of utilizable organic carbon. However, the genus *Capitella* is rare in the EMAP-E VP data. *Capitella* is found in only about ninety of the nearly two thousand EMAP-E VP samples. Moreover, it is not particularly abundant in any of those samples.

One reason why 'capitellid polychaetes' may have been important in the 1990 index is that the capitellid *Mediomastus ambiseta* is the most abundant and wide-spread taxon in the entire Virginian Province. *Mediomastus ambiseta* can be found in salinities ranging from 10 psu through 35 psu. Diaz and Schaffner's (1990) summarized the benthic species characteristic of different salinity and grain

size habitats in Chesapeake Bay. They found that *M. ambiseta* reaches peak abundance in high mesohaline (10-18 psu salinity) muds and mixed mud and sand habitats. However, *M. ambiseta* is often the numerical dominant in high salinity coastal waters. Fuller *et al.* (1988) found *M. ambiseta* was the numerical dominant in Buzzards Bay, reaching abundances of 720,000 m^{-2} in outer New Bedford Harbor. This species would be a poor choice as an indicator of pristine, unpolluted sites. Grassle & Grassle (1985) review the use of *M. ambiseta* as a pollution indicator. Grassle *et al.* (1986) observed *M. ambiseta* increase dramatically in response to eutrophication. Grassle *et al.* (1988) added sewage-sludge to the MERL tanks and again observed substantial increases in the abundance and frequency of *M. ambiseta*. Grassle *et al.* (1981) observed that *M. ambiseta* was the taxon that declined most sharply with the addition of 90 ng/g #2 fuel oil in the MERL ecosystem tanks. Using *M. ambiseta* as an indicator of high petroleum hydrocarbon concentrations in sediments is unwise, since *M. ambiseta* increased dramatically in abundance in heavily oiled offshore stations after the West Falmouth oilspill (Grassle and Smith 1976, Sanders *et al.* 1980). It is very difficult to provide any ecological basis for assuming that more capitellids indicates a lower probability of degradation.

There are two major problems with the Schimmel *et al.* (1994) 1991 biotic index . They used the mean number of species per grab as a discriminating variable. As Weisberg *et al.* (1993, Fig. 4-2) showed, salinity has a profound effect on species richness. We show the strong effect of salinity on species richness in Figure 3 (p. 13) Any index based on species richness which fails to take salinity into account will classify many non-degraded low-salinity sites as degraded. Strobel *et al.* (1995, p. A-12) noted this, stating that the 1991 Index is "highly correlated with salinity and appared to misclassify good sites in the oligohaline [<5 psu] and impacted sites in the meso- [5-18 psu] and polyhaline [>18 psu]."

The 1991 and 1992 biotic indices failed to incorporate a correction for the effects of salinity on species richness because they combined salinity with total organic carbon concentration (TOC) in the normalization. This was not a proper way to assess the covariation of salinity and diversity. Figure 5 (p. 14) shows the expected species at different TOC concentrations predicted by that function at three different salinities (1 psu, 18 psu, 30 psu). All EMAP-E VP samples with greater than 3.5% TOC are expected to have less than 0 species. Dividing observed by expected species number can produce high adjusted species richness values in the range 3 to 3.5% or negative species richness numbers if TOC is greater than 3.5%. Simultaneously normalizing TOC and salinity together was not a good idea.

Total organic carbon concentration in sediments is one of the best indicators of both contamination and eutrophication. It is not a natural environmental factor like salinity, temperature, or depth. Wallace *et al.* (1991) have shown that sediment total organic carbon concentration is tightly coupled with sediment heavy metal concentrations in Boston Harbor. The correlation is often 0.9 or higher. In Boston's Inner Harbor, sediments with TOC concentrations of about 3.3 % are either anoxic in the late summer or contain about six species per grab. Figure 5 (p. 14) shows that these sites would have 100% or more of the expected species richness expected at these organic carbon concentrations. Strobel *et al.* (1995, Figure 3-27) shows that TOC in the Virginian Province ranged from 0 to 7%, with roughly 10% of the Province having TOC concentrations greater than 3% organic carbon. By not adding a proper normalization for salinity, the 1991 and 1992 indices would be highly likely to classify non-degraded oligohaline sites as degraded, as Strobel *et al.* (1995) noted.

The 1990-1993 Index , shown on p. 15, was developed by Strobel *et al.* (1995). This index has three terms: salinity-normalized Gleason's D species richness, spionid abundance, and salinity-adjusted tubificid oligochaete abundance. We will discuss each term of the equation.

The 1990-1993 index, like Weisberg *et al.*'s (1993) Index, normalizes species diversity by salinity. Species diversity is calculated using Gleason's D (Gleason 1922). We show the relationship between Gleason's D and salinity in Figure 6 (p. 16). Washington (1984, p. 661) included Gleason's D for historical purposes only, noting that it "has not been used extensively in the recent literature, being replaced by Margalef's." Gleason's D has some very poor statistical properties (as does Margalef's index). Imagine a situation where all of the individuals in the sediments are independently Poisson distributed (*i.e.*, randomly placed). Gleason's D, the number of species divided by the natural log of the number of individuals, is one of the only diversity indices listed in Washington (1984) that declines as larger samples (either by area or numbers) are collected. Margalef's index also declines with increasing sample size. Most other indices either remain the same (H, H', $E(S_n)$) or increase (total species) with increasing sample size. Even with a fixed sample area, this sample-size dependence is a serious problem. In two grabs containing an identical number of species, with identical frequencies, Gleason's D will find that the sample with the lowest abundance has the highest diversity.

The final two terms of the 1990-1993 index are based on spionid abundance and tubificid oligochaete abundance, the latter scaled by salinity. It is difficult to assess this index using the existing EMAP-E VP publications. Oligochaetes were never identified below Class Oligochaeta in samples collected from areas where bottom salinity was greater than 5 psu. We are assuming that Strobel *et al.* (1995) are following Weisberg *et al.* (1993, p. 2-12) in assuming that most oligochaetes in habitats with salinities > 5 psu are tubificids. This is not true, but given the assumption that most marine oligochaetes are tubificids, we can calculate how many tubificids and spionids per m^2 are sufficient to produce a classification of "degraded" if the Gleason's D diversity is 100% of the expected value. Figure 7 plots this relationship. If a sample has 100% of the expected Gleason's D diversity, then observing more than 7000 spionids per m^2 at 30 psu salinity indicates that a sample is degraded. Observing 17000 tubificids per m^2 at 30 psu indicates degradation. Fewer tubificids are required to indicate degradation at lower salinities.

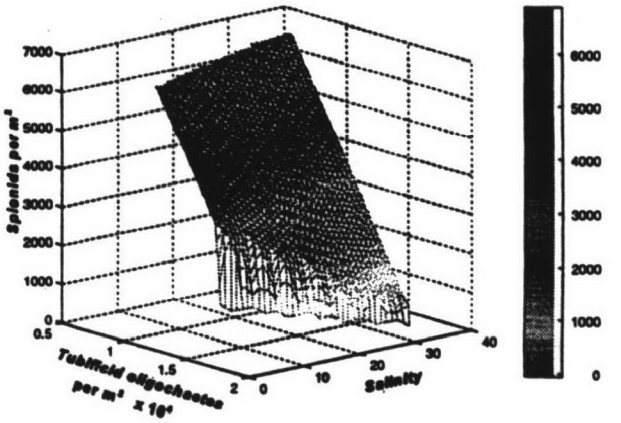


Figure 7 The 1990-1993 EMAP-E VP index (p. 15) was recast to predict the number of tubificid oligochaetes and spionid polychaetes necessary to equal 100% of the expected Gleason's D diversity at salinities from 0 to 35 psu (plotted in Fig. 6, p. 16). A sample with 100% Gleason's D diversity that plots to the right or above this veil would be classified as degraded. At 30 psu, 7000 spionids per m^2 or 17,000 tubificids per m^2 indicates degradation.

Spionid polychaetes are a species-rich successful family of polychaete worms. There are a handful of spionid polychaete species that have been used as pollution indicators, most notably *Streblospio benedicti* and *Polydora cornuta*. However, both of these species are natural components of shallow or mesohaline habitats in the Virginian province. Dauer *et al.* (1981) reviews the factors controlling the distribution and abundance of the six major spionid species in Chesapeake Bay. Members of the polychaete family Spionida are among the most important members of the Chesapeake Bay benthos in all sediment types and most salinities. The family Spionidae cannot be used as a pollution indicator. Spionids are among the most abundant surface deposit and suspension feeding organisms in habitats ranging from the intertidal zone to the deep sea. The abundance of individuals belonging to this polychaete family does not indicate either pollution or disturbance. The 1990-1993 index sets a 5000-

7000 spionid per m^2 threshold for degradation (Fig. 7) and would classify many pristine areas as degraded.

Inadequate taxonomic data and documentation

One of the three terms in the 1990-1993 Index is based on the abundance of tubificid oligochaetes. This family of organisms was never identified in samples collected in areas with more than 5 psu. The only variable in the EMAP-E VP for these samples is the number of individuals of Class Oligochaeta. In evaluating this index, we assumed that Strobel *et al.* (1995) followed Weisberg *et al.* (1993) in arguing that most oligochaetes in marine waters are tubificids. This assumption may not be true. If only individuals properly identified as tubificids are used, then all marine samples automatically have 0 tubificid abundance and after scaling, the second term in the 1990-1993 benthic degradation index (p. 15) becomes positive. We would not recommend basing one of the three terms of the biotic index on a variable that was not measured in the majority of stations.

It is difficult to evaluate the 1991 index, because it is based on the abundance of opportunistic polychaetes. The list of species considered to be opportunistic is not provided in any of the EMAP-E reports.

Community Structure Analyses of Virginian Province

The 1918 samples in the full EMAP data set were analyzed using COMPAH and PCA-H. A subset of the full data set was created. This subset contained all samples for which salinity data existed and which had infaunal abundances greater than 25 individuals. Replicate grabs from each sampling event were summed and used only if the maximum CNESS distance among the three replicates was less than 0.7. We used only base sampling sites represented by three replicate grabs in this analysis. A CNESS value of 0.7 indicates tremendous differences in community structure. Only 371 'sampling events' in the full EMAP data set met both the CNESS cutoff and salinity criteria.

Diversity analyses

In this section we will evaluate the correlations among diversity indices using the EMAP-E VP data, and the covariation of diversity with salinity. Of the diversity indices that might be used in the EMAP-E VP program, the two with the richest body of theory are Shannon's H' and Hurlbert's expected number of species $E(S_n)$. $E(S_{10})$ is the expected number of species if 10 individuals are drawn at random from a sample. Peet (1974) and Smith *et al.* (1979a) showed that Hurlbert's $E(S_{10})$ is highly correlated with the Shannon's H' diversity index. Figure 8 shows this relationship.

Either $E(S_{10})$ or H' would provide an assessment of diversity of EMAP-E VP samples. However, both of these indices are

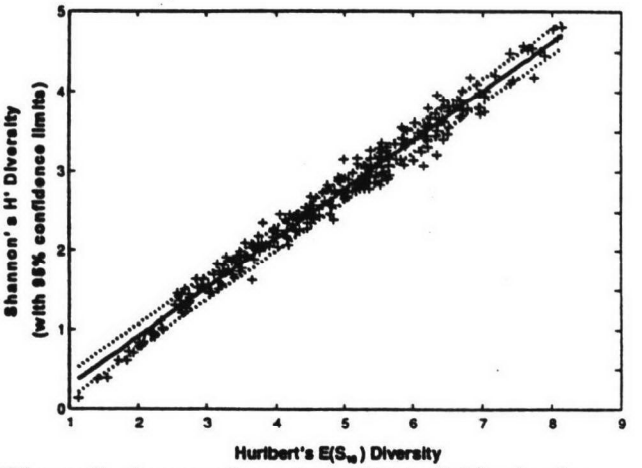


Figure 8. At a random size of 10 individuals, the Sanders-Hurlbert expected number of species $E(S_n)$ is highly correlated with Shannon's H' diversity. The above shows the association with EMAP-E data (all 4 years, replicates combined). The R^2 is 97.8%. The 95% confidence limits are based on 3 replicate grabs.

sensitive to the evenness component of diversity and neither one is particularly sensitive to species richness. At a larger random sample size, $E(S_n)$ becomes increasingly sensitive to species richness. The relationship between $E(S_{10})$ and total species per event is shown in Figure 9. A nearly identical pattern (but with a different scale) is found when Shannon's H' is plotted versus total species. $E(S_{10})$ is correlated with Total species per event (Figure 9), but the two diversity indices are obviously measuring different components of species diversity. It is possible to have a sampling site with over 60 species collected in 3 grabs that would have a species diversity much lower than the median ($E(S_{10})<5$). This pattern would be expected if one or a few species made up most of the individuals in a sample.

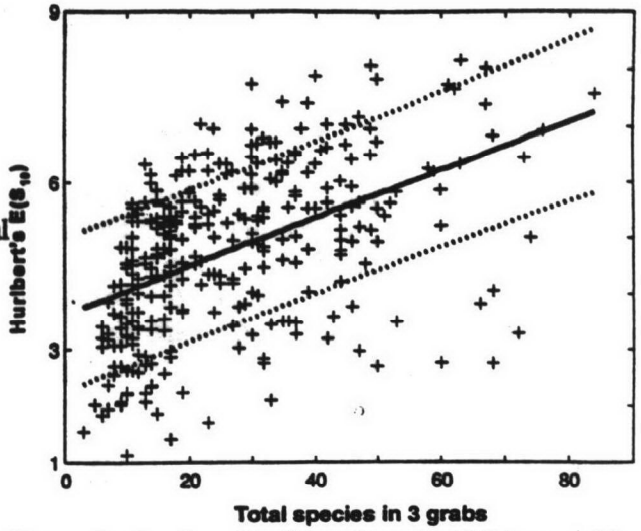


Figure 9. Sanders-Hurlbert diversity $E(S_n)$ at n=10 is only weakly correlated with species per sampling event (R^2=23.1%). The 95% confidence limit is based on 3 replicates.

Neither $E(S_{10})$ nor Shannon's H' are strongly correlated with Gleason's D diversity (Figure 10).

We have performed an analysis that shows at a glance the correlations among the major diversity indices and Hurlbert's $E(S_n)$ with increasing sample size. The diversity of the 371 EMAP-E VP event data set was analyzed using four different diversity indices. The nonparametric correlation between the ranked diversity was compared with the $E(S_n)$ diversity with n ranging from 2 to 200. $E(S_2)$ is Simpson's diversity+1. At larger random sample sizes, $E(S_n)$ becomes more strongly correlated with both Gleason's D and total number of species per sampling event (Figure 11). Figure 11 clearly shows that there is no universal index of diversity. Gleason's D clearly falls in the class of indices that are more heavily influenced by species richness.

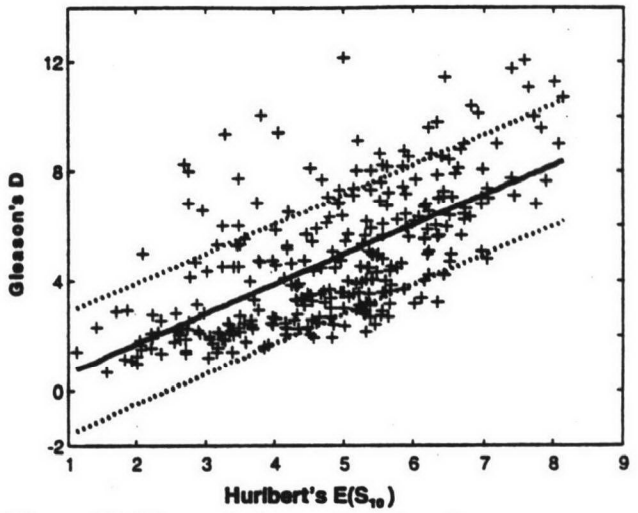


Figure 10 Gleason's D species diversity vs. Hurlbert's $E(S_{10})$. The 95% confidence limits for 3 replicates are shown.

Shannon's H' is sensitive to species richness, but it is also strongly influenced by species evenness. In a later section we will review the effects of pollution on diversity. Pollution and disturbance can affect both the richness and diversity components of diversity. One virtue of analyzing the effects of pollution in the EMAP-E Virginian Province using the evenness component of diversity is that it shows virtually no statistical association with salinity (Figure 12).

Sanders-Hurlbert $E(S_{10})$ is positively correlated with salinity (Figure 13), but this relationship is much weaker than either the correlation between total species and salinity (Figure 3, p. 13) or Gleason's D

and salinity (Figure 6, p. 16). At this random sample size, $E(S_{10})$ is sensitive to both the species richness and evenness components of diversity.

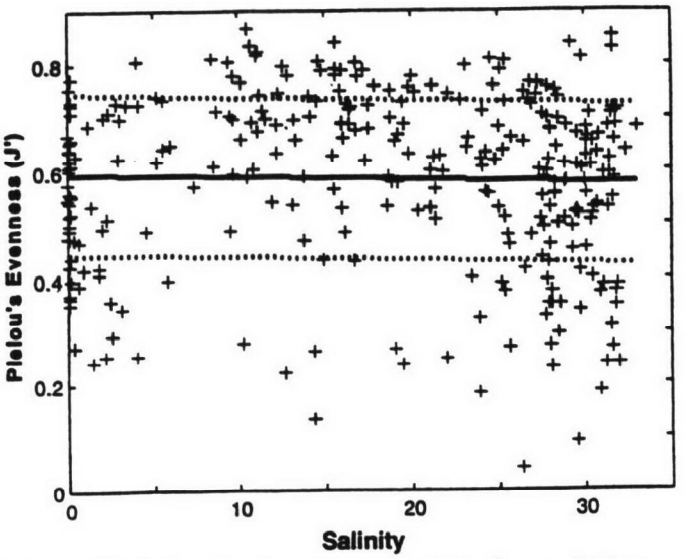


Figure 11. There is virtually no statistical association between species evenness, as estimated by J', the evenness measure for Shannon's H', and salinity (R^2=0.2%).

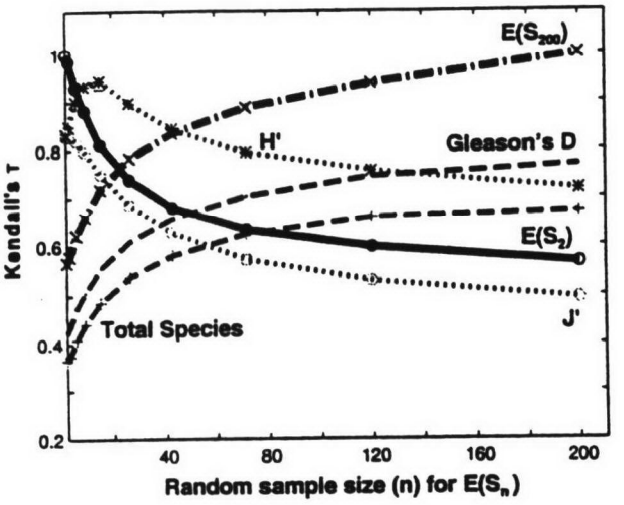


Figure 12. The nonparametric Kendall's τ correlation between Sanders-Hurlbert diversity $E(S_n)$ at various random sample sizes, n, is plotted versus other diversity indices. Brillouin's H (not shown) plots just below the line for Shannon's H'. $E(S_{200})$ is the largest n shown. At small n, $E(S_n)$ is sensitive to both species richness and evenness. At high n, $E(S_n)$ is more strongly associated with species richness. $E(S_n)$ is highly correlated with H' at n=10 (see Figure 8).

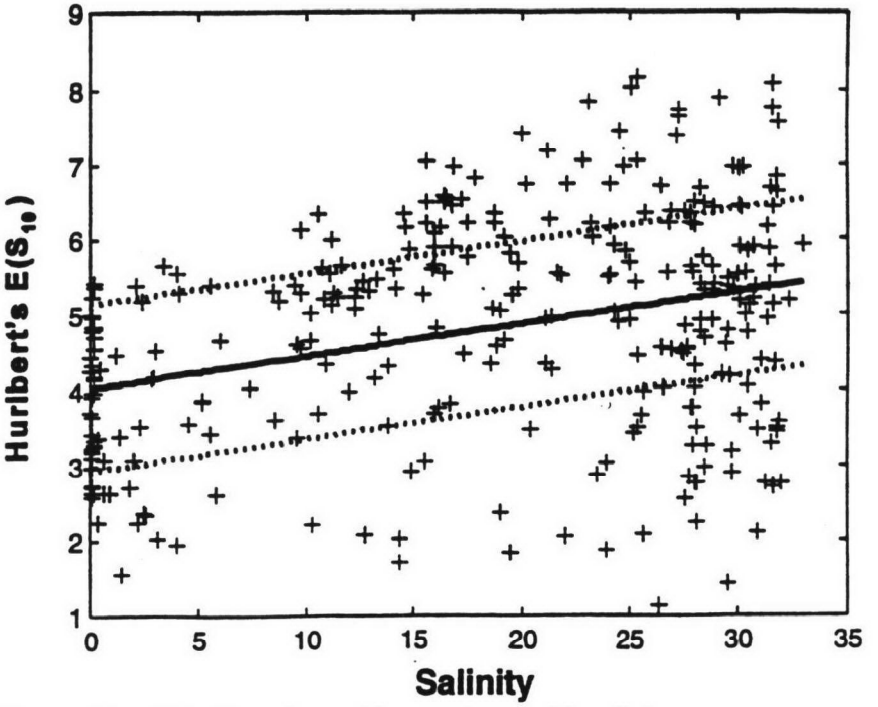


Figure 13. $E(S_{10})$ is only weakly correlated with salinity.

Cluster analysis

Sample clusters

The large sample cluster analysis of all four years of EMAP-E VP data is found in Appendix IV. The major pattern in the data set is the clear break between all samples taken in the 0-5 psu salinity regime from the other mesohaline and oligohaline samples (5 to 35 psu). There is a further break among the higher salinity samples corresponding to a salinity of roughly 15 psu (not the 18 psu used in the stratification of degraded and clean reference sites in the creation of EMAP-E VP degradation indices).

There is a considerable amount of within-site, among-season and among-year variation in the EMAP-E VP data. In Appendix IV, two degraded and two clean reference sites are colored to show the extent of this variation. On a qualitative level, there appears to be as much variation among samples taken at the same site during different seasons (*e.g.*, New Bedford Harbor **099** sampled on August 15, 1990 and September 4, 1990) as there is between any difference between degraded vs. clean (using the criteria in Weisberg *et al.* 1993 and Schimmel *et al.* 1994). There appears to be as much variation at New Bedford site **099**, sampled during the same year but 3 weeks apart, as between any pair of estuarine stations (salinity > 5 psu) in the entire data set. It was impossible to analyze the full extent of within site variation relative to the degraded vs. non-degraded dichotomy since most of the 'degraded' samples, especially in the oligohaline and mesohaline portions of the Virginian Province, had fewer than 25 individuals per grab and were dropped from the analysis.

Species clusters

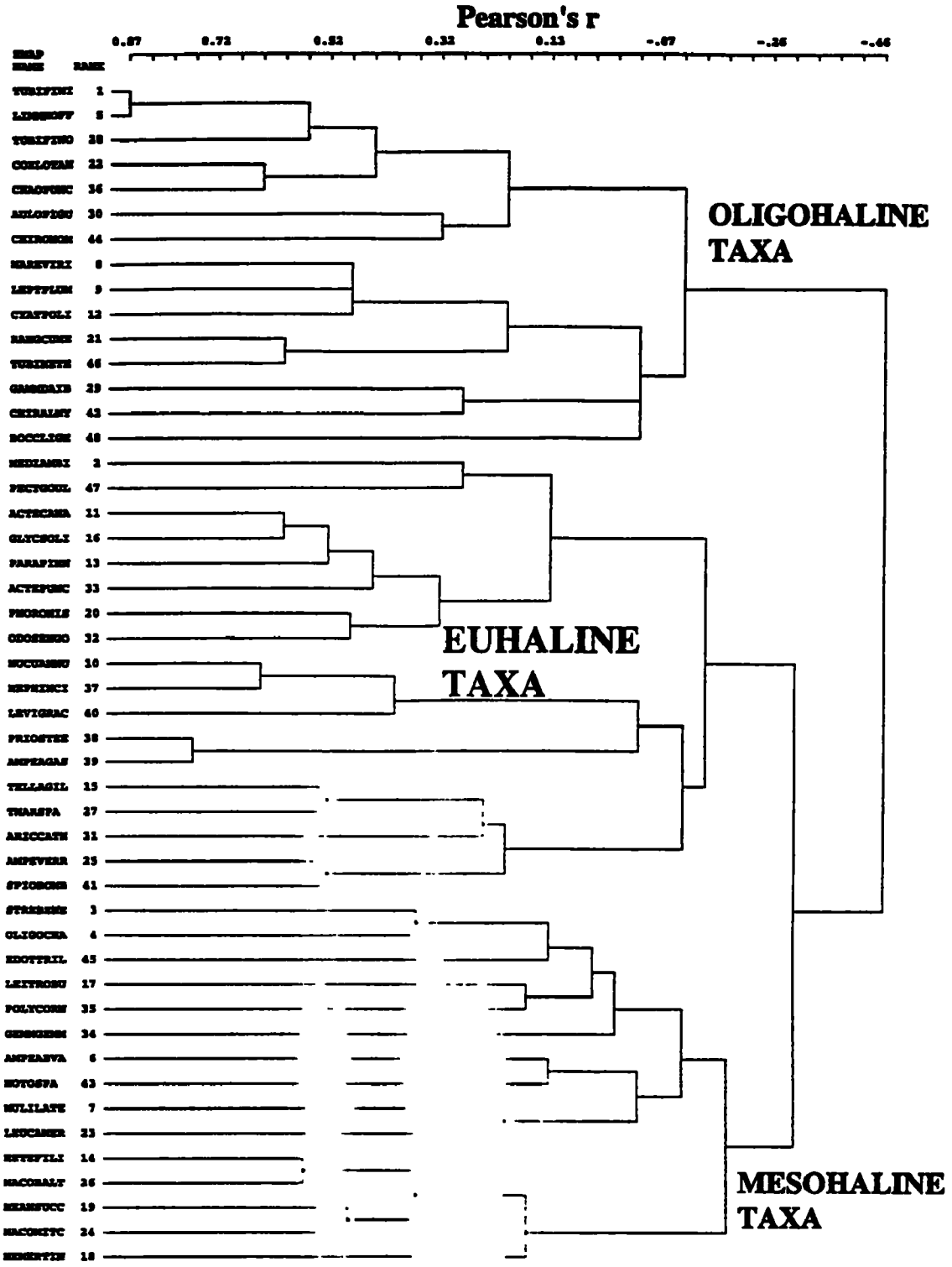
Clustering of species reveals three distinct groupings of species (Figure 14), roughly corresponding to the oligohaline, mesohaline, and euhaline habitats in the Virginian Province . All species that contributed at least 0.5% of the variation in the EMAP-E VP CNESS distances among stations are

shown. Within each of these large salinity-controlled groupings are groups that are characteristic of different grain sizes, biogeographic regions, and depths.

The low salinity species assemblage in Figure 14 consists of two sub groupings. The first subgrouping (**TUBIFWI** to **CHIRONOM**) are mainly taxa which could only be found in samples from 0-5 psu salinity, since they involve taxonomic designations not used for samples taken from areas higher than 5 psu salinity. The most important contributor to CNESS distances in the 1990-1993 EMAP-E VP data is the taxon **TUBIFIWI**, which is the EMAP-E VP code for **Tubificidae with capiliform chaetae** (see Appendix II for translations for the EMAP-E VP species codes). This group probably does not represent a single species. The fifth most important taxon is **LIMNHOFF**, *Limnodrilus hoffmeisteri*. **TUBIFWO**, the 28th most important contributor is another composite taxon; the EMAP-E VP species code stands for **Tubificidae without capiliform chaetae.**

The oligohaline species group also includes some very important macroinfaunal species. The spionid polychaete *Marenzelleria viridis* (**MAREVIRI**), formerly called *Scolecolepides viridis*, is the eighth most important contributor to CNESS distances in the Virginian Province. It tends to occur with the amphipod *Leptocheirus plumulosus* (**LEPTPLUM**) and the isopod *Cyathura polita* (**CYATPOLI**). These oligohaline to low mesohaline taxa tend to be geographically wide-spread in the Virginian Province. These latter three taxa are also abundant throughout the Gulf of Maine region (EMAP-E VP's Arcadian Province).

Figure 14. Cluster analysis of the 48 species that contribute most to CNESS (m=25) variation.



The euhaline species assemblage, shown in Figure 14, consists of two subgroupings. The most important species in the first grouping and the second most important taxon contributing to CNESS faunal distances in the entire Virginian Province is the capitellid polychaete *Mediomastus ambiseta* (MEDIAMBI). This head-down subsurface deposit feeder is also the most abundant taxon in the entire Virginian Province.

Included within the second euhaline species assemblage is the *Nucula annulata* (NUCUANNU), *Nephtys incisa* (NEPHINCI) group. These two taxa, tenth and thirty-seventh most important contributors to CNESS distance, are the classic indicator species for both Long Island Sound and Buzzards Bay infaunal communities (Sanders 1956, 1960). Sanders (1956), in his Yale Ph.D. dissertation, described the Long Island Sound benthos using the Petersen-Thorson descriptive designations as a *Nucula proxima - Nephtys incisa* community. Buzzards Bay was described as being a *Nucula proxima - Yoldia limatula - Nephtys incisa* community. *Yoldia limatula* (YOLDLIMA), a larger but less abundant protobranch bivalve, was not among the top forty-eight species contributing the CNESS distances, but is the first taxon to cluster with *Nucula annulata* in the species cluster analysis of all 551 EMAP-E VP taxa (Appendix V). Subsequent to Sanders' surveys of Long Island Sound and Buzzards Bay, Hampson (1971) found that there are two *Nucula* sibling species in the region: *Nucula proxima* dominates in nearshore fine sands and *Nucula annulata* dominates offshore muds. The two species have nearly allopatric distributions, and can be distinguished by the locations of the abductor muscles on the inside of the shells. Both have probably been combined in the EMAP-E VP designation NUCUANNU since the widespread and abundant taxon *Nucula proxima* is not among the EMAP-E VP species.

Within the second euhaline species assemblage are the tellinid bivalve *Tellina agilis* (TELLAGIL), the cirratulid polychaete *Tharyx sp. A* Morris (THARSPA), the paraonid polychaete *Arricidea catherinae* (ARICCATH), the ampeliscid amphipod *Ampelisca verrilli* (AMPEVERR), and the spionid polychaete *Spiophanes bombyx* (SPIOBOMB).

The mesohaline species assemblage, shown in Figure 14, also consists of two sub groupings. The mesohaline taxa include some of the most abundant and wide-spread taxa in the Virginian and Arcadian provinces. All of these taxa can be found in both the shallow subtidal zone (usually in intermediate salinities) and the intertidal zone. The spionid polychaete *Streblospio benedicti* Webster (STREBENE) is a typical numerical dominant in intertidal zones throughout the Virginian and Arcadian Provinces (*e.g.*, 1982, Trueblood *et al.* 1994, Diaz and Schaffner 1990). This spionid is the third most important contributor to the variance in CNESS distances among Virginian province samples. In the subtidal, *S. benedicti* dominates in areas of intermediate salinities (≈15-25 psu). The EMAP-E VP taxon with the highest affinity to this spionid is the class Oligochaeta (OLIGOCHA). This composite EMAP-E VP taxon is only used for samples having salinities greater than 5 psu, at lower salinities the oligochaetes are further divided into species and designations such as *Tubificoides* with capiliform setae (TUBIFIWI, see above). Also associated with this *Streblospio benedicti* - Oligochaete assemblage are other taxa characteristic of the intertidal zone, but which also can be very abundant in shallow subtidal mesohaline environments. These include the spionid polychaete *Polydora cornuta*, formerly called *P. ligni*, (POLYCORN), the orbiniid polychaete *Leitoscoloplos robustus* (LEITROBU), the isopod *Edotea triloba* (EDOTTRIL), and the venerid bivalve *Gemma gemma* (GEMMGEMM). Each of these taxa is abundant in intertidal and shallow subtidal mesohaline zones throughout the Virginian and Arcadian provinces.

Included in the first mesohaline species assemblage is the *Ampelisca abdita-Ampelisca vadorum* complex (AMPEABVA). This sibling species group is the third most abundant taxon in the Virginian province (1st in the NY/NJ REMAP data) and the sixth most important contributor to the variance in

CNESS distances among stations. *Ampelisca abdita* is the species used in the EMAP-E VP amphipod toxicity assays. *Ampelisca abdita* and *A. vadorum* constitute a sibling species complex (Mills 1967). Since the juveniles cannot be distinguished, the adults of both species are pooled with the juveniles in the EMAP-E VP taxon (**AMPEABVA**). This sibling species complex co-occurs with the capitellid polychaete Notomastus sp. A Ewing (**NOTOSPA**). The opportunistic mactrid bivalve *Mulinia lateralis* (**MULILATE**) is the seventh most important contributor to CNESS distances. It is weakly associated with the cumacean *Leucon americanus* (**LEUCAMER**).

The following mesohaline taxa form a well-defined assemblage, characteristic of slightly lower salinities than the remaining mesohaline taxa: the capitellid polychaete *Heteromastus filiformis* (**HETEFILI**), the opportunistic tellinid bivalve *Macoma balthica* (**MACOBALT**), the nereid polychaete *Neanthes succinea* (**NEANSUCC**), the tellinid bivalve *Macoma mitchelli* (**MACMITC**), and members of the class Nemertinea (**NEMERTIN**). Each of these taxa can be found in intertidal zones throughout the Virginian and Arcadian provinces, and thrive in lower mesohaline salinities in the lower subtidal.

Notable for its absence from the species cluster analysis in Figure 14 is the sibling species complex *Capitella*. Figure 14 contains only the most important contributors to CNESS distance, and *Capitella* is a minor component of the Virginian Province communities, being found in only eighty nine samples. As shown in Appendix V, the pollution-indicating *Capitella* sibling species complex appears to be just another relatively rare euhaline taxon. Surprisingly, the species with the highest affinity to *Capitella* in the full species cluster analysis (Appendix V) is the portunid crab *Ovalipes ocellatus* (**OVALOCEL**). Of the forty eight taxa shown in Figure 14, *Capitella* is associated most closely with the cirratulid polychaete *Tharyx* sp. A Morris (**THARSPA**).

PCA-H analysis

The first step in the PCA-H analysis was to determine a random sample size, or NESSm, for the CNESS faunal distance index. This random sample size should produce a faunal distance index that is sensitive to the contribution of both rare and abundant species in the community. A NESSm of approximately 20-25 produces an index that is highly correlated (tau > 0.8) with both CNESS (NESSm=1 or Orloci's chord distance) and CNESS (NESSm=100).

Figure 15 shows the Gabriel covariance biplot of species (Gabriel 1971). This is a different way of plotting the species data that were clustered in Figure 14. This figure shows the major species groups in the entire Virginian Province. Only those species that contributed at least 1% to the variation in community structure (measured by CNESS) are plotted. This figure shows the major gradient in species distributions as a function of salinity in the Virginian province. The cluster of species vectors at about 4 o'clock consists of species that were only identified in samples taken from less than 5 psu salinity areas. Oligochaetes, *Mulinia lateralis*, and *Streblospio benedicti* are all characteristic of intermediate salinities in the Virginian Province (about 15 psu). The spionid polychaete *Marenzelleria viridis*, the isopod *Cyathura polita*, and the aorid amphipod *Leptocheirus plumulosus* are characteristic of slightly lower salinities (5-10 psu). *Ampelisca abdita* and *A. vadorum* are associated with higher salinities. The key species indicating euhaline conditions in the Virginian province is the capitellid polychaete *Mediomastus ambiseta*. The final three species vectors represent Howard Sanders' classic Long Island Sound and Buzzards Bay *Nucula-Yoldia-Nephtys* incisa community (Sanders 1956 and 1960).

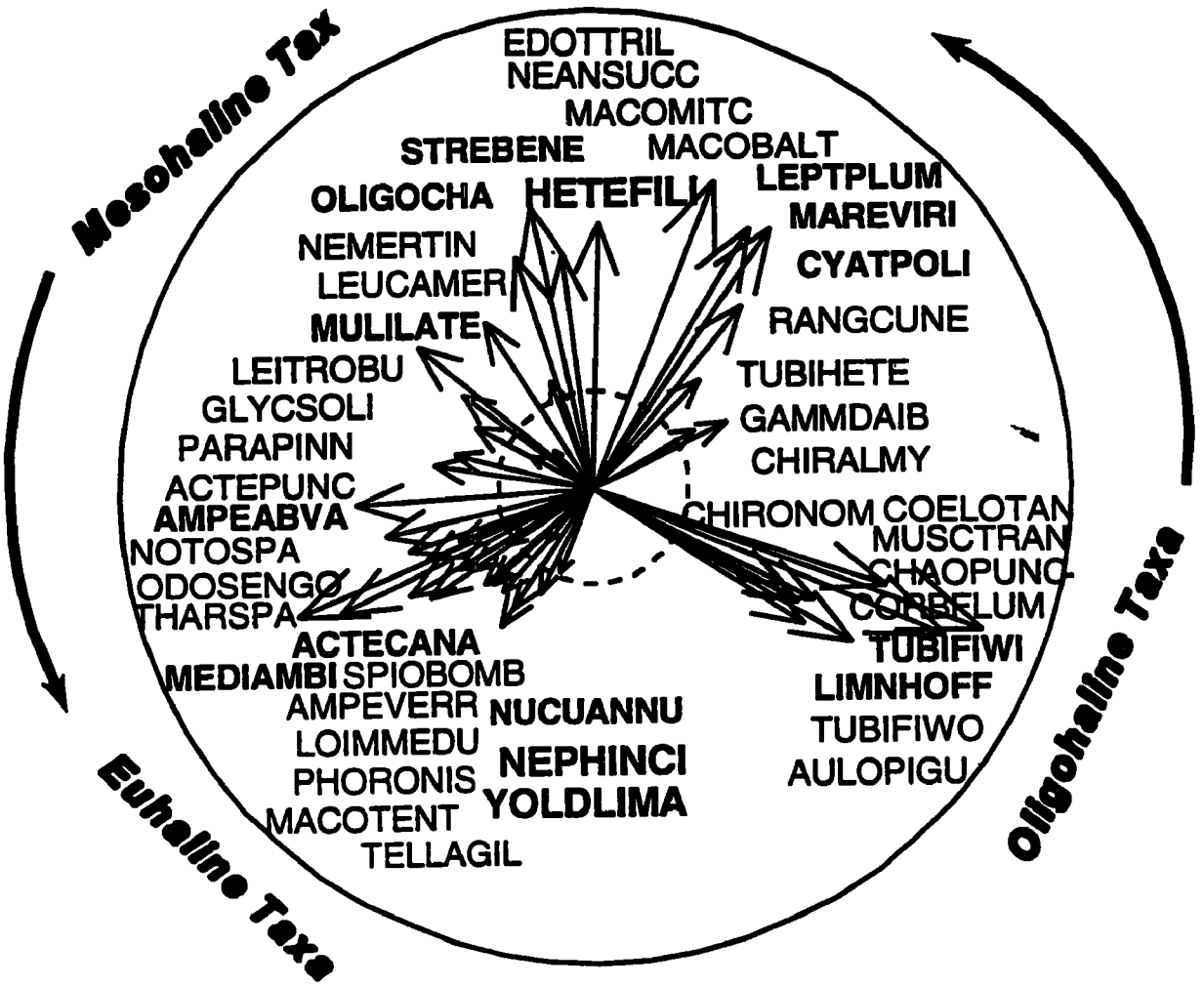


Figure 15 This is the Gabriel covariance biplot corresponding to the species clusters shown in Figure 14. Each of the 48 most important species is indicated by a vector (arrow), and the cosine of the angle between vectors is a measure of whether species are likely to be found in the same samples. A remarkable feature of this plot is that the major species groupings in different salinity regimes can be read sequentially by moving from 4 o'clock counterclockwise to 7 o'clock. The species codes can be found in Appendix III. Some key species discussed in the text are bolded.

Figure 16 shows the Gabriel Euclidean distance biplot for the 1736 samples containing more than 25 individuals (out of 1918 total samples). The most important taxon accounting for CNESS variation among samples is the oligochaete taxon '*Tubificoides* with capiliform chaetae' (**TUBIFIWI** in Figures 14 and 15). This taxon alone accounts for 5% of the total CNESS variation among samples. The samples in the upper left portion of this plot are all characterized by having high frequencies of *Tubificoides* with capiliform chaetae and *Limnodrilus hoffmeisteri*. The relative frequency of these key species can be determined by projecting each sample onto the species vectors at right angles.

As one moves counterclockwise around Figure 16 from the upper left, the samples are distributed according to salinity. The key species contributing to the position of samples in the first two PCA-H axes are the oligohaline isopod *Cyathura polita* (**CYATPOLI** in Figures 14-16), the spionid polychaete *Marenzelleria viridis* (**MAREVIRI**), the aorid amphipod *Leptocheirus plumulosa* (**LEPTPLUM**), the capitellid polychaete *Heteromastus filiformis* (**HETEFILI**), the spionid

polychaete *Streblospio benedicti* (**STREBENE**), and members of the class oligochaeta (**OLIGOCHA** - an EMAP-E VP designation used only for oligochaetes collected from samples with salinity > 5 psu). The upper right euhaline portion of the biplot is controlled by two euhaline taxa: the capitellid polychaete *Mediomastus ambiseta* (**MEDIAMBI**), and the gastropod *Acteocina canaliculata* (**ACTECANA**).

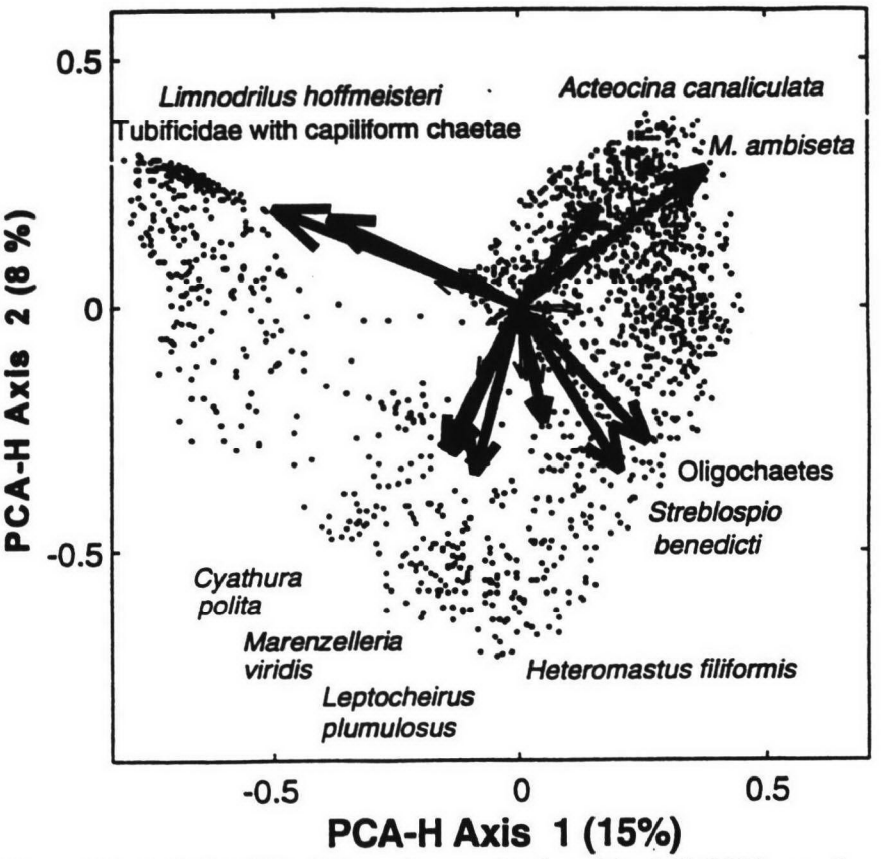


Figure 16. *A Gabriel Euclidean distance biplot of the full (1918 sample, 551 species) EMAP Virginian Province data at m=25. All species vectors are plotted; only those accounting for 2% of the variation in the first 2 dimensions are labeled. The ten most important species contributing to CNESS distances are Tubificoides with capilliform chaetae (55), M. ambiseta, S. benedicti, oligochaetes (4%), Ampelisca abdita-vadorum complex (3%, not shown), Mullinia lateralis (3%, not shown), Marenzelleria (formerly Scolecolepides) viridis (3%), and Nucula annulata (2%, not shown). The important species not shown in this plot are important contributors to the third PCA-H axis.*

The 1736 samples in Figure 16 were pooled if salinity data existed for the samples and if the CNESS distances among replicates were less than 0.7 (a large CNESS distance, see Methods). The biplot prooduced for these 320 samples are analyzed in Figures 17-23.

Figure 17 shows the PCA-H ordination of samples, with all samples in 5 psu increments being surrounded with different colored convex hulls. This figure shows clearly that PCA-H axis 1 serves largely to separate samples with salinities less than 5 psu from the remaining samples. Undoubtedly, some of this clear demarcation among samples is due to the use of different taxonomic designations for

EMAP-E VP samples taken from areas with less than 5 psu. It is also clear that there is a second, but less distinct break in community structure between the 5-15 and 15-35 psu samples.
In the first two PCA-H axes, the 15-35 psu samples plot on top of each other, but they are separable in the plot of the 2 vs. 3 PCA-H axes, which are shown in Figure 18.

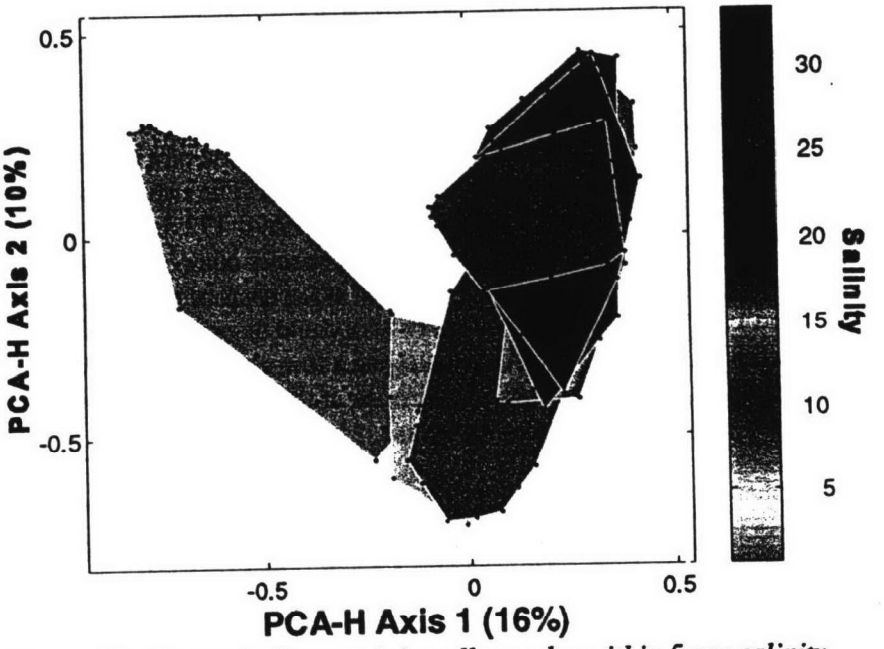


Figure 17. Convex hulls containing all samples within 5 psu salinity ranges are plotted vs. PCA-H Axes 1 and 2. PCA-H Axis 1 is controlled almost entirely by the contrast between 0-5 and 5-35 psu salinity.

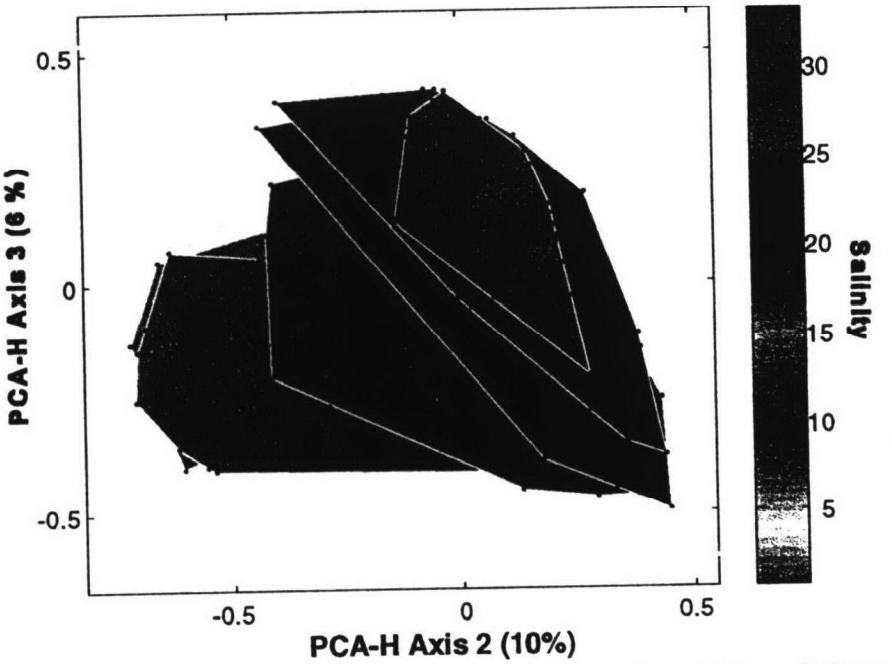


Figure 18. Convex hulls are drawn around all samples within each 5 psu salinity range vs. PCA-H Axes 2 and 3. Salinity is still a major determinant of PCA-H scores in the second and higher dimensions.

In the two dimensional PCA-H displays in Figure 17, the salinity groupings appear to form a horse-shoe (often called a Kendall's horseshoe) or U shape. This is the expected low-dimensional projection of salinity-controlled coenocline. Salinity continues to control community structure in the 3rd and higher PCA-H dimensions (Fig. 18).

The strong effect of salinity on PCA-H site scores in the first two PCA-H dimensions is graphically shown in Figure 19. The salinity of each sampling event is plotted in the third dimension vs. the first two PCA-H site scores (shown in Figure 17). The samples shown in the contour plot above the figure are distributed in a counter-clockwise fashion from the lower left of the plot to the upper right. The euhaline portion of the estuarine coenocline is shown in the upper right. The two arrows in the mesohaline (10-15 psu) portion of the plot mark two Hudson River samples (VA90-177 and VA90-198), which had measured salinities of 7.35 and 9.55 psu, but which had species compositions characteristic of salinities 3 or 4 psu higher. These two samples produced a 'hole' in the contour plot (marked with the red and green contours for 15 and 10 psu, respectively). This pattern could be produced in a tidal river system when the salinity decreased from 11 to 14 psu to 7 to 10 psu a few weeks before the benthic grab samples were taken. Within the oligohaline and mesohaline portions of the Virginian province, species composition is a very good predictor of salinity (but not vice versa).

The upper right euhaline portion of Figure 19 reveals a rugged mountainous topography. Samples within this region have species compositions characteristic of salinities greater than 15 psu, but there isn't a clear one-to-one correspondence between salinity and community structure.

Figure 20 shows the total number of species per sampling event vs. PCA-H axes 1 and 2. At salinities less than 15 psu, the number of species per sampling event is closely coupled to salinity. At salinities greater than 15 psu, there is a great deal of variation in the total species per sampling event. Undoubtedly some of this variation is due to the effects of disturbance, and some is due to depth, grain-

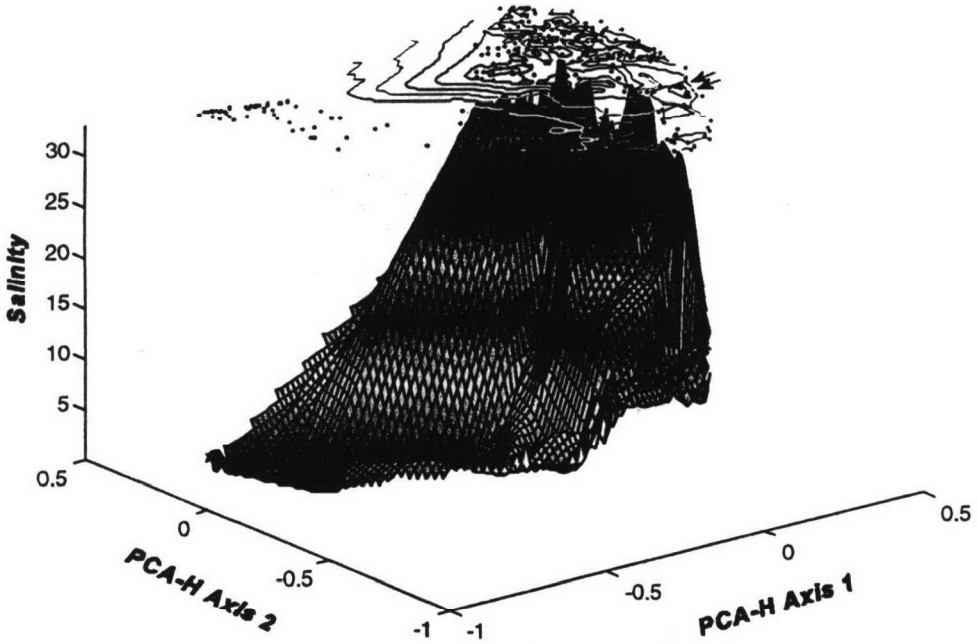


Figure 19. Salinity is plotted against PCA-H Axis 1 and 2, showing that salinity is a major factor controlling community structure. The arrows on the right indicate the two Hudson River samples discussed in the text.

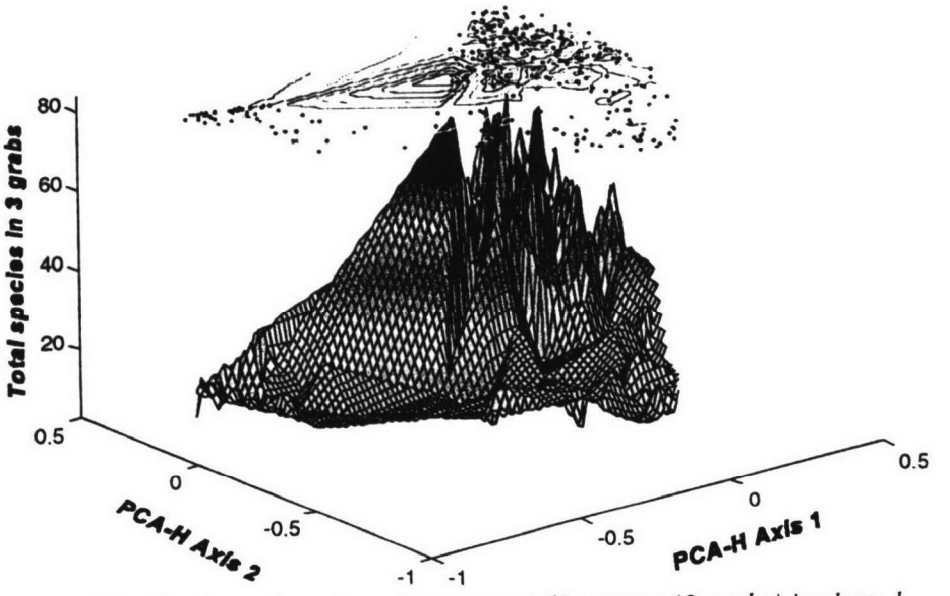


Figure 20. Total number of species per sampling event (3 grabs) is plotted against PCA-H Axes 1 and 2. Total species in 3 grabs in the oligohaline habits (lower left, see Figs. 17 and 19) is uniformly low. Total species in 3 grabs in the euhaline habitats (upper right, see also Figs. 17 & 19) in the Virginian province is much higher, with a much higher variance.

size and biogeographic factors. All of these factors are secondary to the dominant salinity effect.

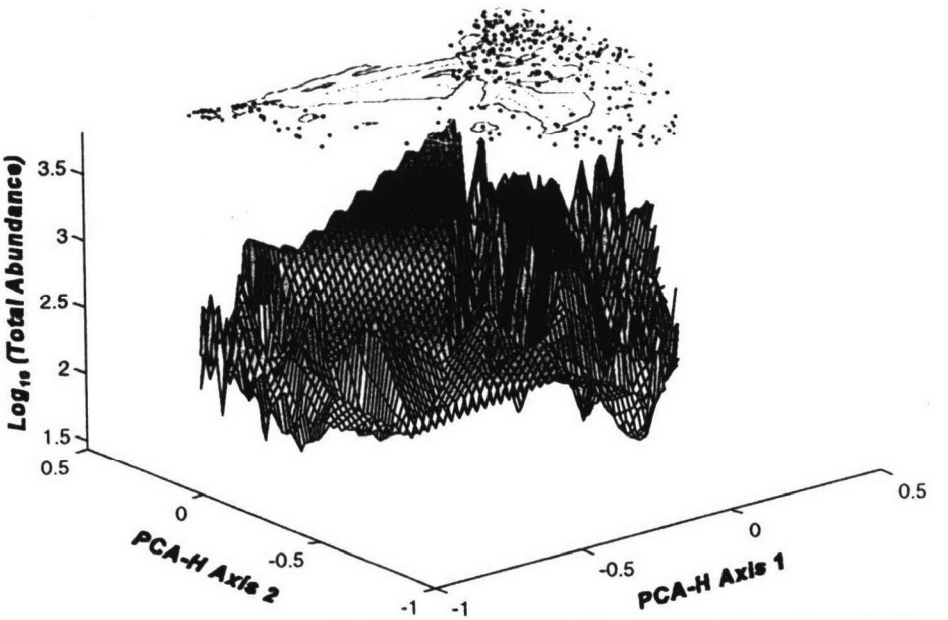


Figure 21. Log_{10} (Total individuals in 3 0.044 m^2 grabs) is plotted vs. PCA-H Axes 1 and 2. Infaunal abundances are very low in the oligohaline (<10 psu) portion of the Virginian Province. Abundances are more variable in the euhaline estuarine habitats.

Figure 21 shows that the oligohaline and mesohaline portions of the Virginian province are also associated with relatively low population abundances (< 1000 individuals per 3 0.044 m^2 grab samples). We plot the $\log_{10}$ of abundance, because abundance in 3 grabs varies from 25 (the lower cutoff for our analyses) to over three thousand.

Figure 22 shows the plot of the Sanders-Hurlbert $E(S_{10})$ diversity index vs. PCA-H axes 1 vs. 2. This diversity index exhibits a very high correlation with Shannon's H' (see Fig. 8 p. 23). Shannon's H' is far less sensitive to salinity effects than 'Total species per sampling event'. Shannon's H', while often used as a species richness index, is very sensitive to species evenness, or the relative distribution of individuals among species. The 'potholes' in Figure 22 indicate samples which have roughly the same salinity-controlled species composition as adjacent samples, but which have very low species evenness. One of the predicted effects of pollution is a drastic reduction in species evenness in a sample. Pollution or disturbance could produce the 'potholes' in Figure 22.

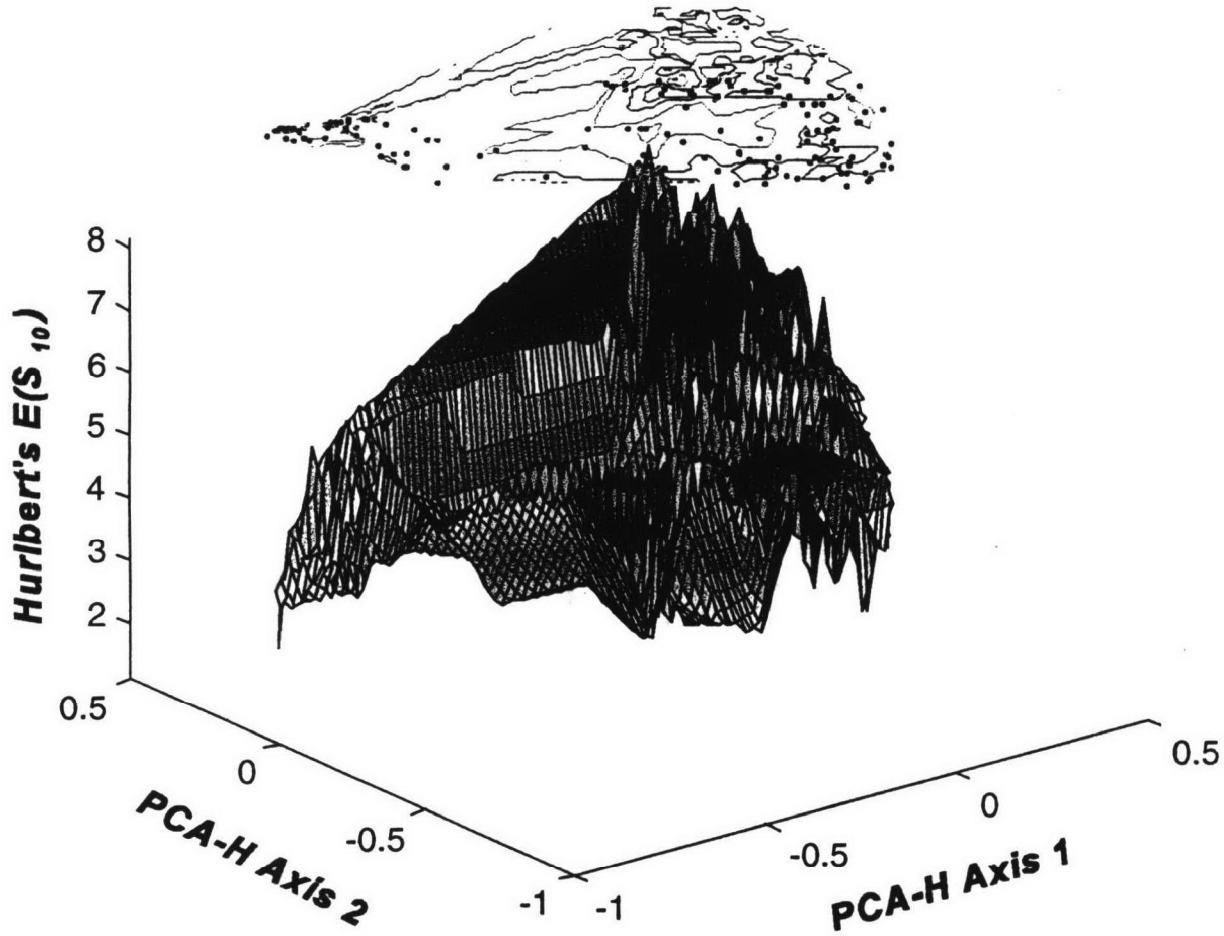


Figure 22. $E(S_{10})$ is plotted *vs.* PCA-H Axes 1 and 2. $E(S_{10})$ is not as sensitive to salinity effects as total species. 'Potholes' in the landscape may pinpoint the degraded areas within each salinity regime.

CONCLUSIONS

On the central role of salinity

It is apparent from our analyses that salinity is the dominant factor controlling EMAP-E VP community structure. Part of this is due to the differences in taxonomy used to sort EMAP-E VP samples from low-salinity regions. More than that, salinity is a major determinant of species richness and community composition. This comes as no surprise. Sanders *et al.* (1965) reached this conclusion in their survey of the Pocasset River in Massachusetts They concluded that the variance in salinity as well as its absolute value restricts the number of species present. Boesch (1977b) and Diaz and Schaffner (1990) have stressed the central role played by salinity in controlling benthic community structure in Chesapeake Bay. To our knowledge, the analyses in this report provide one of the clearest demonstrations of the role of salinity as the major factor controlling community structure in a broad biogeographic region.

Weisberg *et al.* 's (1993) 1990 EMAP-E VP benthic degradation index (Weisberg *et al.* 1993) explicitly accounted for the effects of salinity on species richness. Salinity effects were not properly assessed in the 1991 and 1992 indices, but Strobel *et al.* (1995) again designed their 1990-1993 index to remove the strong effects of salinity. The sampling properties of Gleason's D diversity are not well worked out. Gleason's D diversity is not among the diversity indices that ecologists use. We would strongly recommend that future analyses use Shannon's H' or Hurlbert's $E(S_n)$. Hurlbert's $E(S_n)$ has the advantage that it can be made more sensitive to species richness by increasing the sample size. Total species per grab is an acceptable index of diversity. However, as our analyses show, it cannot be used without careful removal of the overriding effects of salinity. Salinity is strongly correlated with the total number of species (Figure 3, p. 13). Without explicitly removing the effects of salinity, a degradation index based on species richness would have a tendency to identify oligohaline and mesohaline habitats as degraded. This tendency would be compounded if the list of opportunistic taxa used in several EMAP-E VP indices included species that are the natural dominants of oligohaline and mesohaline environments.

Suggestions for improving EMAP-E VP

Sampling

Two major problems appeared in our preparation of the EMAP-E VP data for community structure analysis. First, many of the replicate grabs from a site were extremely heterogeneous (CNESS > 0.7). Approximately 1/4 of the sampling sites were discarded because the three replicate grab samples were too heterogeneous to be considered true replicates. If the goal of the analysis is to characterize community structure alone, then this heterogeneity is important. However, in comparing sediment chemistry data collected from a different set of grabs than the benthic community structure data, it is essential that the benthic samples exhibit adequate replication. A CNESS distance of 0.7 or above indicates drastic changes in community structure, comparable to sampling sand vs. mud or sampling the same community in early spring and late summer (see Trueblood *et al.* 1994). We suspect that the small-scale heterogeneity was such that different sediment types were sampled with the three replicate biology grabs. If the three benthic grab samples indicate differences in community structure comparable to sampling sand vs. mud, then we felt that we could not trust the corresponding chemical data from the site. Would it correspond to the sandy benthic samples or the muddy ones? The extent

of the inter-replicate within site variance can be obtained by examining the clustering patterns of the sample cluster analysis in Appendix IV.

A second troubling feature of the EMAP-E VP analysis is shown in Appendix IV. In the 1990 sampling, triplicate box cores were taken from a site (STA 099) in New Bedford Harbor on August 15 and September 4, 1990. The differences in community structure at this single site with samples taken three weeks apart is as great as that observed between 'degraded' Chesapeake Bay euhaline samples and 'Clean' Nantucket Sound samples. Additional seasonal sampling should be carried out in the Virginian province to establish the extent of seasonal variability in the benthic communities.

Taxonomic issues

The EMAP-E VP program should have archived taxonomic reference material. The taxonomy of even the most wide-spread taxa in the Virginian province changes on the decadal time scale. Future ecologists will never know what species were really sampled in the EMAP-E VP . This is not the fault of the consulting firm which analyzed the EMAP-E VP data (Cove Associates). Cove Associates uses the latest taxonomic keys and certifies their species identifications with experts. Unfortunately, every year brings new taxonomic revisions. Currently, the status of the most abundant taxon in the EMAP-E VP data is in doubt. *Mediomastus ambiseta* was first described on the East Coast only in the early 1970s by Hobson (1971). Before that time, all *Mediomastus* were probably incorrectly identified as the capitellid *Heteromastus filiformis*, another Virginian province taxon which thrives at much lower salinity.

Mediomastus is not just another worm. It is the most abundant taxon in the entire Virginian province. There is a dramatic break in the distribution of *Mediomastus ambiseta* and *M. californiensis* at Cape Cod. Tim Morris at Cove Associates, who identified the capitellids in the EMAP-E VP program, was responsible for correcting a decades-old misclassification of *Mediomastus* in the Gulf of Maine. Throughout the 1960s and 1970s, the dominant *Mediomastus* species in Massachusetts Bay and Cape Cod Bay was misidentified as *Capitella capitata*, *Heteromastus filiformis*, or *Mediomastus ambiseta*. When Cove Associates was hired by the MWRA to process benthic samples in Massachusetts Bay in the mid 1980s, Morris identified the dominant *Mediomastus* species as *Mediomastus californiensis*. Since Morris's revelation, not a single *Mediomastus ambiseta* has been positively identified North of Cape Cod. All *Mediomastus* appear to be *M. californiensis*. *Mediomastus californiensis* was originally described from a California mudflat, and is the numerical dominant at the Los Angeles sewer outfall (Swartz *et al.* 1986), and in many areas of Puget Sound (Llanso, unpublished Puget Sound Ambient Monitoring data). Swartz *et al.* (1986) concluded that *M. californiensis* was an indicator of mild organic enrichment. In 1973, Day published a key to the polychaetes of the North Carolina region, listing *Mediomastus californiensis* as being common off Beaufort North Carolina in 10-20 meters depth. Day (1973) did not list *M. ambiseta*, and his description of *M. californiensis* lists the presence of the key characteristic that separates *M. ambiseta* and *M. californiensis* (abdominal neuropodia with hooks). In 1981, Ewing and Dauer published a key to the Chesapeake Bay capitellids that included both *M. ambiseta* and *M. californiensis*. *Mediomastus californiensis* is the only *Mediomastus* species found in the offshore Minerals Management Survey of the Gulf of Mexico (Ewing 1984).

The only *Mediomastus* species identified in the first three years of the EMAP-E VP program was *Mediomastus ambiseta*. Before the processing of the final year of EMAP-E VP data, the 1993 sampling, Morris (pers. comm.) identified *M. californiensis* for the first time within the Virginian province. This key species was found in only thirteen samples in the 1993 sampling. Cove Associates keeps archive samples of the *Mediomastus* collected from Massachusetts Bay and the Gulf of Maine,

and Morris has been examining the individuals of this key genus. Virtually all of the *Mediomastus* individuals from the first three years of EMAP-E VP sampling were destroyed in order to estimate biomass. This is very unfortunate. Reference material from the EMAP-E VP program would have been very valuable in determining the broad-scale distribution of this key genus. The problem is even more serious because the extensive Minerals Management Service Survey of the Georges Bank region (Neff *et al.* 1989, Battelle & WHOI, 1985) identified a third *Mediomastus* species: *Mediomastus fragilis*. This identification was confirmed by Linda Warren, who has recently revised the genus *Mediomastus* (Warren *et al.* 1994). *Mediomastus fragilis*, first identified in Northern Europe, would key out as *Mediomastus californiensis* using North American polychaete keys.

Many of the other numerically dominant taxa in the EMAP-E VP data set also require taxonomic work. Oligochaetes are the most important group of species in distinguishing oligohaline and mesohaline benthic habitats. The most important taxon controlling CNESS distances among samples is the odd species group **'Tubificidae with capiliform chaetae'**. None of the oligochaetes in the EMAP-E program from areas with more than 5 psu salinity were archived future taxonomic analysis. We will never know how many mesohaline oligochaete species were present in the Virginian Province from 1990-1993. The 1990-1993 benthic index cannot be properly evaluated because we do not know the proportion of oligochaetes that are members of the oligochaete family Tubificidae. The true extent of species turnover along the Virginian Province salinity gradient can never be properly assessed with the EMAP-E VP data because of the lack of taxonomy of the oligochaetes collected in areas having more than 5 psu salinity.

Nucula proxima and *Nucula annulata* are among the numerically dominant taxa in the Northern Virginian province. *Nucula annulata* is the tenth most important taxon contributing to CNESS distances in our analysis. Howard Sanders (1956, 1960) described the Long Island Sound and Buzzards Bay communities inhabiting subtidal muds as *Nucula proxima-Nephtys incisa* communities. George Hampson (1971) showed that the offshore mud-dwelling species was *Nucula annulata*, while the inshore sand-dwelling species in Buzzards Bay was *Nucula proxima*. *Nucula proxima* and *N. annulata* can be easily confused, but their habitats are very different. *N. proxima* thrives in nearshore fine sands, but *N. annulata* is found in offshore muds. The two species show little overlap in their distributions. In the EMAP-E VP data, *N. annulata* is found in both nearshore sand and offshore mud habitats, and *N. proxima* is not included in the EMAP-E VP species list. We must assume that *N. proxima* was called *N. annulata* in these analyses. If preserved samples were available, it would be a simple matter to obtain samples for nearshore sandy environments to determine whether the dominant protobranch bivalve was *N. proxima* and not *N. annulata*. Dr. Robert Prezant, a malacologist at Indiana University of Pennsylvannia, has been sampling the Assateague/Chincoteague area of Virginia for many years. He has sampled many *Nucula* from this shallow sandy area, that the EMAP-E program uses as one of its undegraded reference stations. The EMAP-E program lists only *Nucula annulata* from this shallow sandy area. Dr. Prezant has closely examined the Chincoteague/Assateague *Nucula*. All are *Nucula proxima*, in accordance with Hampson's (1971) description of the distribution of *Nucula* species. In analyzing the EMAP-E data, it is vital to be able to distinguish the dominant species from inshore sandy areas from offshore muds. The fact that *N. proxima* was missed in the four-year EMAP-E VP program is the type of slipup that could have been resolved readily if archive material were available. Unfortunately, all bivalve individuals collected during the EMAP-E VP program were destroyed to determine bivalve biomass for the EMAP-E VP degradation indices.

The cost for archiving benthic samples is high, but most other federal benthic surveys have managed this cost. Archiving samples is not incompatible with measuring biomass. The Minerals Management Service (MMS) insists that biomass be determined, but they also require that all samples be archived.

Only subsets of the individuals need to be analyzed to produce biomass estimates. The remaining material is archived at the Smithsonian. This MMS material is an important resource in the ongoing taxonomic revisions of our nation's marine communities. The EMAP-E VP was designed to serve as a multi-decade monitoring and assessment program. Archiving benthic samples should be a requirement of all such long-term monitoring plans.

Data analysis

Warwick (1993) asked whether there is an 'absolute' measure of benthic community structure that can determine whether a site was affected by pollution. After assessing indices similar to the EMAP-E VP degradation index, and several other indices of degradation, he answered 'No.' There is no clear-cut index that can determine whether an observed distribution of species in a sample is the result of pollution. Only marine sites that are nearly azoic or dominated by members of the genus *Capitella* can be unambiguously defined as degraded. Warwick (1993) even discounts the use of *Capitella* as a pollution indicator, regarding it more of an indicator of organic enrichment than toxicity. It is equally risky to assign a site with high species richness or abundance as being non-degraded. In the West Falmouth oil spill (Grassle and Grassle 1974, Sanders *et al.* 1980), the Amoco Cadiz oil spill (Cabioch *et al.* 1982) and even the MERL eutrophication experiments (Smith *et al.* 1979b), species diversity is insensitive to drastic changes in toxic loadings. However, species composition is sensitive to very low changes in pollutant input (*e.g.*, Grassle *et al.* 1981).

Dubious indices and statistics

In soft-bottom benthic ecology, there has been a plethora of dubious indices proposed to assess community structure. Most of these indices and approaches share a few common features:

- They are less expensive than standard benthic sampling which relies on the identification of all individuals to species.
- They rarely require taxonomic identifications beneath the level of family or competent taxonomists.
- Some require no benthic sampling or a reduced number of replicate samples.

While some of these indices may have merit, all should be viewed with caution, and none should be made the sole basis of a monitoring program. Some indices, such as Jack Word's (1978, 1980 a & b) infaunal trophic index (published only in the SCCWRP biennial reports), can be ruled out almost immediately as being too seriously flawed to merit discussion as a monitoring tool. Word's index forces improper polychaete trophic guild classifications into an improperly constructed mathematical formula to produce an index of pollution effects. Ferraro *et al.* (1989) provide one of the few published uses of Word's infaunal trophic index.

The following is a list of indices that have been proposed to assess marine benthic degradation. We will divide them into two groups. The first group is composed of seriously flawed indices.

Seriously flawed:

- The nematode/copepod ratio (Raffaelli & Mason 1981, Warwick 1981, Raffaelli 1981, 1982 & 1987, Amjad & Gray 1983, criticized by Lambshead *et al.* 1983 & 1984 Shaw *et al.* 1983).

- **BRAT** the benthic resource assessment technique (Lunz & Kendall 1982). Benthic individuals are ranked by their presence in the guts of important bottom feeding fish species. Benthic habitats composed of "good" fish food are giving a higher BRAT ranking than habitats containing species that are rarely fed on by bottom-feeding fish. This index, as originally proposed had merit. The index was later simplified to matching the size composition of infauna in fish stomachs with the size composition of benthic communities.
- Jack Word's infaunal trophic index (ITI) (Word 1978, 1980 a, b, & c, Ferraro *et al.* 1989)

Indices that are worth investigating:

- Organism-sediment index (OSI™) (Rhoads & Germano 1986). This index was applied to the 1990 EMAP-E VP data (see Figure 4, p 14). Difficulty in obtaining samples in coarse sediments greatly reduces the utility of sediment-profile imaging for EMAP-E VP scale monitoring. Grizzle and Pennimen (1991) found a close correspondence between the OSI™ and traditional benthic community structure analysis in the a polluted New Jersey habitat. O'Connor *et al.* (1989) applied the OSI™ to British benthic communities.
- Warwick's species abundance-biomass comparison (the ABC method) (Clarke 1990, Warwick and Clarke 1991, Warwick *et al.* 1987, 1989, 1990, Essink and Beukema 1986, reviewed by Beukema 1988, McManus and Pauly 1990,). Dauer *et al.* (1993) found that the ABC method was a poor predictor of degraded conditions in the Elizabeth River in Chesapeake Bay.
- Caswell's (1976, 1983) neutral model as a pollution or disturbance index. The infinite alleles model of population genetics predicts a logarithmic distribution of species frequencies. When applied to the benthos, Caswell's neutral model is assessing the fit of the log-series to benthic abundance data. Lambshead *et al.* (1983) and Lambshead and Platt (1985) introduced this method for assessing disturbance pollution. Goldman and Lambshead (1989) wrote an improved version of Caswell's program for assessing the effects of disturbance on benthic communities. Warwick *et al.* (1990) applied the neutral model to a pollution study in Bermuda and Warwick (1993) applied the neutral model to a well-characterized pollution gradient in a Norwegian fjord. Both studies found the lack of fit to the neutral model to be a very poor predictor of degradation.
- Departures from the log-normal distribution of individuals among species [Gray & Mirza 1979, Gray 1979a & b, Stenseth 1979, Gray 1980, Mirza & Gray 1981, Gray 1982, 1983, 1989, Gray & Pearson 1982, Gray & Christie 1983, Pearson *et al.* 1983, Bonsdorf and Kovisto 1982, Nelson 1987; poor fit found by Rygg (1986)]
- The variance in species frequencies among replicates at a site. Warwick (1993) argues that polluted sites have a higher variance in faunal similarity than non-degraded communities.

World-wide, no 'degradation index' has yet been found to classify single benthic samples into degraded and non-degraded categories (Warwick 1993). While environmental regulators might need this information desperately (*e.g.*, O'Connor and Dewling 1986), benthic ecologists have been unable to identify a single index that is reliable. No benthic ecologist has developed an index that can be applied for pollution assessment over large geographic areas. Rhoads and Germano's (1986)

organism-sediment index (OSI™) has been one of the most widely used and highly regarded. It is disturbing that the one test of the OSI index vs. the EMAP-E VP index in Weisberg *et al.* (1983) found virtually no statistical association between the two sets of degraded-nondegraded classifications (see Figure 4, p. 14).

The EMAP-E VP analyses of pollution effects has been hindered by not directly incorporating analyses of pollutant concentration, grain size, depth, and salinity in the biotic Integrity indices. Weisberg *et al.* (1993) and Strobel *et al.* (1995) do include salinity normalization of expected species diversity, but far more use could have been made of the extensive physical and chemical data in developing the benthic index. Coats (1995) has recently applied Gallagher's PCA-H method to establish a monitoring baseline for the Massachusetts Water Resource Authority. He produced PCA-H diagrams similar in style to those presented in this report. Coats then determined that grain size was the dominant factor controlling community structure in Massachusetts Bay. He developed a modification of the PCA-H method which he calls detrended PCA-H which removes the dominant grain-size effect from the major patterns in community structure. Coats (1995) then performed a full power analyses of the four years of MWRA Massachusetts Bay data, showing how pollution effects that might result from the MWRA sewage effluent outfall could be detected and assessed.

Coats (1995) DPCA-H method has great potential. However, Coats applied this method to only one small, approximately 100 km^2 region of Massachusetts Bay. This is smaller than many of the estuaries measured in the EMAP-E VP program.

In addition to the PCA-H method, techniques which assess the distribution of individuals among species might be a valuable tool in determining which samples in the EMAP-E program might exhibit patterns indiating disturbance or pollution. John Gray introduced the "log-normal" plotting technique as a indicator of pollution or disturbance. In Gray's method, the distribution of individuals are fit to the log-normal distribution. Recent disturbance or pollution produces a characteristic break in the normally linear plot of the number of species vs. the number of individuals, when plotted on normal probability paper. John Lambshead, at the Natural History Museum in London, has developed another method which is based on Fisher *et al.*'s (1943) log-series. According to Lambshead, undisturbed communities have distributions which are close to the log-series. Lambshead tests his fit to the log series, using Caswell's neutral model, and Goldman and Lambshead (1989) have written a program called CASVAR which tests benthic community structure data to see how closely it conforms to the log series.

The lead author of this report has recently applied a modified form of these methods to the EMAP-E VP data. They seem to work quite well. Samples from the EMAP-E VP reference test data set (listed in Schimmel *et al.* 1994) seem to conform to the log-series expectations. Most of the samples from the "degraded" test data set reveal two types of departure from log-series expectation. Most of the degraded stations exhibit very low evenness, compared to log-series expectations. However, in samples with very low infaunal abundances and very few species, the evenness is much higher than log-series expectations. This failure to recognize departures on either side of the log-series expectation may have produced some of the negative critiques of the log-series method (*e.g.*, Warwick 1993).

Considerable work needs to be done on fitting the log-series to the EMAP-E VP data. Some of the degraded test data sites in Schimmel *et al.* (1994) have distributions of individuals among species which are close to the log-series expectation. For example, the three grabs from the Kill van Kull degraded site (VA91-373, sampled on 8/3/91) have log-series distribution patterns. There is no sign of impact. Analysis of the species composition of this site indicates that two of the three grabs have benthic populations typical of shallow depths and salinities of 28 psu. This site was flagged as

degraded by Schimmel *et al.* (1994) because four sediment contaminants exceeded the 1990 Long and Morgan ER-M concentrations (silver, mercury, nickel, and zinc). However, using the Long *et al.* (1995) revised ER-M values, only mercury and nickel exceed ER-M. The Long *et al.* (1995) ER-M for mercury is 0.71 µg/g, and the Kill van Kull site had 1.76 µg/g. The ER-M for nickel was 51.6 µg/g and the Kill van Kull site had 57.6 µg/g. The organic carbon concentration at this site was 1.8%. It is entirely possible that the relatively high metal and organic pollutant concentrations at this site could be bound to organic carbon or acid-volatile sulfide phases (see Di Toro *et al.* 1990, 1991, 1992), making the mercury unavailable to the biota. The Kill van Kull appears to have a 'reference' benthic community, despite having relatively high sediment contaminant concentrations. Even within the three replicate grab samples from this site, there are some striking differences. Replicate grab three has a distribution of individuals among species that is least similar to the log series. This same grab contains a few species like *Mulinia lateralis* and *Streblospio benedicti* that are usually regarded as opportunistic.

Further work of this sort must be done to assess whether nearly one quarter of the nearshore area in the the Virginian Province is truly degraded (Table 1, p. 16). The EMAP-E VP dataset with its synoptic measurements of benthic community structure, sediment contaminant levels, and abiotic variables will be an invaluable resource in establishing the causal connection between sediment contaminant concentrations and altered patterns in community structure.

Have the EMAP Goals and Objectives Been Met?

The EMAP-E VP has created a benthic data set that may be unmatched in the world in terms of broad-scale geographic coverage. With the physical and chemical data available for each sampling event, these data should prove to be a rich resource for benthic ecologists for decades to come. The Virginian Province EMAP-E VP program has collected the necessary data to assess the scale and pattern of variability in benthic communities. Understanding this variability, and separating the natural and anthropogenic contributors to it, should be the goal of the Assessment portion of EMAP.

The EPA can be proud that it has created this outstanding database. There is nothing to match it in scale or scope. The EMAP-E VP program has not been succesful in developing a benthic degradation index. This is not surprising. Benthic ecologists have been searching for indices that will reliably indicate pollution or disturbance for the past three decades, if not longer. No index has been found to work reliably.

The EMAP-E VP indices are flawed, but the obstacles faced by the EMAP-E investigators were massive. The EMAP-E VP program attempted to find an index that would work across a very large biogeographic province in habitats as diverse as sandy fresh water habitats in the upper Hudson River to marine subtidal muds like Buzzards Bay, Massachusetts. It is not surprising that the indices developed for the EMAP-E VP program have flaws.

We would encourage the EMAP-E VP program to critically evaluate the latest index: Strobel *et al.*'s (1995) 1990-1993 index. It would be very unfortunate if government agencies began using 7000 spionids per m^2 as a regulatory guideline indicating degradation.

The EMAP-E VP data set could become a rich resource for ecologists and regulators alike if it were made more accessible and in a wider variety of formats. It is difficult to access the EMAP-E VP SAS abundance, species name, chemistry and water column data files in order to do most analyses. It doesn't have to be this way. As a model data base management system, EPA should look to NOAA's Coastal Zone Color Scanner data distribution network. CZCS data is distributed in a wide variety of

formats, from the beautiful World-Wide Web graphic displays of chlorophyll *a* concentration throughout the world to the detailed pixel-by-pixel reflectance data needed by investigators interested in perfecting the chlorophyll *a* algorithm. The lead author will provide the community structure data used to produce this report in ASCII or MATLAB™ format to any investigator that might request it.

If future programs like EMAP-E VP are implemented, I would strongly recommend that a subset or perhaps all of the benthic animals identified to species be archived. Many of the species, especially the numerical dominants in the EMAP-E VP program, are taxonomically difficult. These taxa include the *Mediomastus ambiseta-californiensis-fragilis* complex, the *Nucula annulata- proxima-atacellana* complex, oligochaetes, the *Ampelisca abdita-vadorum* complex, and the *Capitella* sibling species complex. Each of these numerically dominant groups has undergone massive taxonomic revision over the last thirty years, the time scale of the planned EMAP-E VP program. Without archival material, future ecologists and regulators will never know what species were really present in the period 1990-1993 in the Virginian Province.

Acknowledgments

David Shull provided valuable editorial assistance and commentary in producing this report. Ana Ranasinghe and Steve Weisberg (Versar, Columbia Maryland) provided invaluable assistance in analyzing the EMAP-E VP data. The lead author travelled to Columbia Maryland in February 1995, where the final species list used in this report were agreed upon. Ranasinghe and Weisberg helped us identify many undocumented features of the EMAP-E VP dataset, informed us when our SAS data were in error, and in late June 1995 provided a SAS program that converts EMAP-E VP data from its raw form to the form that we needed for our analyses. Without their assistance and Ana's SAS program, this work could not have been completed. Nancy Mountford and Tim Morris (Cove Associates) were very helpful in addressing the taxonomic issues involved in preparing the EMAP-E VP species abundance data for the community structure analyses discussed in this report. Joel O'Connor and Darvene Adams were very helpful in providing data for the NY/NJ REMAP program in the form that I needed it.

REFERENCES

Amjad, S. and J. S. Gray. 1983. Use of the nematode-copepod ratio as an index of organic pollution. Marine Pollution Bulletin *14*: 178-181.

Battelle New England & Woods Hole Oceanographic Institution. 1985. Georges Bank Benthic infauna monitoring program. Final Report for Third Year of Sampling, Volume 3: Appendices. Prepared for U. S. Dept. of the Interior, Minerals Management Service.

Beukema, J. J. 1988. An evaluation of the ABC method (abundance/biomass comparison) as applied to macrobenthic communities living on tidal flats in the Dutch Wadden Sea. Marine Biology 99: 425-433.

Boesch, D. F. 1977a. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033. US. EPA Environmental Laboratory, Corvallis OR.

Boesch, D. F. 1977b. A new look at the zonation of benthos along the estuarine gradient. Pp. 245-266 in B. C. Coull, ed., The ecology of marine benthos. University of S. Carolina Press, Columbia SC. 467 pp.

Boesch, D. F. and R. Rosenberg. 1981. Response to stress in marine benthic communities. Pp. 179-200 *in* G. W. Barrett and R. Rosenberg, *eds.*, Stress effects on natural ecosystems. John Wiley & Sons, NY.

Bonsdoff, E. and V. Kovisto. 1982. The use of the log-normal distribution of individuals among species in monitoring zoobenthos in the northern Baltic Archipelago. Mar. Poll. Bull. *13*: 324.

Cabioch, L, J.-C. Daurin, C. Retiere, V. Rivain, and D. Archambault. 1982. Evolution de peuplements de Rescoff, perturbes par les hydrocarboures de l'Amoco Cadiz. Neth J. Sea Res. *16*; 491-501. In French, English Summary.

Caswell, H. 1976. Community structure: a neutral model analysis. Ecol. Monogr. *46*:327-354.

Caswell, H. 1983. Reply to a comment by Ugland and Gray. Ecology *64*: 605-606.

Chapman, P. M. R. N. Dexter and L. Goldstein. 1987. Development of monitoring programmes to assess the long-term health of aquatic ecosystems. Marine Pollution Bulletin *18*: 521-528.

Clarke, K. R. 1990. Comparisons of dominance curves. J. exp. Mar. Biol. Ecol. *138*: 143-157.

Coats, D. A. 1995. 1994 Annual soft-bottom benthic monitoring Massachusetts Bay outfall studies. MWRA Enviro. Quality Dept. Tech. Rpt series 95-20. Massachusetts Water Resources Authority, Boston MA. 194 pp.

Dauer, D. M., C. A. Maybury, and R. M. Ewing. 1981. Feeding behavior and general ecology of several spionid polychaetes from the Chesapeake Bay. J. exp. mar. Biol. Ecol. 54: 21-38.

Dauer, D. M., M. W. Luckenbach, and A. J. Rodi. 1993. Abundance biomass comparison (ABC method): Effects of an estuarine gradient, anoxic/hypoxic events and contaminated sediments. Marine Biology 116: 507-518.

Diaz, R. J. and L. C. Schaffner. 1990. The functional role of estuarine benthos. Pp. 25-56 *in* M. Haier and E. C. Krome, *eds.*, Perspectives on the Chesapeake Bay, 1990. Advances in estuarine sciences. Chesapeake Research Consortium, Gloucester Pt., Virginia.

Digby, P. G. N. and R. A. Kempton. 1987. Multivariate analysis of ecological communities. Chapman & Hall, New York.

DiToro, D. M., J.D. Mahony, D. J Hansen, K. J. Scott, M. B. Hicks, S. M. Mayr, and M. S. Redmond. 1990. Toxicity of cadmium in sediments: the role of acid volatile sulfide. Environ. Sci. Technol. *9*: 1487-1502.

DiToro, D. M., C. Zarba, D. J. Hansen, W. Berry, R. C. Swartz, C. E. Cowan, S. P. Pavlou, H. E. Allen, N. A. Thomas and P R. Paquin. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environ. Sci. Technol. *10*: 1541-1583.

DiToro, D., J. D. Mahoney, D. J. Hansen, K. J. Scott, A. R. Carlson and G. T. Ankey. 1992. Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments. Environ. Sci. Technol. *26*: 96-101.

Essink, K. and J. J. Beukema. 1986. Long-term changes in intertidal flat macrozoobenthos as an indicator of stress by organic pollution. Hydrobiologia *142*: 209-215.

Ewing, R. M. 1984. Capitellidae. Chapter 14 in W. Uebelacker and P. G. Johnson, eds. Taxonomic guide to the polychaetes of the northern Gulf of Mexico. Barry A. Vittor & Associates, Report prepared for the Dept. of the Interior Minerals Management Service.

Ewing, R. M. and D. M. Dauer. 1981. A new species of *Amastigos* (Polychaeta: Capitellidae) from the Chesapeake Bay and Atlantic Coast of the United States with notes on the Capitellidae of the Chesapeake Bay. Proc. Biol. Soc. Wash. 94: 163-168.

Fager, E. W. 1972. Diversity: a sampling study. Amer. Natur. *106*: 293-310.

Ferraro, S. P., F. A. Cole, W. A. DeBen, and R. C. Swartz. 1989. Power-cost efficiency of eight macrobenthic sampling schemes in Puget Sound, Washington, USA. Can. J. Fish. Aquat. Sci. *46*: 2157-2165.

Field, J. G., K. R. Clarke, and R. M. Warwick. 1982. A practical guide for analysing multispecies distribution patterns. Mar. Ecol. Prog. Ser. 8: 37-52.

Fisher, R. A., A. S. Corbet, and C. B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. J. Anim. Ecology 12: 42-58.

Fuller, C. M., C. A. Butman and N. M. Conway. 1988. Periodicity in fecal pellet production by the capitellid polychaete *Mediomastus ambiseta* throughout the day. Ophelia 29: 83-91.

Gabriel, K. R. 1971. The biplot graphic display of matrices with application to principal component analysis. Biometrika *58*: 453-467.

Gallagher, E. D., P. A. Jumars, and D. D. Trueblood. 1983. Facilitation of soft-bottom benthic succession by tube builders. Ecoogy *64*: 1200-1216.

Gallagher, E. D., G. B. Gardner, and P. A. Jumars. 1990. Competition among the pioneers in a seasonal soft-bottom benthic succession: field experiments and analysis of the Gilpin-Ayala competition model. Oecologia *83*. 427-442.

Gallagher, E. D., G. T. Wallace and R. P. Eganhouse. 1992. The effects of the Fox Point CSO on chemical and biological pollution indices in Boston Harbor's Dorchester Bay. 130 pp.

Gleason, H. A. 1922. On the relation between species and area. Ecology 3: 158.

Goldman, N. and P. J. D. Lambshead. 1989 Optimization of the Ewens/Caswell neutral model program for community diversity analysis. Mar. Ecol. Prog. Ser. *50*: 255-261.

Gower, J. C. 1987. Introduction to ordination techniques. Pp. 3-64 in Legendre, P. and L. Legendre, eds., Developments in numerical ecology. Proc. NATO Advanced Research Workshop on Numerical Ecology. NATO ASI Series G: Ecological Sciences 14, Springer Verlag.

Grassle, J. F. and J. P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. J. Mar. Res. *32*: 253-284.

Grassle, J. F. and W. Smith. 1976. A similarity measure sensitive to the contribution of rare species and its use in investigation of variation in marine benthic communities. Oecologia *25*: 13-25.

Grassle, J. F., R. Elmgren, and J. P. Grassle. 1981. Response of benthic communities in MERL ecosystems to low level chronic additions of No. 2 Fuel Oil. Mar. Environ. Res. *4*: 279-297.

Grassle, J. F., J. P. Grassle, L. S. Brown-Leger, R. F. Petrecca and N. J. Copley. 1986. Subtidal macrobenthos of Narragansett Bay. Field and mesocosm studies of the effects of eutrophication and organic input on benthic populations. Pp. 421-433 *in* Marine Biology of Polar regions and effects of stress on Marine Organisms. J. S. Gray and M. E. Christinasen, *eds.*, John Wiley and Sons.

Grassle, J. P. and J. F. Grassle 1976. Sibling species in the marine pollution indicator *Capitella* (Polychaeta). Science *192*: 567-569.

Grassle, J. P. and J. F. Grassle 1985. The utility of studying the effects of pollutants on single species populations in benthos of mesocosms and coastal ecosystems. Pp. 621-642 in H. H. White, ed., Concepts in Marine Pollution Measurements. Maryland Sea Grant Publication, College Park MD.

Gray, J. S. 1976. Are baseline surveys worthwhile? New Sci. 70: 219-221.

Gray, J. S. 1979. Pollution-induced changes in populations. Phil. Trans. R. Sco. B. *286*: 545-561.

Gray, J. S. 1979. The development of a monitoring programme for Norway's coastal marine fauna. Ambio *8*: 176-179.

Gray, J. S. 1980. The measurement of effects of pollutants on benthic communities. Rapp. P.-v. Re'un Cons. perm int. Explor. Mer. *179*: 188-193.

Gray, J. S. 1982. Effects of pollutants on marine ecosystems. Neth. J. Sea Res. *16*: 424-443.

Gray, J. S. 1983. Use and misuse of the log-normal plotting method for detection of effects of pollution - a reply to Shaw *et al.* Mar. Ecol. Prog. Ser. *11*: 203-204.

Gray, J. S. 1989. Do bioassays adequately predict ecological effects of pollutants? Hydrobiologia *188/189*: 397-402.

Gray, J. S. 1989. Effects of environmental stress on species-rich assemblages. Biol. J. Linnaen Soc. *37*: 19-32.

Gray, J. S. and F. B. Mirza. 1979. A possible method for the detection of pollution-induced disturbance on marine benthic communities. Marine Pollution Bulletin *10*: 142-146.

Gray, J. S. and T. H. Pearson. 1982. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. I. Comparative methodology. Mar. Ecol. Prog. Ser. *9*: 111-119.

Gray, J. S. and H. Christie. 1983. Predicting long-term changes in marine benthic communities. Mar. Ecol. Prog. Ser. *13*: 87-94.

Gray, J. S., K. R. Clarke, R. M. Warwick and G. Hobbs. 1990. Detection of initial effects of pollution in marine benthos, an example from the Ekofisk and Eldfisk oilfields, North Sea. Mar. Ecol. Prog. Ser. *66*: 285-300.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & sons, New York.

Greenacre, M. J. 1984. Theory and application of correspondence analysis. Academic Press, London. 364 pp.

Grizzle, R. E. and C. A. Penniman. 1991. Effects of organic enrichment on estuarine macrofaunal benthos: a comparison of sediment profile imaging and traditional methods. Mar. Ecol. Prog. Ser. *74*: 249-262.

Hampson, G. R. 1971. A species pair of the genus Nucula (Bivalvia) from the eastern coast of the United States. Proc. malac. Soc. Lond. *39*: 333-342.

Heltshe, J. R. and N. E. Forrester. 1985. Statistical evaluation of the jackknife estimate of diversity when using quadrat samples. Ecology *66*: 107-111.

Hobson, K. D. 1971. Polychaeta new to New England, with additions to the description of *Aberranta enigmatica* Hartman. Proc. Biol. Soc. Wash. 84: 245-252.

Hurlbert, S. H. 1971. The non-concept of species diversity: a critique and alternative parameters. Ecology *52*: 577-586.

Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs *54*: 187-211.

Jumars, P. J. 1981. Limits in predicting and detecting benthic community response to manganese nodule mining. Marine Mining *3*: 213-228.

Kenkel, N. C. and L. Orloci. 1986. Applying metric and nonmetric multidimensional scaling to ecological studies: some new results. Ecology *67*: 919-928.

Lambshead, P. J. D. 1984. The Nematode/Copepod ratio-some anomalous results from the Firth of Clyde. Mar. Poll. Bull. *15*: 256-259.

Lambshead, P. J. D. 1986. Sub-catastrophic sewage and industrial waste contamination as revealed by marine nematode faunal analyses. Mar. Ecol. Prog. Ser. *29*: 247-260.

Lambshead, P. J. D., H. M. Platt, and K. M. Shaw. 1983. The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. J. Nat. Hist. *17*: 859-874.

Lambshead, P. J. and H. M Platt. 1985. Structural patterns of marine benthic assemblages and relationship with emperical statistical models. Pp. 371-380 *in* P. E. Gibbs, *ed.*, Proc. 19th Eur. Marine Biol. Symposium, Cambridge University Press, Cambridge.

Lambshead, P. J. D. and H. M. Platt. 1988. Analyzing disturbance with the Ewens/Caswell neutral model: theoretical review and practical assessment. Mar. Ecol. Prog. Ser. *43*: 31-41.

Legendre, L. & P. Legendre 1983. Numerical Ecology. Elsevier, Amsterdam.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, U.S. A., in 1963-1964. Fiskdir. Skr. Ser. Havunders. *14:* 229-256.

Lie, U. and R. A. Evans. 1973. Long-term variability in the structure of subtidal benthic communities in Puget Sound, Washington, USA. Marine Biology *21*: 122-126.

Long, E. R. and L. G. Morgan. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52 US Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Rockville, MD. 175 pp.+2 Appendices.

Long, E. R., D. D. MacDonald, S. L. Smith and F. D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental management *19*: 81-97.

Lunz, J. D. and D. R. Kendall. 1982. Benthic resources assessment technique: a method for quantifying the effects of benthic community changes on fish resources. Oceans: 1021-1027.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton.

May, R. M. 1975. Patterns of species abundance and diversity. Pp. 81-120 *in* M. L. Cody and J. M. Diamond, eds., Belknap Press, Cambridge.

McManus, J. W. and D. Pauly. 1990. Measuring ecological stress: variations on a theme by R. M. Warwick. Marine Biology *106*: 305-308.

Messer, J. J., R. A. Linthurst, and W. S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment *17*: 67-78.

Mirza, F. B. and J. S. Gray. 1981. The fauna of benthic sediments from the organically enriched Oslofjord, Norway. J. exp. mar. Biol. Ecol. *54*: 181-207.

Neff, J. M., M. H. Bothner, N. J. Maciolek and J. F. Grassle. 1989. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. Marine Env. Res. *27*: 77-114.

Nichols, F. H. 1975. Dynamics and energetics of three deposit-feeding benthic invertebrate populstions in Puget Sound, Washington. Ecol. Monogr. *45*: 57-82.

Nichols, F. H. 1985. Abundance fluctuations among benthic invertebrates in two Pacific estuaries. Estuaries. *8*: 136-144.

Nichols, F. H. 1988. Long-term changes in a deep Puget Sound benthic community: local or basin-wide? Proc. 1st Ann. meeting on Puget Sd. Res. *1*: 65-71.

O'Connor, B. D. S., J. Costelloe, B. F. Keegan, and D. C. Rhoads. 1989. The use of REMOTS technology in monitoring coastal enrichment resulting from mariculture. Mar. Poll. Bull. *8*: 384-390.

O'Connor, J. S. and R. T. Dewling. 1986. Indices of marine degradation: their utility. Environmental Management *10*: 335-343.

Orloci, L. 1978. Multivariate analysis in vegetation research. Junk, the Hague.

Overton, W. S. 1989. Design report of the environmental monitoring and assessment program. U.S. EPA, Environmental Research Laboratory, Corvallis, OR.

Overton, W. S., D. White, and D. L. Stevens. 1990. Design report for EMAP: Environmental Monitoring and Assessment Program. EPA/600/3-91/053. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. *16*: 229-311.

Pearson, T. H., J. S. Gray, and P. J. Johannessen. 1983. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. 2. Data analyses. Mar. Ecol. Prog. Ser. 12: 237-255.

Peet, R. K. 1974. The measurement of species diversity. Ann. Rev. Ecol. Syst. *5*: 285-307.

Pielou, E. C. 1969. An introduction to mathematical ecology. Wiley-Interscience, New York.

Pielou, E. C. 1975. Ecological diversity. Wiley, New York.

Pielou, E. C. 1977. Mathematical ecology. John Wiley and Sons, New York..

Pielou, E. C. 1984. The interpretation of ecological data. John Wiley & Sons, New York. 263 pp.

Platt, H. M. N. and P. J. D. Lambshead. 1985. Neutral model analysis of patterns of marine benthic species diversity. Mar. Ecol. Prog. Ser. *24*: 75-81.

Raffaelli, D. 1981. Monitoring with meiofauna - a reply to Coull, Hicks and Wells (1981) and additional data. Mar. Poll. Bull. *12*: 381-382.

Raffaelli, D. 1982. An assessment of the potential of major meiofauna groups for monitoring organic pollution. Marine Environmental Research *7*: 151-163.

Raffaelli, D. 1987. The behaviour of the nematode/copepod ratio in organic pollution studies. Mar. Env. Res. 23: 135-152.

Raffaelli, D. G. and C. F. Mason. 1981. Pollution monitoring with meiofauna, using the ratio of nematodes to copepods. Mar. Poll. Bull. *12*: 158-163.

Ranasinghe, J. A., S. B. Weisberg, D. M. Dauer, L. C. Schaffner, R. J. Diaz and J. B. Frithsen. 1993. Chesapeake Bay Benthic Community Restoration Goals. December 1993 report for the EPA and Maryland Governor's Council on Chesapeake Bay research.

Rhoads, D. C. and J. D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiologia *142*: 291-308

Rygg, B. 1986. Heavy metal pollution and log-normal distribution of individuals among species in benthic communities. Marine Pollution Bulletin *17*: 31-36.

Sanders, H. L. 1956. The biology of marine bottom communities. Bull. Bingham Oceanographic Collection *15*: 345-414.

Sanders, H. L. 1960. Benthic studies in Buzzards Bay III. The structure of the soft-bottom community. Limnol. Oceanogr. *5*: 138-153.

Sanders, H. L. 1968. Marine benthic diversity: A comparative study. Amer. Natur. *102*: 243-282.

Sanders, H. L., P. C. Mangelsdorf and G. R. Hampson. 1965. Salinity and faunal distribution in the Pocasset River, Massachusetts. Limnol. Oceanogr. *10*: 216-220.

Sanders, H. L., J. F. Grassle, G. R. Hampson, L. S. Morse, S. Garner-Price, and C. C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. J. Marine Research *38:* 265-380.

Schimmel, S. C, B. D. Melzian, D. E. Campbell, C. J. Strobel, S. J. Benyi, J. S. Rosen and H. W. Buffum. 1994. Statistical Summary: EMAP-Estuaries Virginain Province -1991. US Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Narragansett, RI EPA/620/R-94/005.

Schubel, J. R., D. F. Boesch, T. M. Church, J. W. Farrington, S. L. Rathbun, S. Saila, and K. Tenore. 1992. Review of the U. S. Environmental Protection Agency's Environmental Monitoring and Assessment Program-Estuaries (EMAP-Estuaries). A report of review panel convened by the Estuarine Research Foundation on 30-31 March 1992.

Sedgewick, R. 1992. Algorithms in C++. Addison-Wesley, Reading MA. 656 pp.

Shaw, K. M., P. J. D. Lambshead and H. M. Platt. 1983. Detection of pollution-induced disturbance in marine benthic assemblages with special reference to nematodes. Mar. Ecol. Prog. Ser. *11*: 195-202.

Simberloff, D. 1972. Properties of the rarefaction diversity measurement . Amer. Natur. *106*: 414-418.

Simberloff, D. 1979. Rarefaction as a distribution-free method of expressing and estimating diversity. Pp. 159-176 *in* J. F. Grassle, G. P. Patil, W. Smith, and C. Tallie, *eds.*, Ecological diversity in theory and practice. International Cooperative Publishing House, Fairland, MD.

Smith, W. and J. F. Grassle. 1977. Sampling properties of a family of diversity measures. Biometrics *33*: 283-292.

Smith, W., J. F. Grassle, and D. Kravitz. 1979a. Measures of diversity with unbiased estimates. Pp. 177-191 in J. F. Grassle, G. P. Patil, W. Smith, and C. Tallie (eds.), Ecological diversity in theory and practice. International Cooperative Publishing House, Fairland, MD.

Smith, W., V. R. Gibson, L. S. Brown-Leger and J. F. Grassle. 1979b. Diversity as an indicator of pollution: cautionary results from microcosm experiments. Pp. 269-277 *in* J. F. Grassle, G. P. Patil, W. Smith, and C. Tallie, *eds*, Ecological diversity in theory and practice. International Cooperative Publishing House, Fairland, MD.

Stenseth, N. C. 1979. Where have all the species gone? On the nature of extinction and the Red Queen hypothesis. Oikos *33*: 196-227.

Strobel, C. J. S. J. Benyi, D. J. Keith, H. W. Buffum, and E. A. Petrocelli. 1994. Statistical Summary: EMAP-Estuaries Virginian Province - 1992. U. S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Narragansett, RI EPA/620/R-94/019.

Strobel, C. J., H. W. Buffum, S. J. Benyi, E. A. Petrocelli, D. R. Reifsteck, and D. J. Keith. 1995. Statistical Sumary: EMAP-Estuaries Virginian Province - 1990 to 1993. U. S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Naragansett, RI. EPA/620/R-94/026.

Summers, J. K., J. M. Macauley, P. T. Heitmuller, V. D. Engle, A. M. Adams, and G. T. Brooks. 1992. Annual Statistical Summary: EMAP-Estuaries Louisianian Province - 1991. U. S. Environmental Protection Agency. Office of Research and Development, Environmental Research Laboratory. Gulf Breeze. FL EPA/600/R-93/001.

Swartz, R. C., F. A. Cole, D. W. Schults and W. A. DeBen. 1986. Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Mar. Ecol. Prog. Ser. *31*: 1-13.

ter Braak, C. J. J. 1983. Principal components biplots and alpha and beta diversity. Ecology *64*: 454-462.

Trueblood, D. D., E. D. Gallagher, and D. M. Gould. 1994. Three stages of seasonal succession on the Savin Hill Cove mudflat, Boston Harbor. Limnol. Oceanogr. *39*: 1440-1454.

Ugland, K. I. and J. S. Gray. 1983. Reanalysis of Caswell's neutral model. Ecology *64*: 603-605.

Underwood, A. J. 1981. Techniques of analysis of variance in experimental marine biology and ecology. Oceanogr. Mar Biol. Ann Rev *19* 513-605.

Wallace, G. T., C. F. Krahforst, L. C. Pitts, J. P. Shine, M. M. Studer, and C. R. Bollinger. 1991. Assessment of the chemical composition of the Fox Point CSO effluent and associated subtidal and intertidal environments. Analysis of CSO effluents, reciving water and surface sediments for trace metals prior to CSO modification. Final Report to MA Dept. of Environmental Protection, Office of Research and Standards. 225 pp.

Warren, L. M., P. A. Hutchings, and S. Doyle. 1994. A revision of the genus *Mediomastus* Hartman 1944 (Poychaeta: Capitellidae). Records of the Australian Museum *46*: 227-256.

Warwick, R. M. 1981. The Nematode/Copepod ratio and its use in pollution ecology. Mar. Poll. Bull. *12*: 329-333.

Warwick, R. M. 1993. Environmental impact studies on marine communities: pragmatical considerations. Aust. J. Ecology *18*: 63-80.

Warwick, R. M. 1988. Effects on community structure of a pollution gradient -SUMMARY. Mar. Ecol. Prog. Ser. 46: 207-211.

Warwick, R. M., T. H. Pearson, and Ruswahyuni. 1987. Detection of pollution effects on marine macrobenthos: further evaluation of the species abundance/biomass method. Marine Biology *95*: 193-200.

Warwick, R. M. and K. R. Clarke. 1991. A comparison of some methods for analysing changes in benthic community structure. J. Mar. Biol. Assoc. U. K. 71: 225-244.

Warwick, R. M., H. M. Platt, K. R. Clarke, J. Aghard. and J. Gobin. 1990. Analysis of macrobenthic and meiobenthic community structure in relation to pollution and disturbance in Hamilton Harbour, Bermuda. J. exp. Mar. Biol. Ecol. *138*: 119-142.

Washington, H. G. 1984. Diversity, biotic and similarity indices: a review with special relvance to aquatic ecosystems. Water Res. *18*: 653-694.

Weisberg, S. B, J. B. Frithsen, A. F. Holland, J. F. Paul, K. J. Scott, J. K. Summers, H. T. Wilson, R. M. Valente, D. G. Heimbuch, G. Gerritsen, S. C. Schimmel and R. W. Latimer. 1993. EMAP-Estuaries, Virginian Province 1990 Demonstration Project Report. EPA/620/R-93/006. Narragansett, RI: US Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development.

Word, J. Q. 1978. The infaunal trophic index. Annual Report 1978. Southern California Coastal Water Research Project. El Segundo, California. pp 19-39.

Word, J. Q. 1980a. Classification of benthic invertebrates into infaunal trophic index feeding groups. Annual Report 1980. Southern California Coastal Water Research Project. El Segundo, California. Pp. 103-121.

Word, J. Q. 1980b. Effects of screen size and replication on the infaunal trophic index. Annual Report 1980. Southern California Coastal Water Research Project. El Segundo, California. p. 123-130.

Word, J. Q. 1980c. Extension of the infaunal trophic index to a depth of 800 meters. Annual Report 1980. Southern California Coastal Water Research Project. El Segundo, California.

APPENDIX I METHODS FOR ANALYZING COMMUNITY STRUCTURE

Diversity indices

This section will survey the major diversity and similarity (or dissimilarity measures) in use in community ecology today. Magurran (1988) provides a review of the history of diversity measures in community ecology. She ignores the most common method used to assess diversity in marine benthic communities: Sanders-Hurlbert rarefaction.

Sanders (1968) introduced the rarefaction method for assessing species diversity. Single samples are plotted as rarefaction curves representing the number of species observed in the sample and the number of species expected from randomly drawn subsamples of the total sample. Unfortunately, Sanders method for calculating rarefaction curves was wrong. This error was pointed out by Fager (1972), and corrections were published by Hurlbert (1971) and Simberloff (1972). Hurlbert (1971) criticizes the use of diversity indices and introduces a correction to Sanders' (1968) rarefaction method. Simberloff (1972) introduced an identical correction for Sanders' rarefaction method, but Hurlbert (1971) gets priority. Simberloff (1979) introduced a variance estimator for $E(S_n)$, but Smith and Grassle (1977) proposed a better measure earlier. This modified rarefaction method is now routinely described as Hurlbert's $E(S_n)$. Peet (1974) and Pielou (1969, 1977) review the use of H' and other measures of diversity.

Species richness indices

While there are indices specifically designed to assess species evenness or equitability, there are no unbiased estimators of species richness *per se*. An unbiased estimator is a statistic that has an expected value equal to the true value. The EMAP-E VP program used the total number of species per sampling event (usually three replicate samples) as an index of species richness in the 1990, 1991, and 1992 biotic indices. While this is a straightforward measure of species richness, it is also a biased statistic. Bias means that the expected value of the statistic will be a strong function of sample size. Total number of species per event will vary strongly with the number of samples taken. This bias is not alleviated by calculating the mean number of species per grab. Even with samples drawn from the same theoretical distribution, the total number of species will vary strongly with the number of individuals sampled.

The information content measures of diversity, Brillouin's H and Shannon's H' are often used as measures of species richness. Shannon's H' is the older and more widely used:

$$H' = -\sum p_k \log p_k, \qquad (6)$$

where, p_k is the frequency of species k in the sample, and S is the number of species. Pielou (1977) recommends Brillouin's information content, appreviated H, should be used to calculate the diversity of fully enumerated samples:

$$\textit{Brillouin's } H = \frac{1}{N} * \log\left(\frac{N!}{N_1!\, N_2! \ldots N_s!}\right), \qquad (7)$$

where, N is the total number of individuals in a sample, and N_i is the abundance of species i. Both H and H' can be calculated using Naparien logarithms, $\log_{10}$ or $\log_2$. H' assumes an infinite population, and if used it should include an estimate of the variance. Both are highly sensitive to differences in species evenness. Pielou (1977) regarded this feature as desirable. Deep-sea benthic ecologists often use the Sanders-Hurlbert rarefaction index $E(S_n)$ as an index of species richness. While at large n, the index becomes more sensitive to species richness, it is still very sensitive to differences in species evenness.

Magurran (1988), following May (1975), advocates using the log-series α as a measure of species richness. A MATLAB m.file, logseries.m, that calculates the log-series α and its variance estimator is available from the senior author. Magurran (1988, p. 11) describes the Menhinick species richness index, which is simply the number of species divided by √(number of individuals). This index is similar to Margalef's species richness index which is (Total species-1)/ √(number of individuals).

Species evenness indices

Two samples containing the same number of species can differ in their species diversity. Community ecologists, following Pielou (1977) regard samples with a more equitable distribution of individuals among species as being more diverse. Hurlbert (1971) introduced statistics to measure the evenness component of Brillouin's H, called V, and Shannon's H', called J'. An alternate measure of the evenness component for Brillouin's H is called E. If the individuals are equally distributed among S species, the maximum value for H' is log(S). Both V and J' range from 0 to 1. A sample containing just one species has an undefined evenness.

Simpson's diversity, known as Gini diversity in genetics, is often used as a species richness index, but it is very sensitive to species evenness. Simpson's diversity index has both biased and unbiased estimators. Smith and Grassle (1977) showed that the unbiased estimator for Simpson's diversity is one minus the Sanders-Hurlbert expected number of species at n=2 (Simpson's diversity=$E(S_2)$-1). At such a low rarefaction sample size, Simpson's diversity and $E(S_2)$ are influenced strongly by both species richness and evenness. As shown by Peet (1974) and Smith *et al.* (1979a), there is usually a very strong correlation ($r>0.95$) between Shannon's H' and $E(S_{10})$. This holds for the EMAP-E VP data, but does not hold for species-rich deep-sea communities. Hurlbert's $E(S_n)$ index can be made less sensitive to species evenness component of diversity by increasing n, but there is no set rarefaction sample size n at which point $E(S_n)$ can be regarded as a species richness index. In some deep-sea benthic samples, $E(S_{51})$ is strongly correlated with J', but not with any of the other indices regarded as species richness indices (*e.g.*, H, H', total species per sample, and log-series α).

It would be nice if there were an expected species evenness for a given community. Departures from this expected evenness might indicate disturbance. Caswell (1976) borrowed the Ewens infinite alleles model from population genetics to establish a 'null model' for the expected H', given the number of individuals and species in a sample. The lack of fit to the Caswell neutral model is being used as an index of pollution, especially by Lambshead and co-workers in Great Britain. Goldman and Lambshead (1989) describe a program CASVAR.FOR which they use to fit Caswell's neutral model to benthic data. The Ewens infinite alleles model fits data to a log series, and the results of the neutral model tests are similar to that obtained by fitting the log-series to community structure data. May (1975) was the first to show that rarefaction curves generated from shallow-water data seem to conform to the expectations produced by the log-series (Fisher *et al.* 1943). An unfortunate consequence of applying the neutral model and fitting the log-series to benthic data is that highly impacted, species-poor, benthic communities often depart from the log-series and neutral model expectations in having too equitable a distribution of individuals among species. Warwick (1993)

tested the neutral model using data from a known pollution gradient and concluded that it was a poor predictor of benthic degradation. John Gray proposed that both undisturbed and highly impacted benthic communities should conform to the log-normal distribution. Gray and Mirza (1979) proposed that departures from the log-normal distribution of individuals among species could be used to assess transitions from one 'stable state' to another. Stenseth (1979) provided a mathematical model for Gray's empirical result. Lambshead *et al.* (1983) analyzed the distributions of individuals among species in a number of published benthic data sets, finding that they conformed neither to the log-normal (canonical or otherwise) or log-series. Hughes (1984, 1986) provides analyses and a model showing that the expected number of individuals among species in shallow-water benthic communities is even more inequitable than log-series expectations.

Jackknifed diversity indices

All diversity indices are biased to some extent. Bias corrections exist for H' (Peet 1974). This jackknife method can be applied to any diversity index. Smith and Grassle (1977) showed that $E(S_n)$ is a minimum variance unbiased estimator of diversity, but only if the underlying populations are independently Poisson distributed. Heltshe and Forester (1985) present the jackknife bias correction and variance estimator for the Brillouin and H' diversity estimators. The lead author has adapted this jackknife bias correction for $E(S_n)$ and programmed the algorithm in MATLAB. Organic enrichment often dramatically increases the number of benthic individuals in a sample. Using a strongly biased species richness index, such as 'Total species per event', greatly weakens the utility of diversity as an indicator of pollution effects.

Rarefaction, CNESS and Principal Components Analysis of Hypergeometric probabilities (PCA-H)

The clear and concise description of benthic community structure is fundamental to the analysis of both basic and applied benthic ecological problems. We define community structure as "the variation and covariation of species abundances in time and space."

Sanders' (1968) rarefied species diversity, modified by Hurlbert as $E(S_n)$, and Grassle & Smith's (1976) faunal similarity index NESS are both based on the sample x spp. matrix of hypergeometric probabilities (H). These hypergeometric probabilities are simply the probability of sampling species k in sample i with a random draw of m individuals:

$$H_{iklm} = 1 - \frac{\binom{Total_{i.} - x_{ik}}{m}}{\binom{Total_{i.}}{m}} .$$

$$= 1 - \left[\frac{\frac{(Total_{i.} - x_{ik})!}{m! * (TOTAL_{i.} - x_{ij} - m)!}}{\frac{Total_{i.}!}{m! * (TOTAL_{i.} - m)!}} \right] . \quad (8)$$

$Total_{i.}$ = *the sample total.*

x_{ik} = *the abundance of species k in sample i.*

m=*NESSm*=*Number of individuals to be drawn at random.*

! = *a factorial.*

Any sample by species matrix of counts can be converted quickly to a hypergeometric probability matrix **H**. In the original calculation of NESS and Hurlbert's $E(S_n)$, fractional abundances, that might arise from calculating the mean species abundances in replicate samples, were rounded to integers prior to the calculation of hypergeometric probabilities using factorials. However, this rounding is not a good idea. In all of The lead author's programs for calculating E(Sn), NESS, NNESS, and CNESS, factorials are calculated using the natural log of the Γ (gamma) distribution since $\Gamma(n+1)=n!$. The Γ distribution is continuous, and since it does not require integer values, $E(S_n)$, NNESS, and CNESS can be calculated using non-integer data. The senior author provides FORTRAN and Matlab programs (with documentation) for calculating hypergeometric probabilities, Hurlbert's $E(S_n)$, NESS, and CNESS.

$E(S_n)_i$, or the rarefied species diversity for sample i with a random draw of n individual is simply the row sum of the **H** matrix. It is defined as:

$$E(S_n) = \sum_{k=1}^{S} 1 - \frac{\binom{N-N_k}{n}}{\binom{N}{n}} .$$

where, n = *random sample size.*

$\binom{N}{n}$ = *binomial coefficient.* (9)

= *No. of ways to sample N objects, n at a time.*

$$= \frac{N!}{(N-n)! * n!}$$

N = *Total individuals in sample.*

N_k = *Individuals of species k.*

S = *Number of species.*

Smith and Grassle (1977) determined that $E(S_n)$ was a minimum variance unbiased estimator (MVUE) of diversity and presented equations to estimate the variance of $E(S_n)$.

NESS, NNESS, and CNESS

The NESS faunal similarity index was described by Grassle and Smith (1976). Trueblood *et al.* (1994) correct a flaw in the original index, calling this new version NNESS. They also proposed a metric verson of NNESS, called CNESS. The equations for NNESS and CNESS are shown below:

$$NNESS_{ijm} = \frac{ESS_{ijm}}{\frac{1}{2}*(ESS_{iim} + ESS_{jjm})}$$

$$CNESS_{ijm} = \sqrt{2 * \left(1 - \frac{ESS_{ijm}}{\sqrt{ESS_{iim} * ESS_{jjm}}}\right)} \quad (10)$$

NESS and CNESS are families of similarity and dissimilarity indices. NNESS at its upper and lower sample sizes converges to the Sorensen binary and Morisita similarity indices. NNESS at its upper and lower sample sizes converges to Sorensen's index and the Morisita-Horn similarity index. At a sample size of 1, CNESS is Orloci's (1978) chord distance. Kenkel and Orloci (1986) showed that the chord distance analyzed with non-metric multidimensional scaling (NMDS) was the best of eight procedures tested for recovering the patterns in complex simulated ecological data. No one has apparently described a binary similarity index corresponding to CNESS at $m=\infty$.

Principal Components Analysis of Hypergeometric Probabilities (PCA-H)

There is a major advantage of CNESS over NNESS. While both indices have a straightforward geometric interpretation, CNESS is a metric but NNESS is only a semimetric. CNESS is the Pythagorean distance between the intersection of sample vectors, with positions determined by the **H** matrix, and the unit hypersphere. These intersection points with the unit hypersphere are calculated through a row normalization of the **H** (*i.e.*, the sum of squared elements in each row is 1). Because these distances are chords on the hypersphere, they are called chord distances. CNESS is the chord distance between sample vectors at a distance of one unit from the origin. These Pythagorean distances are calculated in S-dimensional ordination space, where S is the number of species. For samples containing more than 3 species, the human mind cannot perceive the distribution of samples in ordination space. We can perceive the distances among samples only in 2- or 3-dimensional displays.

Principal component analysis projects the major sources of variation in a complex swarm of points in S-dimensional space in fewer dimensions, often only 2 or 3. The first step in a principal components analysis of hypergeometric probabilities, called PCA-H here, is to row-normalize the **H** matrix so that the sum of the squared elements on each row is 1. This is the mathematical equivalent of projecting sample points onto the unit hypersphere. CNESS is the Pythagorean distance among sample points projected onto the hypersphere. Geometrically, these distances are the lengths of chords between points on the hypersphere, hence the name chord distance (reserved for $CNESS_{ijm=1}$). This row-normalized **H** matrix is then centered by column, so that the mean of each column is 0. This new matrix, called **XR**, contains all of the information necessary to calculate CNESS, which is simply the

Pythagorean distance among samples with coordinates specified by the rows of **XR**. Principal components analysis identifies which linear combination of species is most important in determining the CNESS distances among samples. PCA creates a low-dimension projection of **XR** by transforming the original S axes to new axes, now called principal components, that are linear functions of the old. The number of principal components is the minimum of the number of samples or species in the original data. Pythagorean distances between samples plotted with respect to these new axes will be the same as those calculated with the original axes in **XR**. However, these new axes or principal components are derived so that the first axis represents the largest source of variation in CNESS distances among samples. The second and higher principal components reflect less important sources of variation in CNESS distances among samples, and are orthogonal to all previous ordination axes. These principal components are also normed so that the sum of the squared elements of each principal component equals 1. If **V** is the matrix of principal components, with the number of rows equal to number of species and the number of columns equal to the number of components, the first principal component is represented by the first column of the matrix, V(:,1). Orthogonal and normal principal components (=orthonormal) implies that $V(:,j)'*V(:,i) = 0 \; \forall \; i \neq j$ and $V*V'=I$, where **I** is the identity matrix. The positions of each sample in this new multidimensional space, defined by the principal components, are contained in the sample x principal component score matrix **Y**, which can be calculated by: **Y=XR*V**. The Y matrix of principal component scores is identical to that obtained by a principal coordinates analysis of the original CNESS matrix.

The relative amounts of variation explained by each principal component are provided by the sum of the squared principal component scores for each axis, divided by the sum of the squared coordinates for all samples in the original **XR** matrix. If an Eigenanalysis is used to calculate principal components, the percentage of variation explained by each component is the eigenvalue corresponding to that component divided by the sum of the eigenvalues for all components.

There are at least a dozen different algorithms to calculate the principal components of a given data set. These will be summarized in a later section on the matrix algebra of PCA-H. These algorithms can differ greatly in the amount of computer memory required, processing speed and numerical accuracy. The large size of the EMAP-E data set required using some non-standard, but still highly accurate, methods to calculate principal components.

PCA-H retains the information on species frequencies. A simple metric scaling or Principal Coordinates analysis or a Non-metric multidimensional scaling of CNESS distances does not retain the information on which species control contribute to differences in faunal composition among samples. Gabriel's (1971) graphical biplot can retrieve this species frequency data and show the relative importance of each species to the CNESS distances among samples. The biplot reveals those species that account for the major sources of variation in CNESS distances among samples. A graphical biplot of PCA-H results shows the relative CNESS distances among samples and the species that account for the distances. In the biplot, species are represented by vectors (arrows). The terminus for the arrows are the elements of V, which may be called the species loadings. Since the square of these coordinates for each axis sum to 1, the relative lengths of arrows in a 2-dimensional biplot shows the relative importance of each species in controlling the CNESS distances among samples. The sample positions in the first 2 principal components can be calculated using **Y(:,1:2)=XR*V(:,1:2)**. The longer a species' arrow, the more important that species is in controlling the position of samples in a two-dimensional display. The length and direction of the arrow away from the origin are important. The cosine of the angle with each axes is directly related to the principal component loading for that species on that axis. The relative species composition of a sample can be determined by projecting the sample points at right angles onto the longest species vectors. Digby and Kempton (1987) provide a clear description of the use of Gabriel (1971) graphical biplot. Note that the asymmetric display used

by Digby and Kempton, and in this report, is different from and preferable to that originally described by Gabriel.

Ter Braak (1983) came very close to describing the PCA-H method. In his discussion of the geometric relationship between faunal similarity and diversity, he stated that samples might be plotted according to their hypergeometric probabilities. The distances between samples i and j in his proposed ordination would be $\sqrt{(ESS_{ii}+ESS_{jj}-2ESS_{ij})}$. This distance measure would have the unfortunate consequence of having no set upper limit and would be heavily dependent on the diversity of samples.

The full set of MATLAB programs needed to perform all PCA-H analyses in Trueblood *et al.* (1994) are now on the lead author's web page.

Choosing the appropriate sample size, m

The lead author developed a non-parametric procedure using Kendall's non-parametric rank order correlation coefficient (τ=tau) to find a value for m that yielded a distance index that was highly correlated with both the $CNESS_{m=1}$ and $CNESS_{m=large\ n}$ matrices. This procedure is described in Trueblood *et al.* (1994), and the program that performs it (findcnm.m) is provided on the lead author's web page.

The largest sample size m for which NNESS or CNESS can be calculated is set by the minimum sample total in the data set. The original NESS algorithm was even more restrictive, with the largest m being half the minimum sample total. One can extend the range of m by transforming the **H** matrix to 1's and zeros (*i.e.*, the Boolean transform option in COMPAH) and then calculating the chord distance among samples. This procedure is equivalent to calculating CNESS at $m=\infty$.

The m size that is sensitive to both the rare and abundant species varies depending upon the distribution of individuals among species. For most soft-bottom benthic data, m=10-20 is an appropriate sample size. Trueblood *et al.* (1994) found that m=15 was appropriate for an intertidal benthic community. If the species distributions are heavily dominated by one or a few species, then m should be increased above 10. A NESSm value of 20-25 appears optimal for the EMAP-E data.

Interpreting the graphical displays:

Graphical biplots

The biplot produced by PCA-H is the asymmetrical Euclidean distances biplot. The plot presents a low-dimensional projection of the samples, representing the best least-squares fit of the original CNESS distances. For this reason, samples will always be less than $\sqrt{2}$ units apart.

Species are plotted as vectors. The relative frequencies of a species in a sample can be estimated by projecting the sample orthogonally onto the appropriate species vector. Only one tail of the species vector is shown, but each species vector projects in the opposite direction as well. The origin represents the mean frequencies of a species in the normalized H matrix. The length of the species vectors indicates the importance of that species in that 2-dimensional projection.

Digby and Kempton (1987) provide a particularly clear explanation of how the Euclidean distance biplot method can be used to recover the basic structure of the original data matrix.

This biplot method is different from the dual display biplot in correspondence analysis (see Greenacre 1984). That biplot is a symmetric biplot in which both samples and species are plotted in scaled coordinates. In that display, the angles between samples and species vectors determine the association between a given species and sample.

The asymmetric Gabriel Euclidean distance biplot display should not be used to examine the statistical association among species (*i.e.*, the R-mode ordination). To analyze the association of species among samples, the species should be plotted in scaled coordinates such that the sum of the squared species coordinates in each dimension equals the eigenvalue for that dimension (Legendre and Legendre 1983). This scaling, called the covariance biplot, is performed using the MATLAB m.file rmode.m. Non-significant species vectors are not labeled. The data can also be clustered using the same similarity measure, the angle between species vectors. COMPAH can perform this clustering using the following steps:

1) Calculate the hypergeometric probability matrix, **H**
2) Standardize the **H** matrix by station (the sum of squared **H** elements for each station will sum to 1)
3) Cluster using Pearson's r (the equivalent of clustering based on the angular cosines among species vectors in the r-mode plot)

Some applications of the Gabriel biplot method rescale the species vectors uniformly to aid in the projection of samples onto species vectors. As noted by Gower (1987), this is not a good idea. The endpoint of a species vector indicates the maximum value for a species. If a sample point is plotted at a greater distance than the tip of a species vector, then its position is determined by a combination of species.

The Geometry of Sanders-Hurlbert E(S_n) and CNESS

A simple 3-species, 3-sample data set is used to demonstrate the geometric interpretation of the Sanders-Hurlbert E(Sn) diversity index and CNESS. Both are related to distances among samples and the origin when sample points are plotted using the hypergeometric probability matrix **H**.

Figure 22 shows the position of three sample points, A-C, in a 3-dimensional space determined by the abundances of Species 1-3. The Euclidean distances among sample points in this species space is a very poor indicator of faunal similarity. One of the more troubling aspects of straight Euclidean distance is the 'double-zero' problem. Samples sharing no species will appear similar because they both have sample coordinates near the origin.

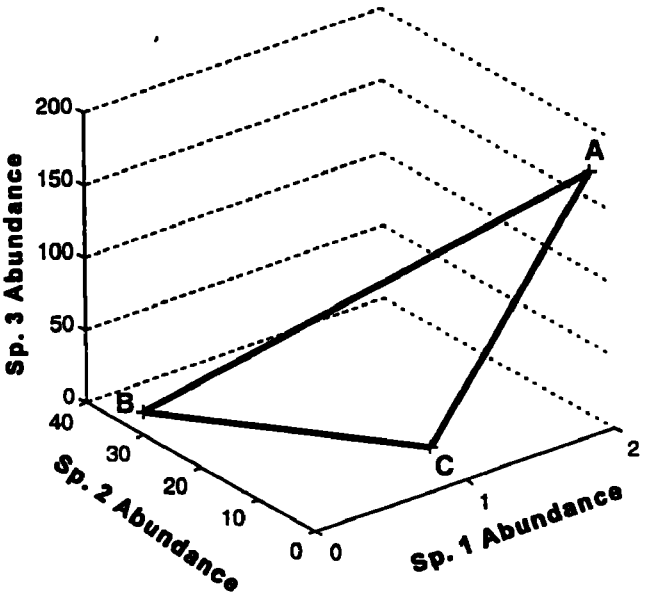


Figure 23. Three samples are plotted in species space. The Pythagorean distance among samples is a poor, unbounded, distance measure of faunal similarity. Note the greatly compressed vertical scale.

Plotting samples by the relative frequencies of species in samples (Figure 24) is an excellent basis for ordination. Using such a plot, ter Braak (1983) describes the geometric interpretation of faunal similarity and Gini-Simpson diversity index. Unfortunately, Euclidean distances among sample points determined solely by species frequencies are often very insensitive to the rarer species in a community.

Figure 25 shows the Sanders-Hurlbert rarefaction curves for the three samples. Sample C has the same three species as sample A but has greater evenness. Sample A is as species-rich as sample C, but the equitability among species frequencies is low.

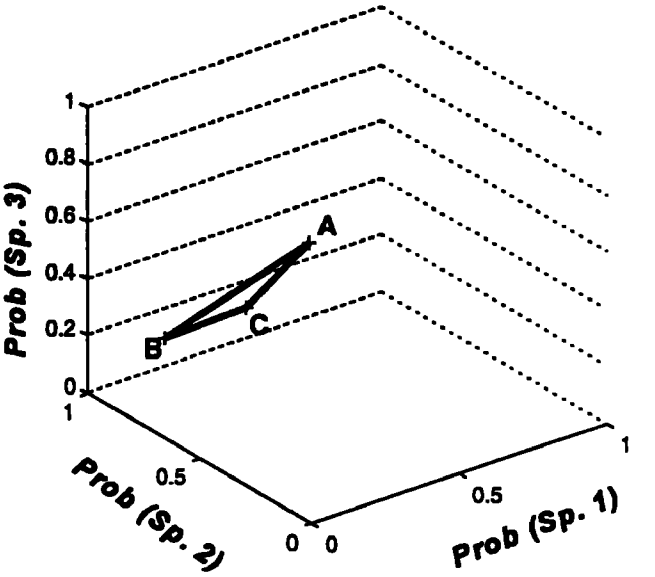


Figure 24.The same three stations can be plotted using the probability that they will be sampled with a random draw of 1, 2, or m individuals (the hypergeometric probabilities). The H(m=1) sample coordinates are shown.

There is a straightforward geometric interpretation of the rarefaction curves shown in Figure 25. The Sanders-Hurlbert $E(S_n)$ is the City-Block distance (=Manhattan metric) from the origin to the sample point plotted using hypergeometric probabilities. This city block distance is shown in Figure 26.

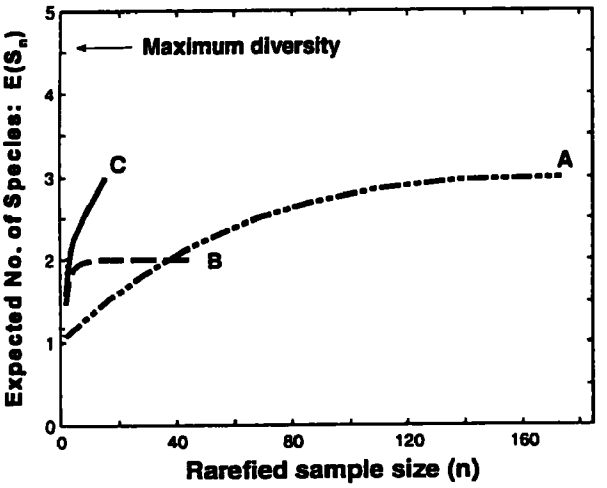


Figure 25. The Sanders-Hurlbert rarefaction curves for the three samples shown in the previous figures. While A and C have the same species rihcness (all 3 species), sample C has the greater evenness.

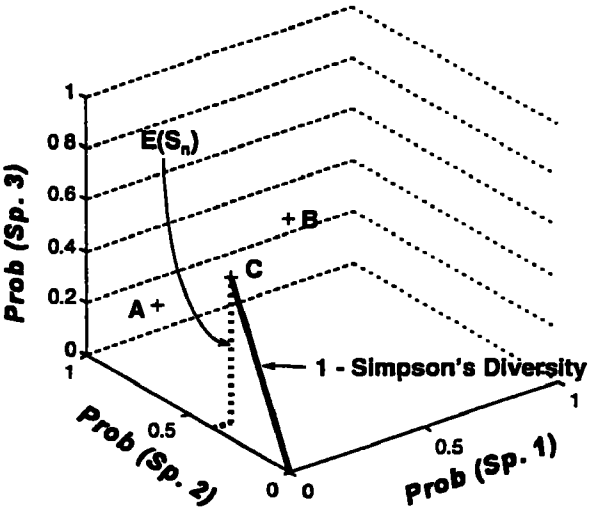


Figure 26. The Sanders-Hurlbert diversity from the previous picture is the city-block distance between the origin and the sample point, with points plotted using hypergeometric probabilities. The Euclidena distance to the origin is $\sqrt{ESS_n}$. At m=1, the distance between a sample point and the origin is Simpson's diversity; the closer to the origin, the higher the diversity (ter Braak 1983).

Figure 27 shows the position of sample points plotted using hypergeometric probabilities at NESSm values from 1 to 40. Both the Pythagorean distance and city-block distance between the origin and sample points increases monotonically. The city block distance is $E(S_n)$, and it is this distance that is plotted in rarefaction curves (*e.g.*, Figure 25). With increasing NESSm, the probability of sampling at least one individual of the abundant taxa approaches 1.0. That is why both CNESS and NNESS become relatively insensitive to changes in the abundance of dominant species at large random sample sizes.

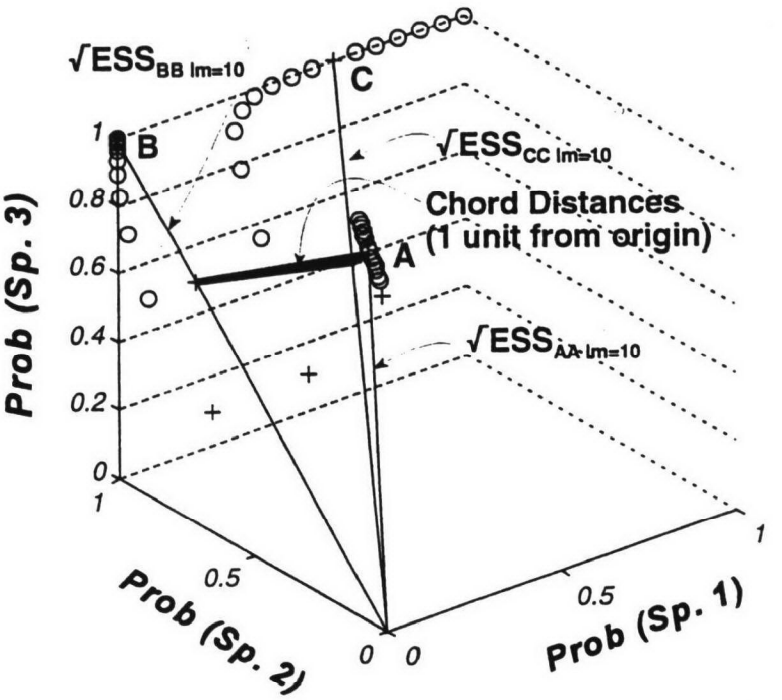


Figure 27. $CNESS_{m=10}$ is the Euclidean distance between sample points 1 unit from the origin on the vectors connecting the origin and sample positions set with $\boldsymbol{H}_{m=10}$. The original species frequencies are plotted as +'s.

Figure 27 shows the chord distances among sample vectors at a distance one unit from the origin. These coordinates are from the row-normalized **H** matrix. The distances among these points are the CNESS faunal distances. These distances also serve as chords along the unit hypersphere and are also known as chord distances.

Figure 28 shows the same configuration of points as in Figure 27 after subtracting the mean value for each species (centering). Centering the normalized H matrix leaves the distances among points unaltered but rigidly translates the data points so that the centroid is at the origin. If the data are not centered prior to PCA, then the distances among stations are reflected in the second and higher PCA axes. The first PCA axis serves only to center the data.

Figure 29 shows the results of the metric scaling of the three sample points using NESSm=1 (identical to performing a Principal coordinates analysis of Orloci's chord distance or a PCA-H with NESSm=1) and NESSm=10. A Procrustes rotation (Digby and Kempton 1987) was used to rigidly rotate the PCA-H (NESSm=1) ordination to fit the PCA-H (NESSm=10) ordination.

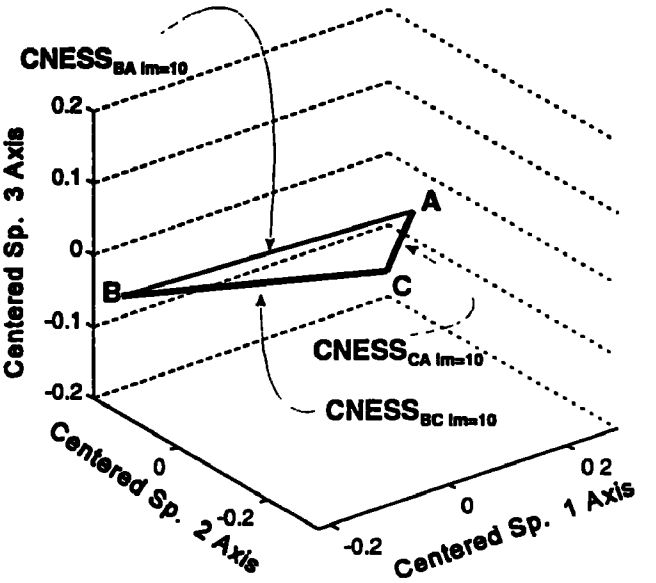


Figure 28. After centering the normalized data by species, the CNESS distances from the previous plot can be seen more clearly. Principal components analysis will show the planar projection of this 3-d configuration.

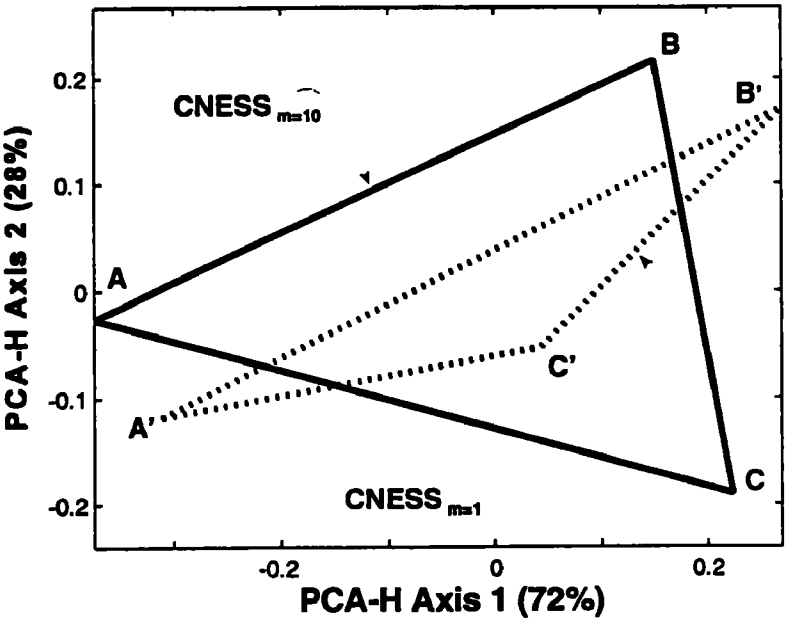


Figure 29. The CNESS distances among sample points at NESSm=1 (Orloci's chord distance) [dotted lines] and CNESS (NESSm=10) [solid lines]. These plots are identical to those produced using principal coorndinates analysis of Orloci's chord distance (=PCA-H with NESSm=1).

The Gabriel Euclidean distance biplots for the two metric scalings shown in Figure 29 are shown in Figures 30 and 31. Species 1, the rarest of the three species in the data contributes virtually nothing to the CNESS distances among samples (note that only 3% of the CNESS variation is expressed on the 2nd PCA-H axis).

With NESSm=10, Species 1 becomes an important contributor to CNESS distances (Figure 31)

Figure 32 shows the Gabriel covariance plot of species vectors. The R-mode clustering of the normalized **H** matrix using Pearson's r is mathematically equivalent to clustering species using the cosine of the angles among species vectors in the covariance biplot.

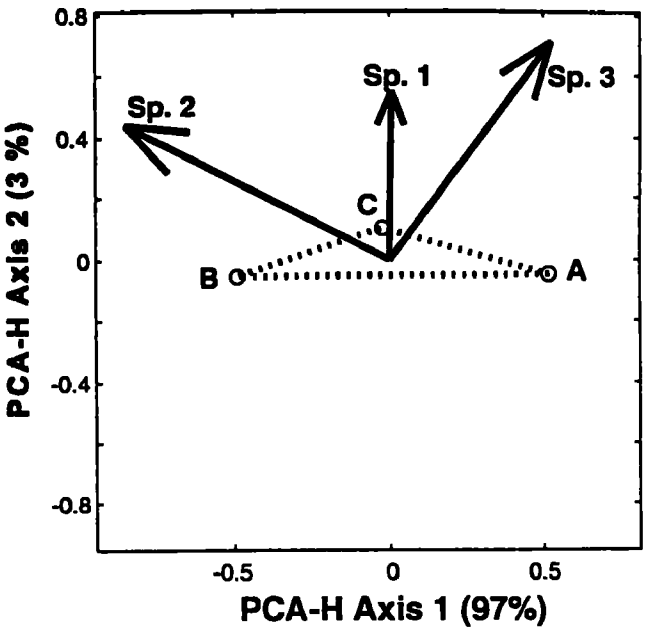


Figure 30. The Gabriel Euclidean distance biplot showing the species contribution to CNESS distance at NESSm=1. Species 1 contributes little to CNESS distance). Only 3% of the variation is on Axis 2.

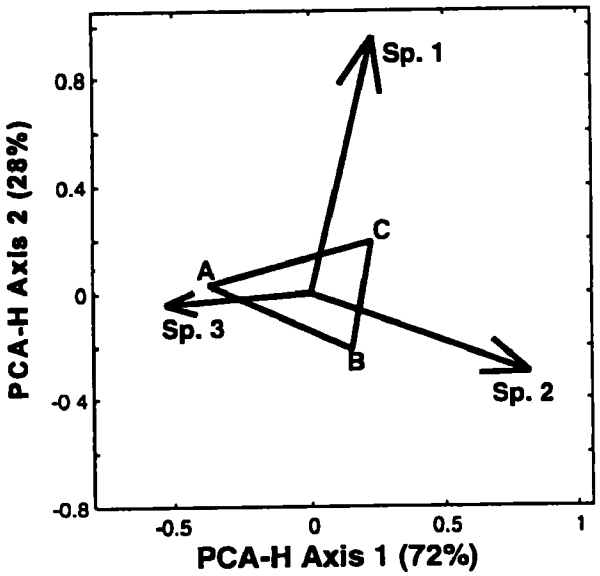


Figure 31. The Gabriel Euclidean distance biplot for CNESS (m=10). Species 1, the rarest species, now contributes much more to CNESS distances among samples and PCA-H axis 2 explains 28% of the variance in CNESS.

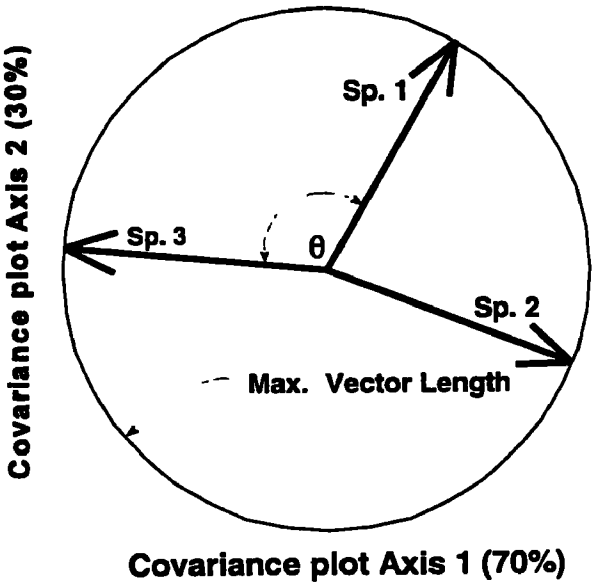


Figure 32. The covariance plot showing the inverse relationship between the frequencies of Species 2 and 3. The cosine of angles among species vectors can be clustered for na R-mode analysis (see Trueblood et al. 1994.)

APPENDIX II TERMS AND DEFINITIONS

Arch Effect (=Kendall's horseshoe) The horse-shoe like shape produced when coenocline data are analyzed using Q-mode ordination. The arch can be observed in most forms of PCA and non-metric multidimensional scaling. The arch has at least two and perhaps three causes and no clear-cut solutions other than plotting using the appropriate full dimensionality:

(1) In principal coordinate analysis and non-metric multidimensional scaling, the similarity or dissimilarity values may "bottom out" so that samples sharing no species cannot be ranked. Williamson's step-across procedure has been proposed as a solution to this problem.

(2) non-linearity in the data. Most Eigenanalysis procedures fit a linear, additive model to the data. If species abundances are not linearly related to each other, the arch phenomenon occurs.

(3) Inherently, high-dimension data. For example, when the frequency of heterozygotes, homozygous recessive, and homozygous genotypes is analyzed by CA, a 2-dimensional arched structure is produced.

Centered data Data presented as deviations from their mean value.

Centered SSCP matrix In standard PCA, data are usually (but not always standardized by the mean (*i.e.*, centered). For Q-mode analysis, the mean of each species is usually subtracted from each species' cell. The centered SSCP matrix is the sum of squares and cross products matrix formed by multiplying the data matrix by its transpose.

Correlation A standardized form of covariance obtained by dividing the covariance of two variables by the product of the standard deviations of x and y.

Covariance a measure of association between 2 variables; covariance is the mean of the cross products of the centered data; expected value of the sum of cross products between 2 variables expressed as deviations from their respective mean. The covariance between z-transformed variables is also known as correlation.

DPCA-H Coats' (1995) term for detrended Principal components analysis of hypergeometric probabilities.

Eigenanalysis The process of finding the eigenvalue-eigenvector pairs of a square matrix A. The eigenvalues are the elements of the diagonal matrix L and the eigenvectors are the columns of U where A=U'LU.

eigenvalues (=characteristic values, latent values) a set of real or even imaginary scalars which can be used with their associated eigenvectors as an alternate description of a square matrix A. An N x N matrix A is said to have an eigenvector **u** and corresponding eigenvalue λ if

$$A\boldsymbol{u} = \lambda\boldsymbol{u}.$$

Every square, full-rank matrix A can be decomposed into a product of the diagonal eigenvalue matrix L and eigenvector matrix U such that: A=U'LU, where U' is the transpose of the U matrix.

eigenvectors a column vector associated with its respective eigenvalue; Normalized eigenvectors of unit length (sum of squares of elements equal 1.0) are the principal components. **Right eigenvectors u_R** satisfy:

$$Au_R = \lambda u_R \tag{12}$$

where, λ is the eigenvalue associated with the eigenvector u_r and **A** is a square matrix. left eigenvectors u_L satisfy:

$$u_L A = \lambda u_L \tag{13}$$

Every left eigenvector is the transpose of a right eigenvector of the transpose of **A**. The left and right eigenvalues are identical.

Graphical biplot Legendre and Legendre (1983) review this technique, introduced by Gabriel (1971). Greenacre addresses the graphical biplot, or joint display in Correspondence analysis. There are 3 types of graphical biplots. In the first, the variable loadings for the R-mode PCA are normalized so that the sum of squares of loadings equal the eigenvalue for the axis. The site scores are normalized so that the sum of squared PCA scores on each is are one. This is a **covariance biplot.** In this scaling, the angle between arrows of each pair of species, plotted as vectors provides an approximation of their pair-wise correlation, *i.e.*, $r \approx \cos\theta$. The orthogonal projection of sites onto species vectors indicates the rank order of sites with respect to that species.

In the second form of graphical biplot called the **Euclidean distance plot**, the eigenvectors (species loadings) are standardized to unit sums of squares and the site scores are standardized so that the sums of squares equals the eigenvalue of each axis (a normalized eigenvector times the vector of observations will produce site scores with a sum of squares = λ). This plot is intended to preserve the Euclidean distances between sites and is called a **Euclidean distance plot.**

Greenacre (1984) calls both of these plots asymmetric, since the sites and variables are scaled differently. The third type of graphical biplot is the symmetric biplot where sites and variable vectors are scaled so that the sum of squared elements equals the eigenvalue.

Loadings The elements of the eigenvectors are also the weights or **loadings** of the various original descriptors. If the eigenvectors have been normalized to unit length (*i.e.*, the sum of the squared loadings for a variable across factors equals 1.0), then the elements of the eigenvector matrix (the loadings) are direction cosines of the angles between the original descriptors and the principal axes. So that if the element of the U vector (the loading for a variable) is .8944, the angle is $\cos^{-1}$ (.8944)=arc cos(.8944)=26° (Legendre and Legendre 1983).

normalization A term often misused by environmental scientists. Normalization refers to the standardization of an n-dimensional vector to unit length (*i.e.*, a projection of a data point onto the unit hypersphere). The etymology of normalization is from *norm*, the length of a vector. There are an infinite number of eigenvectors associated with each eigenvalue. PCA and FA normalize these eigenvectors to either the unit length or the square of the eigenvalue.

Ordination **Direct ordination** The process of arranging sites (or species) in relation to one or more environmental (or successional) gradients or to abstract axes representing such gradients.

Indirect ordination a collective term for continuous multivariate techniques which arrange objects (*e.g.*, sites or species) along axes, regardless of the interpretation of the axes.

Pielou (1984): Ordination is a procedure for adapting a multidimensional swarm of data points in such a way that when it is projected onto a two-space (*e.g.*, a sheet of paper) any intrinsic pattern the swarm may possess becomes apparent.

orthogonal factors factors that are not correlated with each other.

Orthogonal matrix A square matrix that when used as a transformation matrix, causes a rigid rotation of the data swarm without any change of scale. The product of an orthogonal matrix and its transpose is the identity matrix (Pielou, 1984, p. 253): **A'A=AA'=I**, where **I** is the identity matrix.

PCA-H Principal component analysis of hypergeometric probabilities (Gallagher *et al.* 1992, Trueblood *et al.* 1994.

principal component method Developed by Hotelling. PCA is simply the rotation of the original system of axes in the multidimensional space. The principal axes are orthogonal and the eigenvalues measure the amount of variance associated with each principal axis. PCA is used to summarize in a few important dimensions the greatest part of the variability of a dispersion matrix of a large number of descriptors (R mode) or cases (Q-mode).

principal component scores the value of a principal component for individual points, hence the new coordinates of data points measured along axes created by the principal component method. A principal component score can be regarded as an additional variable for each case, this variable is a linear function of the original variables.

principal coordinates analysis An ordination based on a metric similarity or dissimilarity matrix.

Q-mode, R-mode Legendre & Legendre (1983, p. 172). The measurement of dependence between two descriptors (variables) is achieved my means of coefficients like Pearson's product-moment correlation, r. This type of study of the data matrix is therefore called an **R analysis**. In contrast, a study of an ecological data matrix based upon the relationship between objects is called **Q analysis**. Many authors (*e.g.*, Pielou 1984) reverse this conventional usage.

SSCP the sum-of-squares-and-cross-products matrix. the matrix formed by multiplying a matrix times its transpose. The (i,i)th element is the sum of squares of the *i*th variable. The (*h*,*i*)th element is the sum of cross-products of the *h*'th and *i*th variables.

standardization- an algebraic operation (*e.g.*, x_{ij}/(standard deviation of x_j) performed on a variable or site vector to achieve a desired property (*e.g.*, non-dimensionality, common variance). Standardization requires calculation of the row or column sums of a data matrix. Data measured on different scales must be standardized prior to analysis. Norm standardization is dividing each element by $\sqrt{\sum (x_i)^2}$. If the data have been previously centered, then dividing the centered variables by the norm is equivalent to dividing the original variable by the standard deviation.

transformation A transformation can be performed without knowledge of the row or column sums of a data matrix. A standardization requires such knowledge.

variance a measure of the dispersion of a variable; defined as the sum of squared deviations from the mean divided by the number of cases or entities.

APPENDIX III FULL EMAP-E VIRGINIAN PROVINCE MODIFIED FAUNAL LIST

This appendix shows the full EMAP-E VP faunal list. It also shows which EMAP-E VP faunal groupings must be dropped and those that must be pooled to replicate the community structure analyses in this report.

EMAP-E VP SPECIES CODES

VALID TAXA

NO	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
1	AMPHARCT	*Ampharete arctica*	Annelida	Polychaeta	Ampharetidae
2	ANOBGRAC	*Anobothrus gracilis*	Annelida	Polychaeta	Ampharetidae
3	ASABOCUL	*Asabellides oculata*	Annelida	Polychaeta	Ampharetidae
4	HOBSFLOR	*Hobsonia florida*	Annelida	Polychaeta	Ampharetidae
5	MELIMACU	*Melinna maculata*	Annelida	Polychaeta	Ampharetidae
6	PSEUPAUC	*Pseudeurythoe paucibranchiata*	Annelida	Polychaeta	Amphinomidae
7	ARABSPEA	*Arabellidae sp. A Morris*	Annelida	Polychaeta	Arabellidae
8	DRILLONG	*Drilonereis longa*	Annelida	Polychaeta	Arabellidae
9	DRILSPEB	*Drilonereis sp. B Gardiner*	Annelida	Polychaeta	Arabellidae
10	NOTOSPIN	*Notocirrus spiniferus*	Annelida	Polychaeta	Arabellidae
11	AMASCAPE	*Amastigos caperatus*	Annelida	Polychaeta	Capitellidae
12	HETEFILI	*Heteromastus filiformis*	Annelida	Polychaeta	Capitellidae
13	MEDIAMBI	*Mediomastus ambiseta*	Annelida	Polychaeta	Capitellidae
14	MEDICALI	*Mediomastus californiensis*	Annelida	Polychaeta	Capitellidae
15	NOTOLOBA	*Notomastus lobatus*	Annelida	Polychaeta	Capitellidae
16	NOTOLURI	*Notomastus luridus*	Annelida	Polychaeta	Capitellidae
17	NOTOSPA	*Notomastus sp A Ewing*	Annelida	Polychaeta	Capitellidae
18	CHAEVARI	*Chaetopterus variopedatus*	Annelida	Polychaeta	Chaetopteridae
19	SPIOCOST	*Spiochaetopterus costarum*	Annelida	Polychaeta	Chaetopteridae
20	BHAWHETE	*Bhawania heteroseta*	Annelida	Polychaeta	Chrysopetalidae
21	CAULBIOC	*Caulleriella cf. bioculata*	Annelida	Polychaeta	Cirratulidae
22	CAULSPEB	*Caulleriella sp. B Blake*	Annelida	Polychaeta	Cirratulidae
23	CIRRGRAN	*Cirriformia grandis*	Annelida	Polychaeta	Cirratulidae
24	THARACUT	*Tharyx acutus*	Annelida	Polychaeta	Cirratulidae
25	THARSPA	*Tharyx sp. A Morris*	Annelida	Polychaeta	Cirratulidae
26	COSSSOYE	*Cossura longocirrata*	Annelida	Polychaeta	Cossuridae
27	DORVRUDO	*Dorvillea rudolphi*	Annelida	Polychaeta	Dorvilleidae
28	DORVSPEA	*Dorvilleidae sp. A Hilbig*	Annelida	Polychaeta	Dorvilleidae
29	MEIOSPEA	*Meiodorvillea sp. A Morris*	Annelida	Polychaeta	Dorvilleidae
30	PAROCAEC	*Parougia caeca*	Annelida	Polychaeta	Dorvilleidae
31	PROTKEFE	*Protodorvillea kefersteini*	Annelida	Polychaeta	Dorvilleidae
32	MARPBELL	*Marphysa belli*	Annelida	Polychaeta	Eunicidae
33	MARPSANG	*Marphysa sanguinea*	Annelida	Polychaeta	Eunicidae
34	BRADVILL	*Brada villosa*	Annelida	Polychaeta	Flabelligeridae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
35	PHERAFFI	*Pherusa affinis*	Annelida	Polychaeta	Flabelligeridae
36	GLYCAMER	*Glycera americana*	Annelida	Polychaeta	Glyceridae
37	GLYCDIBR	*Glycera dibranchiata*	Annelida	Polychaeta	Glyceridae
38	GLYCROBU	*Glycera robusta*	Annelida	Polychaeta	Glyceridae
39	HEMIROSE	*Hemipodus roseus*	Annelida	Polychaeta	Glyceridae
40	GLYCSOLI	*Glycinde solitaria*	Annelida	Polychaeta	Goniadidae
41	GONIGRAC	*Goniadella gracilis*	Annelida	Polychaeta	Goniadidae
42	OPHIGIGA	*Ophioglycera gigantea*	Annelida	Polychaeta	Goniadidae
43	GYPTVITT	*Gyptis crypta*	Annelida	Polychaeta	Hesionidae
44	MICRABER	*Microphthalmus aberrans*	Annelida	Polychaeta	Hesionidae
45	MICRFRAG	*Microphthalmus fragilis*	Annelida	Polychaeta	Hesionidae
46	MICRSCZE	*Microphthalmus sczelkowii*	Annelida	Polychaeta	Hesionidae
47	.MICRSIMI	*Microphthalmus similis*	Annelida	Polychaeta	Hesionidae
48	PARALUTE	*Parahesione luteola*	Annelida	Polychaeta	Hesionidae
49	PODAOBSC	*Podarke obscura*	Annelida	Polychaeta	Hesionidae
50	PODALEVI	*Podarkeopsis levifuscina*	Annelida	Polychaeta	Hesionidae
51	NINONIGR	*Ninoe nigripes*	Annelida	Polychaeta	Lumbrineridae
52	LUMBACIC	*Scoletoma acicularum*	Annelida	Polychaeta	Lumbrineridae
53	SCOLHEBE	*Scoletoma hebes*	Annelida	Polychaeta	Lumbrineridae
54	LUMBTENI	*Scoletoma tenuis*	Annelida	Polychaeta	Lumbrineridae
55	CLYMTORQ	*Clymenella torquata*	Annelida	Polychaeta	Maldanidae
56	MACRZONA	*Macroclymene zonalis*	Annelida	Polychaeta	Maldanidae
57	SABAELON	*Sabaco elongatus*	Annelida	Polychaeta	Maldanidae
58	AGLACIRC	*Aglaophamus circinata*	Annelida	Polychaeta	Nephtyidae
59	AGLAVERR	*Aglaophamus verrilli*	Annelida	Polychaeta	Nephtyidae
60	NEPHBUCE	*Nephtys bucera*	Annelida	Polychaeta	Nephtyidae
61	NEPHCRYP	*Nephtys cryptomma*	Annelida	Polychaeta	Nephtyidae
62	NEPHINCI	*Nephtys incisa*	Annelida	Polychaeta	Nephtyidae
63	NEPHPICT	*Nephtys picta*	Annelida	Polychaeta	Nephtyidae
64	CERAIRRI	*Ceratonereis irritabilis*	Annelida	Polychaeta	Nereididae
65	LAEOCULV	*Laeonereis culveri*	Annelida	Polychaeta	Nereididae
66	NEANAREN	*Neanthes arenaceodentata*	Annelida	Polychaeta	Nereididae
67	NEANSUCC	*Neanthes succinea*	Annelida	Polychaeta	Nereididae
68	NEANVIRE	*Neanthes virens*	Annelida	Polychaeta	Nereididae
69	NEREGRAY	*Nereis gravi*	Annelida	Polychaeta	Nereididae
70	PLATDUME	*Platynereis dumerilii*	Annelida	Polychaeta	Nereididae
71	DIOPCUPR	*Diopatra cuprea*	Annelida	Polychaeta	Onuphidae
72	ONUPEREM	*Onuphis eremita*	Annelida	Polychaeta	Onuphidae
73	OPHEBICO	*Ophelia bicornis*	Annelida	Polychaeta	Opheliidae
74	OPHEACUM	*Ophelina acuminata*	Annelida	Polychaeta	Opheliidae
75	TRAVSPEA	*Travisia sp. A Morris*	Annelida	Polychaeta	Opheliidae
76	TRAVSPEB	*Travisia sp B Morris*	Annelida	Polychaeta	Opheliidae
77	LEITFRAG	*Leitoscoloplos fragilis*	Annelida	Polychaeta	Orbiniidae
78	LEITROBU	*Leitoscoloplos robustus*	Annelida	Polychaeta	Orbiniidae
79	ORBIRISE	*Orbinia riseri*	Annelida	Polychaeta	Orbiniidae
80	ORBISWAN	*Orbinia swani*	Annelida	Polychaeta	Orbiniidae
81	SCOLCAPE	*Scoloplos capensis*	Annelida	Polychaeta	Orbiniidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
82	SCOLRUBR	*Scoloplos rubra*	Annelida	Polychaeta	Orbiniidae
83	MYRIOCUL	*Galathowenia oculata*	Annelida	Polychaeta	Oweniidae
84	OWENFUSI	*Owenia fusiformis*	Annelida	Polychaeta	Oweniidae
85	ARICCATH	*Aricidea catherinae*	Annelida	Polychaeta	Paraonidae
86	ARICCERU	*Aricidea cerrutti*	Annelida	Polychaeta	Paraonidae
87	ARICFRAG	*Aricidea fragilis*	Annelida	Polychaeta	Paraonidae
88	ARICWASS	*Aricidea wassi*	Annelida	Polychaeta	Paraonidae
89	CIRRSPEA	*Cirrophorus sp. A Morris*	Annelida	Polychaeta	Paraonidae
90	CIRROSPB	*Cirrophorus sp B Morris*	Annelida	Polychaeta	Paraonidae
91	LEVIGRAC	*Levinsenia gracilis*	Annelida	Polychaeta	Paraonidae
92	LEVISPEA	*Levinsenia sp A Morris*	Annelida	Polychaeta	Paraonidae
93	PARADSPB	*Paradoneis sp B Morris*	Annelida	Polychaeta	Paraonidae
94	PARAFULG	*Paraonis fulgens*	Annelida	Polychaeta	Paraonidae
95	PARAPYGO	*Paraonis pygoenigmatica*	Annelida	Polychaeta	Paraonidae
96	PECTGOUL	*Pectinaria gouldii*	Annelida	Polychaeta	Pectinariidae
97	EUMISANG	*Eumida sanguinea*	Annelida	Polychaeta	Phyllodocidae
98	HESIELON	*Hesionura elongata*	Annelida	Polychaeta	Phyllodocidae
99	ETEOFOLI	*Hypereteone foliosa*	Annelida	Polychaeta	Phyllodocidae
100	ETEOHETE	*Hypereteone heteropoda*	Annelida	Polychaeta	Phyllodocidae
101	HYPELONG	*Hypereteone longa*	Annelida	Polychaeta	Phyllodocidae
102	PARASPEC	*Paranaitis speciosa*	Annelida	Polychaeta	Phyllodocidae
103	PHYLAREN	*Phyllodoce arenae*	Annelida	Polychaeta	Phyllodocidae
104	PHYLMACU	*Phyllodoce maculata*	Annelida	Polychaeta	Phyllodocidae
105	PHYLMUCO	*Phyllodoce mucosa*	Annelida	Polychaeta	Phyllodocidae
106	ANCIHART	*Ancistrosyllis hartmanae*	Annelida	Polychaeta	Pilargidae
107	ANCIJONE	*Ancistrosyllis jonesi*	Annelida	Polychaeta	Pilargidae
108	CABIINCE	*Cabira incerta*	Annelida	Polychaeta	Pilargidae
109	SIGABASS	*Sigambra bassi*	Annelida	Polychaeta	Pilargidae
110	SIGATENT	*Sigambra tentaculata*	Annelida	Polychaeta	Pilargidae
111	PISIREMO	*Pisione remota*	Annelida	Polychaeta	Pisionidae
112	HARMEXTE	*Harmothoe extenuata*	Annelida	Polychaeta	Polynoidae
113	HARMIMBR	*Harmothoe imbricata*	Annelida	Polychaeta	Polynoidae
114	HARMMACG	*Harmothoe macgintiei*	Annelida	Polychaeta	Polynoidae
115	HARTMOOR	*Hartmania moorei*	Annelida	Polychaeta	Polynoidae
116	LEPICOMM	*Lepidametria commensalis*	Annelida	Polychaeta	Polynoidae
117	LEPISQUA	*Lepidonotus squamatus*	Annelida	Polychaeta	Polynoidae
118	LEPISUBL	*Lepidonotus sublevis*	Annelida	Polychaeta	Polynoidae
119	LEPIVARI	*Lepidonotus variabilis*	Annelida	Polychaeta	Polynoidae
120	MALMSPA	*Malmgreniella sp. A Weston*	Annelida	Polychaeta	Polynoidae
121	MALMSPEB	*Malmgreniella sp B Weston*	Annelida	Polychaeta	Polynoidae
122	PROTCHAE	*Protodriloides chaetifer*	Annelida	Polychaeta	Protodrilidae
123	SABEVULG	*Sabellaria vulgaris*	Annelida	Polychaeta	Sabellariidae
124	CHONINFU	*Chone infundibuliformis*	Annelida	Polychaeta	Sabellidae
125	DEMOMICR	*Demonax microphthalmus*	Annelida	Polychaeta	Sabellidae
126	EUCHELEG	*Euchone elegans*	Annelida	Polychaeta	Sabellidae
127	EUCHINCO	*Euchone incolor*	Annelida	Polychaeta	Sabellidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
128	LAONKROY	*Laonome kroeyeri*	Annelida	Polychaeta	Sabellidae
129	MANAAEST	*Manayunkia aestuarina*	Annelida	Polychaeta	Sabellidae
130	MYXIINFU	*Myxicola infundibulum*	Annelida	Polychaeta	Sabellidae
131	PSEURENI	*Pseudopotamilla reniformis*	Annelida	Polychaeta	Sabellidae
132	SCALINFL	*Scalibregma inflatum*	Annelida	Polychaeta	Scalibregmatidae
133	PHOLMINU	*Pholoe minuta*	Annelida	Polychaeta	Sigalionidae
134	SIGAAREN	*Sigalion arenicola*	Annelida	Polychaeta	Sigalionidae
135	STENBOA	*Sthenelais boa*	Annelida	Polychaeta	Sigalionidae
136	STHELIMI	*Sthenelais limicola*	Annelida	Polychaeta	Sigalionidae
137	APOPPYGM	*Apoprionospio pygmaea*	Annelida	Polychaeta	Spionidae
138	BOCLHAMA	*Boccardiella hamata*	Annelida	Polychaeta	Spionidae
139	BOCCLIGE	*Boccardiella ligerica*	Annelida	Polychaeta	Spionidae
140	CARAHOBS	*Carazziella hobsonae*	Annelida	Polychaeta	Spionidae
141	DISPUNCI	*Dispio uncinata*	Annelida	Polychaeta	Spionidae
142	MAREVIRI	*Marenzelleria viridis*	Annelida	Polychaeta	Spionidae
143	PARAPINN	*Paraprionospio pinnata*	Annelida	Polychaeta	Spionidae
144	POLYAGGR	*Polydora aggregata*	Annelida	Polychaeta	Spionidae
145	POLYCAUL	*Polydora cauleryi*	Annelida	Polychaeta	Spionidae
146	POLYCORN	*Polydora cornuta*	Annelida	Polychaeta	Spionidae
147	POLYGIAR	*Polydora giardi*	Annelida	Polychaeta	Spionidae
148	POLYQUAD	*Polydora quadrilobata*	Annelida	Polychaeta	Spionidae
149	POLYSOCI	*Polydora socialis*	Annelida	Polychaeta	Spionidae
150	POLYWEBS	*Polydora websteri*	Annelida	Polychaeta	Spionidae
151	PRIOHETE	*Prionospio heterobranchia*	Annelida	Polychaeta	Spionidae
152	PRIOPERK	*Prionospio perkinsi*	Annelida	Polychaeta	Spionidae
153	PRIOSTEE	*Prionospio steenstrupi*	Annelida	Polychaeta	Spionidae
154	PYGOELEG	*Pygospio elegans*	Annelida	Polychaeta	Spionidae
155	SCOLBOUS	*Scolelepis bousfieldi*	Annelida	Polychaeta	Spionidae
156	SCOLQUAD	*Scolelepis quadrilobata*	Annelida	Polychaeta	Spionidae
157	SCOLSQUA	*Scolelepis squamata*	Annelida	Polychaeta	Spionidae
158	SCOLTEXA	*Scolelepis texana*	Annelida	Polychaeta	Spionidae
159	SPIOFILI	*Spio filicornis*	Annelida	Polychaeta	Spionidae
160	SPIOLIMI	*Spio limicola*	Annelida	Polychaeta	Spionidae
161	SPIOSETO	*Spio setosa*	Annelida	Polychaeta	Spionidae
162	SPIOBOMB	*Spiophanes bombyx*	Annelida	Polychaeta	Spionidae
163	STREBENE	*Streblospio benedicti*	Annelida	Polychaeta	Spionidae
164	STERSCUT	*Sternaspis scutatus*	Annelida	Polychaeta	Sternaspidae
165	AUTOSPEA	*Autolytus sp. A Glasby*	Annelida	Polychaeta	Syllidae
166	BRANWELL	*Branta wellfleetensis*	Annelida	Polychaeta	Syllidae
167	EXOGDISP	*Exogone dispar*	Annelida	Polychaeta	Syllidae
168	EXOGHEBE	*Exogone hebes*	Annelida	Polychaeta	Syllidae
169	EXOGSPEA	*Exogone sp. A Glasby*	Annelida	Polychaeta	Syllidae
170	EXOGVERU	*Exogone verugera*	Annelida	Polychaeta	Syllidae
171	ODONFULG	*Odontosyllis fulgurans*	Annelida	Polychaeta	Syllidae
172	PARALONG	*Parapionosyllis longicirrata*	Annelida	Polychaeta	Syllidae
173	PIONSPEA	*Pionosyllis sp. A Glasby*	Annelida	Polychaeta	Syllidae
174	PIONSPEB	*Pionosyllis sp. B Glasby*	Annelida	Polychaeta	Syllidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
175	PROCCORN	*Proceraea cornuta*	Annelida	Polychaeta	Syllidae
176	SPHAACIC	*Sphaerosyllis aciculata*	Annelida	Polychaeta	Syllidae
177	SPHATAYL	*Sphaerosyllis taylori*	Annelida	Polychaeta	Syllidae
178	STREAREN	*Streptosyllis arenae*	Annelida	Polychaeta	Syllidae
179	STREPETT	*Streptosyllis pettiboneae*	Annelida	Polychaeta	Syllidae
180	STREVARI	*Streptosyllis varians*	Annelida	Polychaeta	Syllidae
181	SYLLCONV	*Syllides convoluta*	Annelida	Polychaeta	Syllidae
182	SYLLVERR	*Syllides verrilli*	Annelida	Polychaeta	Syllidae
183	AMPHORNA	*Amphitrite ornata*	Annelida	Polychaeta	Terebellidae
184	ENOPSANG	*Enoplobranchus sanguineus*	Annelida	Polychaeta	Terebellidae
185	LOIMMEDU	*Loimia medusa*	Annelida	Polychaeta	Terebellidae
186	NICOZOST	*Nicolea zostericola*	Annelida	Polychaeta	Terebellidae
187	PISTCRIS	*Pista cristata*	Annelida	Polychaeta	Terebellidae
188	PISTPALM	*Pista palmata*	Annelida	Polychaeta	Terebellidae
189	POLYHAEM	*Polycirrus cf. haematodes*	Annelida	Polychaeta	Terebellidae
190	POLYEXIM	*Polycirrus eximius*	Annelida	Polychaeta	Terebellidae
191	POLYMEDU	*Polycirrus medusa*	Annelida	Polychaeta	Terebellidae
192	TERESTRO	*Terebellides stroemi*	Annelida	Polychaeta	Trichobranchidae
193	TROCMULT	*Trochochaeta multisetosa*	Annelida	Polychaeta	Trochochaetidae
194	POLYSPEA	*Polychaeta sp A Arcuri*	Annelida	Polychaeta	Unidentified
195	POLYSPEB	*Polychaeta sp B Arcuri*	Annelida	Polychaeta	Unidentified
196	AMPEAGAS	*Ampelisca agassizi*	Arthropoda	Amphipoda	Ampeliscidae
197	AMPEVERR	*Ampelisca verrilli*	Arthropoda	Amphipoda	Ampeliscidae
198	BYBLSERR	*Byblis serrata*	Arthropoda	Amphipoda	Ampeliscidae
199	AMPILONG	*Ampithoe longimanna*	Arthropoda	Amphipoda	Ampithoidae
200	AMPIVALI	*Ampithoe valida*	Arthropoda	Amphipoda	Ampithoidae
201	CYMACOMP	*Cymadusa compta*	Arthropoda	Amphipoda	Ampithoidae
202	LEMBSMIT	*Lembos smithi*	Arthropoda	Amphipoda	Aoridae
203	LEMBWEBS	*Lembos websteri*	Arthropoda	Amphipoda	Aoridae
204	LEPTPING	*Leptocheirus pinguis*	Arthropoda	Amphipoda	Aoridae
205	LEPTPLUM	*Leptocheirus plumulosus*	Arthropoda	Amphipoda	Aoridae
206	MICRANOM	*Microdeutopus anomalus*	Arthropoda	Amphipoda	Aoridae
207	MICRGRYL	*Microdeutopus gryllotalpa*	Arthropoda	Amphipoda	Aoridae
208	PSEUOBLI	*Pseudunciola obliquua*	Arthropoda	Amphipoda	Aoridae
209	RUDINAGL	*Rudilemboides naglei*	Arthropoda	Amphipoda	Aoridae
210	UNCIDISS	*Unciola dissimilis*	Arthropoda	Amphipoda	Aoridae
211	UNCIINER	*Unciola inermis*	Arthropoda	Amphipoda	Aoridae
212	UNCIIRRO	*Unciola irrorata*	Arthropoda	Amphipoda	Aoridae
213	UNCISERR	*Unciola serrata*	Arthropoda	Amphipoda	Aoridae
214	ARIGHAMA	*Arigissa hamatipes*	Arthropoda	Amphipoda	Argissidae
215	BATECATH	*Batea catharinensis*	Arthropoda	Amphipoda	Bateidae
216	CALLLAEV	*Calliopius laeviusculus*	Arthropoda	Amphipoda	Calliopidae
217	COROACHE	*Corophium acherusicum*	Arthropoda	Amphipoda	Corophiidae
218	COROACUT	*Corophium acutum*	Arthropoda	Amphipoda	Corophiidae
219	COROBONN	*Corophium bonellii*	Arthropoda	Amphipoda	Corophiidae
220	COROCRAS	*Corophium crassicorne*	Arthropoda	Amphipoda	Corophiidae
221	COROINSI	*Corophium insidiosum*	Arthropoda	Amphipoda	Corophiidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
222	COROLACU	*Corophium lacustre*	Arthropoda	Amphipoda	Corophiidae
223	COROSEXT	*Corophium sextoni*	Arthropoda	Amphipoda	Corophiidae
224	COROSIMI	*Corophium simile*	Arthropoda	Amphipoda	Corophiidae
225	COROTUBE	*Corophium tuberculatum*	Arthropoda	Amphipoda	Corophiidae
226	DEXATHEC	*Dexamine thea*	Arthropoda	Amphipoda	Dexaminidae
227	GAMMANNU	*Gammarus annulatus*	Arthropoda	Amphipoda	Gammaridae
228	GAMMDAIB	*Gammarus daiberi*	Arthropoda	Amphipoda	Gammaridae
229	GAMMFASC	*Gammarus fasciatus*	Arthropoda	Amphipoda	Gammaridae
230	GAMMOCEA	*Gammarus oceanicus*	Arthropoda	Amphipoda	Gammaridae
231	MUCRMUCR	*Mucrogammarus mucronatus*	Arthropoda	Amphipoda	Gammaridae
232	ACANMILL	*Acanthohaustorius millsi*	Arthropoda	Amphipoda	Haustoriidae
233	ACANSIMI	*Acanthohaustorius similis*	Arthropoda	Amphipoda	Haustoriidae
234	BATHPARK	*Bathyporeia parkeri*	Arthropoda	Amphipoda	Haustoriidae
235	LEPIDYTI	*Lepidactylus dytiscus*	Arthropoda	Amphipoda	Haustoriidae
236	PARAATTE	*Parahaustorius attenuatus*	Arthropoda	Amphipoda	Haustoriidae
237	PARAHOLM	*Parahaustorius holmesi*	Arthropoda	Amphipoda	Haustoriidae
238	PARALNGI	*Parahaustorius longimerus*	Arthropoda	Amphipoda	Haustoriidae
239	PROTDEIC	*Protohaustorius cf deichmannae*	Arthropoda	Amphipoda	Haustoriidae
240	PROTWIGL	*Protohaustorius wigleyi*	Arthropoda	Amphipoda	Haustoriidae
241	PSEUBORE	*Pseudohaustorius borealis*	Arthropoda	Amphipoda	Haustoriidae
242	PSEUCARO	*Pseudohaustorius carolinensis*	Arthropoda	Amphipoda	Haustoriidae
243	GAMMSUTH	*Gammaropsis sutherlandi*	Arthropoda	Amphipoda	Isaeidae
244	MICRRANE	*Microprotopus raneyi*	Arthropoda	Amphipoda	Isaeidae
245	PHOTDENT	*Photis dentata*	Arthropoda	Amphipoda	Isaeidae
246	PHOTPOLL	*Photis pollex*	Arthropoda	Amphipoda	Isaeidae
247	PHOTPUGN	*Photis pugnator*	Arthropoda	Amphipoda	Isaeidae
248	CERATUBU	*Cerapus tubularis*	Arthropoda	Amphipoda	Ischyroceridae
249	ERICBRAS	*Ericthonius brasiliensis*	Arthropoda	Amphipoda	Ischyroceridae
250	ERICFASC	*Ericthonius fasciatus*	Arthropoda	Amphipoda	Ischyroceridae
251	ISCHANGU	*Ischyrocerus anguipes*	Arthropoda	Amphipoda	Ischyroceridae
252	JASSMARM	*Jassa marmorata*	Arthropoda	Amphipoda	Ischyroceridae
253	LISTBARN	*Listriella barnardi*	Arthropoda	Amphipoda	Liljeborgiidae
254	LISTCLYM	*Listriella clymenellae*	Arthropoda	Amphipoda	Liljeborgiidae
255	LISTSMIT	*Listriella smithi*	Arthropoda	Amphipoda	Liljeborgiidae
256	ANONLILJ	*Anonyx liljeborgi*	Arthropoda	Amphipoda	Lysianassidae
257	HIPPSERR	*Hippomedon serratus*	Arthropoda	Amphipoda	Lysianassidae
258	LYSIALBA	*Lysianopsis alba*	Arthropoda	Amphipoda	Lysianassidae
259	ORCHMINU	*Orchomenella minuta*	Arthropoda	Amphipoda	Lysianassidae
260	DULIAPPE	*Dulichiella appendiculata*	Arthropoda	Amphipoda	Melitidae
261	ELASLAEV	*Elasmopus laevis*	Arthropoda	Amphipoda	Melitidae
262	MELINITI	*Melita nitida*	Arthropoda	Amphipoda	Melitidae
263	MONOSPE1	*Monoculodes sp. 1 Watling*	Arthropoda	Amphipoda	Oedicerotidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
264	SYNCAMER	*Synchelidium americanum*	Arthropoda	Amphipoda	Oedicerotidae
265	EOBRSPIN	*Eobrolgus spinosus*	Arthropoda	Amphipoda	Phoxocephalidae
266	HARPPROP	*Harpinia propinqua*	Arthropoda	Amphipoda	Phoxocephalidae
267	PHOXHOLB	*Phoxocephalus holbolli*	Arthropoda	Amphipoda	Phoxocephalidae
268	RHEPEPIS	*Rhepoxynius epistomus*	Arthropoda	Amphipoda	Phoxocephalidae
269	RHEPHUDS	*Rhepoxynius hudsoni*	Arthropoda	Amphipoda	Phoxocephalidae
270	PARAAEST	*Parapleustes aestuarius*	Arthropoda	Amphipoda	Pleustidae
271	PLEUGLAB	*Pleusymtes glaber*	Arthropoda	Amphipoda	Pleustidae
272	STENGRAC	*Stenopleustes gracilis*	Arthropoda	Amphipoda	Pleustidae
273	STENINER	*Stenopleustes inermis*	Arthropoda	Amphipoda	Pleustidae
274	DYOPMONA	*Dyopedos monacanthus*	Arthropoda	Amphipoda	Podoceridae
275	PARACYPR	*Parametopella cypris*	Arthropoda	Amphipoda	Stenothoidae
276	STENMINU	*Stenothoe minuta*	Arthropoda	Amphipoda	Stenothoidae
277	STENVALI	*Stenothoe valida*	Arthropoda	Amphipoda	Stenothoidae
278	HUTCMACR	*Hutchinsoniella macracantha*	Arthropoda	Cephalocarida	Hutchinsoniellida
279	ABLAPARA	*Ablabesmyia parajanta*	Arthropoda	Chironomidae	Tanypodinae
280	PROCSUBL	*Procladius sublettei*	Arthropoda	Chironomidae	Tanypodinae
281	BODOSPEA	*Bodotria sp. A Morris*	Arthropoda	Cumacea	Bodotriidae
282	CYCLVARI	*Cyclaspis varians*	Arthropoda	Cumacea	Bodotriidae
283	MANCSTEL	*Mancocuma stellifera*	Arthropoda	Cumacea	Bodotriidae
284	BODOTRII	*Pseudoleptocuma minor*	Arthropoda	Cumacea	Bodotriidae
285	PSEUMINO	*Pseudoleptocuma minor*	Arthropoda	Cumacea	Bodotriidae
286	DIASQUAD	*Diastylis quadrispinosa*	Arthropoda	Cumacea	Diastylidae
287	DIASSCUL	*Diastylis sculpta*	Arthropoda	Cumacea	Diastylidae
288	OXYUSMIT	*Oxyurostylis smithi*	Arthropoda	Cumacea	Diastylidae
289	EUDOPUSI	*Eudorella pusilla*	Arthropoda	Cumacea	Leuconidae
290	LEUCAMER	*Leucon americanus*	Arthropoda	Cumacea	Leuconidae
291	ALMYPROX	*Almyracuma proximoculi*	Arthropoda	Cumacea	Nannastacidae
292	ALPHHETE	*Alpheus heterochaelis*	Arthropoda	Decapoda	Alpheidae
293	AUTOMSPA	*Automate sp. A Williams*	Arthropoda	Decapoda	Alpheidae
294	CALLSETI	*Callianassa setimanus*	Arthropoda	Decapoda	Callianassidae
295	CRANSEPT	*Crangon septemspinosa*	Arthropoda	Decapoda	Crangonidae
296	LIBIEMAR	*Libinia emarginata*	Arthropoda	Decapoda	Majidae
297	OGYRALPH	*Ogyrides alphaerostris*	Arthropoda	Decapoda	Ogyrididae
298	PAGUACAD	*Pagurus acadianus*	Arthropoda	Decapoda	Paguridae
299	PAGUANNU	*Pagurus annulipes*	Arthropoda	Decapoda	Paguridae
300	PAGULONG	*Pagurus longicarpus*	Arthropoda	Decapoda	Paguridae
301	PAGUPOLL	*Pagurus pollicaris*	Arthropoda	Decapoda	Paguridae
302	EUCEPRAE	*Euceramus praelongus*	Arthropoda	Decapoda	Porcellanidae
303	POLYGIBB	*Polyonyx gibbesi*	Arthropoda	Decapoda	Porcellanidae
304	OVALOCEL	*Ovalipes ocellatus*	Arthropoda	Decapoda	Portunidae
305	PROCVICI	*Processa vicina*	Arthropoda	Decapoda	Processidae
306	UPOGAFFI	*Upogebia affinis*	Arthropoda	Decapoda	Upogebiidae
307	NEOPSAYI	*Dyspanopeus sayi*	Arthropoda	Decapoda	Xanthidae
308	HEXAANGU	*Hexapanopeus angustifrons*	Arthropoda	Decapoda	Xanthidae
309	PANOHERB	*Panopeus herbstii*	Arthropoda	Decapoda	Xanthidae
310	RHITHARR	*Rhithropanopeus harrisii*	Arthropoda	Decapoda	Xanthidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
311	APANMAGN	*Amakusanthura magnifica*	Arthropoda	Isopoda	Anthuridae
312	CYATBURB	*Cyathura burbancki*	Arthropoda	Isopoda	Anthuridae
313	CYATPOLI	*Cyathura polita*	Arthropoda	Isopoda	Anthuridae
314	PTILTENU	*Ptilanthura tenuis*	Arthropoda	Isopoda	Anthuridae
315	POLIPOLI	*Politolana polita*	Arthropoda	Isopoda	Cirolanidae
316	CHIRALMY	*Chiridotea almyra*	Arthropoda	Isopoda	Idoteidae
317	CHIRCOEC	*Chiridotea coeca*	Arthropoda	Isopoda	Idoteidae
318	EDOTTRIL	*Edotea triloba*	Arthropoda	Isopoda	Idoteidae
319	ERICATTE	*Erichsonella attenuata*	Arthropoda	Isopoda	Idoteidae
320	ERICFILI	*Erichsonella filiformis*	Arthropoda	Isopoda	Idoteidae
321	IDOTBALT	*Idotea balthica*	Arthropoda	Isopoda	Idoteidae
322	IDOTPHOS	*Idotea phosphorea*	Arthropoda	Isopoda	Idoteidae
323	JAERMARI	*Jaera marina*	Arthropoda	Isopoda	Janiridae
324	PLEUINER	*Pleurogonium inerme*	Arthropoda	Isopoda	Munnidae
325	PLEUSPIN	*Pleurogonium spinosissmum*	Arthropoda	Isopoda	Munnidae
326	ANCIDEPR	*Ancinus depressus*	Arthropoda	Isopoda	Sphaeromatidae
327	CASSOVAL	*Cassidinidea ovalis*	Arthropoda	Isopoda	Sphaeromatidae
328	PARACAUD	*Paracerceis caudata*	Arthropoda	Isopoda	Sphaeromatidae
329	SPHAQUAD	*Sphaeroma quadridentatum*	Arthropoda	Isopoda	Sphaeromatidae
330	CALLBREV	*Callipallene brevirostris*	Arthropoda	Pycnogonida	Callipallenidae
331	ANOPPETI	*Anoplodactylus petiolatus*	Arthropoda	Pycnogonida	Phoxichilidiidae
332	TANYORBI	*Tanystylum orbiculare*	Arthropoda	Pycnogonida	Tanystylidae
333	NANNGRAY	*Nannosquilla gravi*	Arthropoda	Stomatopoda	Nannosquillidae
334	SQUIEMPU	*Squilla empusa*	Arthropoda	Stomatopoda	Squillidae
335	LEPTDUBI	*Leptochelia dubia*	Arthropoda	Tanaidacea	Nototanaidae
336	TANAPSAM	*Tanaissus psammophilus*	Arthropoda	Tanaidacea	Nototanaidae
337	HARGRAPA	*Hargeria rapax*	Arthropoda	Tanaidacea	Paratanaidae
338	TANASPEA	*Tanaidacea sp. A Williams*	Arthropoda	Tanaidacea	Tanaidacea
339	CYRNFRAT	*Cyrnellus fraternus*	Arthropoda	Trichoptera	Polycentropodidae
340	CERIAMER	*Cerianthéopsis americanus*	Cnidaria	Anthozoa	Cerianthidae
341	CAUDAREN	*Caudina arenata*	Echinodermata	Holothuroidea	Caudinidae
342	STERUNIS	*Stereoderma unisemita*	Echinodermata	Holothuroidea	Cucumariidae
343	HAVESCAB	*Havelockia scabra*	Echinodermata	Holothuroidea	Phyllophoridae
344	PENTPULC	*Pentamera pulcherrima*	Echinodermata	Holothuroidea	Phyllophoridae
345	LEPTTENU	*Leptosynapta tenuis*	Echinodermata	Holothuroidea	Synaptidae
346	SACCKOWA	*Saccoglossus kowalevskii*	Hemichordata	Hemichordata	Harrimaniidae
347	STERCAND	*Stereobalanus candensis*	Hemichordata	Hemichordata	Harrimaniidae
348	ANADOVAL	*Anadara ovalis*	Mollusca	Bivalvia	Arcidae
349	ANADTRAN	*Anadara transversa*	Mollusca	Bivalvia	Arcidae
350	ARCTISLA	*Arctica islandica*	Mollusca	Bivalvia	Arcticidae
351	ASTACAST	*Astarte castanea*	Mollusca	Bivalvia	Astartidae
352	ASTACREN	*Astarte crenata*	Mollusca	Bivalvia	Astartidae
353	ASTASPEA	*Astarte sp. A Mountford*	Mollusca	Bivalvia	Astartidae
354	ASTAUNDA	*Astarte undata*	Mollusca	Bivalvia	Astartidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
355	CERAPINN	*Cerastoderma pinnulatum*	Mollusca	Bivalvia	Cardiidae
356	LAEVMORT	*Laevicardium mortoni*	Mollusca	Bivalvia	Cardiidae
357	CYCLBORE	*Cyclocardia borealis*	Mollusca	Bivalvia	Carditidae
358	CORBFLUM	*Corbicula fluminea*	Mollusca	Bivalvia	Corbiculidae
359	CORBCONT	*Corbula contracta*	Mollusca	Bivalvia	Corbulidae
360	DONAVARI	*Donax variabilis*	Mollusca	Bivalvia	Donacidae
361	ALIGELEV	*Aligena elevata*	Mollusca	Bivalvia	Kelliidae
362	PARVMULT	*Parvilucina multilineata*	Mollusca	Bivalvia	Lucinidae
363	LYONAREN	*Lyonsia arenosa*	Mollusca	Bivalvia	Lyonsiidae
364	LYONHYAL	*Lyonsia hyalina*	Mollusca	Bivalvia	Lyonsiidae
365	MULILATE	*Mulinia lateralis*	Mollusca	Bivalvia	Mactridae
366	RANGCUNE	*Rangia cuneata*	Mollusca	Bivalvia	Mactridae
367	SPISSOLI	*Spisula solidissima*	Mollusca	Bivalvia	Mactridae
368	MYAAREN	*Mya arenaria*	Mollusca	Bivalvia	Myidae
369	YOLDLIMA	*Yoldia limatula*	Mollusca	Bivalvia	Nuculanidae
370	NUCUANNU	*Nucula annulata*	Mollusca	Bivalvia	Nuculidae
371	NUCUDELP	*Nucula delphinodonta*	Mollusca	Bivalvia	Nuculidae
372	CRASVIRG	*Crassostrea virginica*	Mollusca	Bivalvia	Ostreidae
373	PANDGOUL	*Pandora gouldiana*	Mollusca	Bivalvia	Pandoridae
374	AEQUIRRA	*Argopecten irradians*	Mollusca	Bivalvia	Pectinidae
375	PERIMARG	*Periploma margaritacea*	Mollusca	Bivalvia	Periplomatidae
376	PETRPHOL	*Petricola pholadiformis*	Mollusca	Bivalvia	Petricolidae
377	TAGEDIVI	*Tagelus divisus*	Mollusca	Bivalvia	Solecurtidae
378	TAGEPLEB	*Tagelus plebeius*	Mollusca	Bivalvia	Solecurtidae
379	SILICOST	*Siliqua costata*	Mollusca	Bivalvia	Solemyidae
380	SOLEVELU	*Solemya velum*	Mollusca	Bivalvia	Solemyidae
381	ENSIDIRE	*Ensis directus*	Mollusca	Bivalvia	Solenidae
382	MUSCTRAN	*Musculium transversum*	Mollusca	Bivalvia	Sphaeriidae
383	MACOBALT	*Macoma balthica*	Mollusca	Bivalvia	Tellinidae
384	MACOMITC	*Macoma mitchelli*	Mollusca	Bivalvia	Tellinidae
385	MACOTENT	*Macoma tenta*	Mollusca	Bivalvia	Tellinidae
386	TELLAGIL	*Tellina agilis*	Mollusca	Bivalvia	Tellinidae
387	ASTHHEMP	*Asthenothaerus hemphilli*	Mollusca	Bivalvia	Thraciidae
388	BUSHELEG	*Bushia elegans*	Mollusca	Bivalvia	Thraciidae
389	BIVASPEA	*Bivalvia sp A Mountford*	Mollusca	Bivalvia	Unidentified
390	ELLICOMP	*Elliptio complanta*	Mollusca	Bivalvia	Unionidae
391	GEMMGEMM	*Gemma gemma*	Mollusca	Bivalvia	Veneridae
392	MERCMERC	*Mercenaria mercenaria*	Mollusca	Bivalvia	Veneridae
393	PITAMORR	*Pitar morrhuanus*	Mollusca	Bivalvia	Veneridae
394	ACTEPUNC	*Rictaxis punctostriatus*	Mollusca	Gastropoda	Acteonidae
395	LAEVFUSC	*Laevapex fuscus*	Mollusca	Gastropoda	Ancylidae
396	BITHTENT	*Bithynia tentaculata*	Mollusca	Gastropoda	Bithyniidae
397	CAECJOHN	*Caecum johnsoni*	Mollusca	Gastropoda	Caecidae
398	CAECREGU	*Caecum regulare*	Mollusca	Gastropoda	Caecidae
399	CAECSPEA	*Caecum sp A Mountford*	Mollusca	Gastropoda	Caecidae
400	CAECSPEB	*Caecum sp B Mountford*	Mollusca	Gastropoda	Caecidae
401	CALYPSPA	*Calyptraeidae sp. A Mountford*	Mollusca	Gastropoda	Calyptraeidae
402	BITTALTE	*Bittium alternatum*	Mollusca	Gastropoda	Cerithiidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
403	SEILADAM	*Seila adamsi*	Mollusca	Gastropoda	Cerithiopsidae
404	ANACLAFR	*Anachis lafresnayi*	Mollusca	Gastropoda	Columbellidae
405	ANACOBES	*Anachis obesa*	Mollusca	Gastropoda	Columbellidae
406	ASTYLUNA	*Astyris lunata*	Mollusca	Gastropoda	Columbellidae
407	DORIOBSC	*Doridella obscura*	Mollusca	Gastropoda	Corambidae
408	CYLIBIDE	*Cylichnella bidentata*	Mollusca	Gastropoda	Cylichnidae
409	EPITGREE	*Epitonium greenlandicum*	Mollusca	Gastropoda	Epitoniidae
410	EPITHUMP	*Epitonium humphreysi*	Mollusca	Gastropoda	Epitoniidae
411	EPITRUPI	*Epitonium rupicola*	Mollusca	Gastropoda	Epitoniidae
412	CRATPILA	*Cratena pilata*	Mollusca	Gastropoda	Facelinidae
413	GASTSPEA	*Gastropoda sp. A Mountford*	Mollusca	Gastropoda	Gastropoda
414	HAMISOLI	*Haminoea solitaria*	Mollusca	Gastropoda	Haminoeidae
415	AMNILIMO	*Amnicola limosa*	Mollusca	Gastropoda	Hydrobiidae
416	CINCWINK	*Cincinnatia winkleyi*	Mollusca	Gastropoda	Hydrobiidae
417	HYDRTRUN	*Hydrobia truncata*	Mollusca	Gastropoda	Hydrobiidae
418	LITTTENU	*Littoridinops tenuipes*	Mollusca	Gastropoda	Hydrobiidae
419	LACUVINC	*Lacuna vincta*	Mollusca	Gastropoda	Lacunidae
420	EUPLCAUD	*Eupleura caudata*	Mollusca	Gastropoda	Muricidae
421	UROSCINE	*Urosalpinx cinerea*	Mollusca	Gastropoda	Muricidae
422	ILYAOBSO	*Ilyanassa obsoleta*	Mollusca	Gastropoda	Nassariidae
423	NASSTRIV	*Nassarius trivittatus*	Mollusca	Gastropoda	Nassariidae
424	NASSVIBE	*Nassarius vibex*	Mollusca	Gastropoda	Nassariidae
425	NATIPUSI	*Natica pusilla*	Mollusca	Gastropoda	Naticidae
426	POLIHERO	*Polinices heros*	Mollusca	Gastropoda	Naticidae
427	GONIVIRG	*Goniobasis virginica*	Mollusca	Gastropoda	Pleuroceridae
428	BOONBISU	*Boonea bisuturalis*	Mollusca	Gastropoda	Pyramidellidae
429	BOONIMPR	*Boonea impressa*	Mollusca	Gastropoda	Pyramidellidae
430	BOONSEMI	*Boonea seminuda*	Mollusca	Gastropoda	Pyramidellidae
431	ODOSSULC	*cf. Odostomia sulcosa*	Mollusca	Gastropoda	Pyramidellidae
432	FARGBART	*Fargoa bartschi*	Mollusca	Gastropoda	Pyramidellidae
433	FARGBUSH	*Fargoa bushiana*	Mollusca	Gastropoda	Pyramidellidae
434	FARGGIBB	*Fargoa gibbosa*	Mollusca	Gastropoda	Pyramidellidae
435	ODOSENGO	*Odostomia engonia*	Mollusca	Gastropoda	Pyramidellidae
436	ODOSSPEA	*Odostomia sp A Mountford*	Mollusca	Gastropoda	Pyramidellidae
437	SAYECHES	*Savella chesapeakea*	Mollusca	Gastropoda	Pyramidellidae
438	TURBINTE	*Turbonilla interrupta*	Mollusca	Gastropoda	Pyramidellidae
439	TURBSPEB	*Turbonilla sp. B Mountford*	Mollusca	Gastropoda	Pyramidellidae
440	TURB?AEQ	*Turbonilla ?aequalis*	Mollusca	Gastropoda	Pyramidellidae
441	ACTECANA	*Acteocina canaliculata*	Mollusca	Gastropoda	Scaphandridae
442	ACTEORYZ	*Acteocina oryza*	Mollusca	Gastropoda	Scaphandridae
443	KURTATRO	*Kurtziella atrostyla*	Mollusca	Gastropoda	Turridae
444	TURRSPEA	*Turridae sp A Mountford*	Mollusca	Gastropoda	Turridae
445	VALVSINC	*Valvata sincera*	Mollusca	Gastropoda	Valvatidae
446	VALVTRIC	*Valvata tricarinata*	Mollusca	Gastropoda	Valvatidae
447	VITRFLOR	*Vitrinella floridana*	Mollusca	Gastropoda	Vitrinellidae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
Higher-Level Valid Taxa					
448	OLIGOCHA	*Oligochaeta*	Annelida	Oligochaeta	Unidentified
449	ACROCFAM	*Acrocirridae*	Annelida	Polychaeta	Acrocirridae
450	ARABIRMU	*Arabella iricolor-multidentata complex*	Annelida	Polychaeta	Arabellidae
451	CAPITELL	*Capitella spp.*	Annelida	Polychaeta	Capitellidae
452	APHELOCH	*Aphelochaeta spp.*	Annelida	Polychaeta	Cirratulidae
453	DODECACE	*Dodecaceria spp*	Annelida	Polychaeta	Cirratulidae
454	MONTBPDS	*Monticellina baptisteae-dorsobranchialis*	Annelida	Polychaeta	Cirratulidae
455	OPHRYOTR	*Ophryotrocha spp.*	Annelida	Polychaeta	Dorvilleidae
456	MAGELONA	*Magelona spp*	Annelida	Polychaeta	Magelonidae
457	POLYGORD	*Polygordius spp*	Annelida	Polychaeta	Polygordiidae
458	PROTODRI	*Protodrilus spp*	Annelida	Polychaeta	Protodrilidae
459	SPHAEROD	*Sphaerodoropsis spp.*	Annelida	Polychaeta	Sphaerodoridae
460	LAONICE	*Laonice spp*	Annelida	Polychaeta	Spionidae
461	BRANCLSW	*Brania clavata-swedmarki complex*	Annelida	Polychaeta	Syllidae
462	TYPOAL_1	*Typosyllis alternata-sp 1 complex*	Annelida	Polychaeta	Syllidae
463	AMPEABVA	*Ampelisca abdita-vadorum complex*	Arthropoda	Amphipoda	Ampeliscidae
464	GITANOPS	*Gitanopsis spp*	Arthropoda	Amphipoda	Amphilochidae
465	THALASSI	*Thalassinidea*	Arthropoda	Crustacea	Thalassinidea
466	TRICORYT	*Tricorythodes spp*	Arthropoda	Ephemeroptera	Tricorythidae
467	OPHIUROI	*Ophiuroidea*	Echinodermata	Ophiuroidea	Unidentified
468	RAETACF	*cf. Raeta spp.*	Mollusca	Bivalvia	Mactridae
469	PISIDIUM	*Pisidium spp*	Mollusca	Bivalvia	Pisidiidae
470	ANODONTA	*Anodonta spp.*	Mollusca	Bivalvia	Unionidae
471	FERRISSI	*Ferrissia spp*	Mollusca	Gastropoda	Acroloxidae
472	COLUMBEL	*Columbella spp*	Mollusca	Gastropoda	Columbellidae
473	MELANELL	*Melanella spp*	Mollusca	Gastropoda	Elimidae
474	LYOGYRUS	*Lyogyrus spp*	Mollusca	Gastropoda	Hydrobiidae
475	BUSYCON	*Busycon spp.*	Mollusca	Gastropoda	Melongenidae
476	PHYSELLA	*Physella spp.*	Mollusca	Gastropoda	Physidae
477	PROMENET	*Promenetus spp*	Mollusca	Gastropoda	Planorbidae
478	PLEUROCE	*Pleurocera spp*	Mollusca	Gastropoda	Pleuroceridae
479	NEMERTIN	*Nemertinea*	Nemertinea	Nemertinea	Unidentified
480	PHORONIS	*Phoronis spp.*	Phoronida	Phoronida	Phoronidae
481	SIPUNCUL	*Sipuncula*	Sipuncula	Sipuncula	Unidentified

NO	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
FRESHWATER TAXA					
482	ENCHYTRA	*Enchytraeidae*	Annelida	Oligochaeta	Enchytraeidae
483	LUMBRICU	*Lumbriculidae*	Annelida	Oligochaeta	Lumbriculidae
484	ARCTLOMO	*Arcteonais lomondi*	Annelida	Oligochaeta	Naididae
485	BRATUNID	*Bratislavia unidentata*	Annelida	Oligochaeta	Naididae
486	CHAETOGA	*Chaetogaster spp.*	Annelida	Oligochaeta	Naididae
487	DERODIGI	*Dero digitata*	Annelida	Oligochaeta	Naididae
488	NAISPARD	*Nais pardalis*	Annelida	Oligochaeta	Naididae
489	NAISPSEU	*Nais pseudobtusa*	Annelida	Oligochaeta	Naididae
490	PIGUMICH	*Piguetiella michiganensis*	Annelida	Oligochaeta	Naididae
491	SLAVAPPE	*Slavina appendiculata*	Annelida	Oligochaeta	Naididae
492	SPECJOSI	*Specaria josinae*	Annelida	Oligochaeta	Naididae
493	STEPTAND	*Stephensoniana tandyi*	Annelida	Oligochaeta	Naididae
494	STEPTRIV	*Stephensoniana trivandrana*	Annelida	Oligochaeta	Naididae
495	STYLLACU	*Stylaria lacustris*	Annelida	Oligochaeta	Naididae
496	AULOLIMN	*Aulodrilus limnobius*	Annelida	Oligochaeta	Tubificidae
497	AULOPAUC	*Aulodrilus paucichaeta*	Annelida	Oligochaeta	Tubificidae
498	AULOPIGU	*Aulodrilus pigueti*	Annelida	Oligochaeta	Tubificidae
499	AULOPLUR	*Aulodrilus pluriseta*	Annelida	Oligochaeta	Tubificidae
500	BRANSOWE	*Branchiura sowerbyi*	Annelida	Oligochaeta	Tubificidae
501	HABESPEC	*Haber cf. speciosus*	Annelida	Oligochaeta	Tubificidae
502	ILYOTEMP	*Ilyodrilus templetoni*	Annelida	Oligochaeta	Tubificidae
503	ISOCFREY	*Isochaetides freyi*	Annelida	Oligochaeta	Tubificidae
504	LIMNCERV	*Limnodrilus cervix*	Annelida	Oligochaeta	Tubificidae
505	LIMNCLAP	*Limnodrilus claparedianus*	Annelida	Oligochaeta	Tubificidae
506	LIMNHOFF	*Limnodrilus hoffmeisteri*	Annelida	Oligochaeta	Tubificidae
507	LIMNUDEK	*Limnodrilus udekemianus*	Annelida	Oligochaeta	Tubificidae
508	QUISMULT	*Quistadrilus multisetosus*	Annelida	Oligochaeta	Tubificidae
509	TELMVEJD	*Telmatodrilus vejdovskyi*	Annelida	Oligochaeta	Tubificidae
510	TUBIFIWI	*Tubificidae with capiliform chaetae*	Annelida	Oligochaeta	Tubificidae
511	TUBIFIWO	*Tubificidae without capiliform chaetae*	Annelida	Oligochaeta	Tubificidae
512	TUBIBROW	*Tubificoides brownae*	Annelida	Oligochaeta	Tubificidae
513	TUBIHETE	*Tubificoides heterochaetus*	Annelida	Oligochaeta	Tubificidae
514	AXARUS	*Axarus spp.*	Arthropoda	Chironomidae	Chironomini
515	CHIRONOM	*Chironomus spp*	Arthropoda	Chironomidae	Chironomini
516	CLADOPLE	*Cladopelma spp*	Arthropoda	Chironomidae	Chironomini
517	CRYPFULV	*Cryptochironomus fulvus*	Arthropoda	Chironomidae	Chironomini
518	CRYPTOTE	*Cryptotendipes spp*	Arthropoda	Chironomidae	Chironomini
519	DEMICRYP	*Demicryptochironomus spp.*	Arthropoda	Chironomidae	Chironomini
520	DICRNERV	*Dicrotendipes nervosus*	Arthropoda	Chironomidae	Chironomini
521	DICROTEN	*Dicrotendipes spp*	Arthropoda	Chironomidae	Chironomini
522	ENDOCHIR	*Endochironomus spp*	Arthropoda	Chironomidae	Chironomini
523	GLYPTOTE	*Glyptotendipes spp*	Arthropoda	Chironomidae	Chironomini
524	HARNISCH	*Harnischia spp*	Arthropoda	Chironomidae	Chironomini

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
525	MICROCHI	*Microchironomus spp.*	Arthropoda	Chironomidae	Chironomini
526	PARACLAD	*Paracladopelma spp.*	Arthropoda	Chironomidae	Chironomini
527	PARALAUT	*Paralauterborniella spp.*	Arthropoda	Chironomidae	Chironomini
528	POLYTRIP	*Polypedilum tripodura*	Arthropoda	Chironomidae	Chironomini
529	PSEUDOCH	*Pseudochironomus spp.*	Arthropoda	Chironomidae	Chironomini
530	STICTOCH	*Stictochironomus spp.*	Arthropoda	Chironomidae	Chironomini
531	NANOCLAD	*Nanocladius spp.*	Arthropoda	Chironomidae	Orthocladiinae
532	COELOTAN	*Coelotanypus spp.*	Arthropoda	Chironomidae	Tanypodinae
533	PROCHOLO	*Procladius (Holotanypus) spp.*	Arthropoda	Chironomidae	Tanypodinae
534	TANYPUS	*Tanypus spp.*	Arthropoda	Chironomidae	Tanypodinae
535	CLADOTAN	*Cladotanytarsus spp.*	Arthropoda	Chironomidae	Tanytarsini
536	RHEOTANY	*Rheotanytarsus spp.*	Arthropoda	Chironomidae	Tanytarsini
537	TANYTARS	*Tanytarsus spp.*	Arthropoda	Chironomidae	Tanytarsini
538	DUBIRAPH	*Dubiraphia spp.*	Arthropoda	Coleoptera	Elmidae
539	STENELMI	*Stenelmis spp.*	Arthropoda	Coleoptera	Elmidae
540	BEZZIA	*Bezzia spp.*	Arthropoda	Diptera	Ceratopogonidae
541	PALPOMYI	*Palpomyia spp.*	Arthropoda	Diptera	Ceratopogonidae
542	PROBEZZI	*Probezzia spp.*	Arthropoda	Diptera	Ceratopogonidae
543	SPHAEROM	*Sphaeromias spp.*	Arthropoda	Diptera	Ceratopogonidae
544	CHAOPUNC	*Chaoborus punctipennis*	Arthropoda	Diptera	Chaoboridae
545	DOLICHOP	*Dolichopodidae*	Arthropoda	Diptera	Dolichopodidae
546	BRACHYCE	*Brachycercus spp.*	Arthropoda	Ephemeroptera	Caenidae
547	CAENIS	*Caenis spp.*	Arthropoda	Ephemeroptera	Caenidae
548	HEXALIMB	*Hexagenia limbata*	Arthropoda	Ephemeroptera	Ephemeridae
549	HEXAGENI	*Hexagenia spp.*	Arthropoda	Ephemeroptera	Ephemeridae
550	HYDROPTI	*Hydroptila spp.*	Arthropoda	Trichoptera	Hydroptilidae
551	OECETIS	*Oecetis spp.*	Arthropoda	Trichoptera	Leptoceridae
EMAP TAXA POOLED WITH OTHER TAXA					
552	ASYCHIS				
553	AMPEABDI	*Ampelisca abdita*	Arthropoda	Amphipoda	Ampeliscidae
554	AMPEVADO	*Ampelisca vadorum*	Arthropoda	Amphipoda	Ampeliscidae
555	ORCHOMEN	*Orchomenella spp.*	Arthropoda	Amphipoda	Lysianassidae
556	YOLDIA	*Yoldia spp.*	Mollusca	Bivalvia	Nuculanidae
557	PANDORA	*Pandora spp.*	Mollusca	Bivalvia	Pandoridae
558	PANDORID	*Pandoridae*	Mollusca	Bivalvia	Pandoridae
559	SOLEMYA	*Solemya spp*	Mollusca	Bivalvia	Solemyidae
560	SOLEMYID	*Solemyidae*	Mollusca	Bivalvia	Solemyidae
561	MUSCULIU	*Musculium spp.*	Mollusca	Bivalvia	Sphaeriidae
562	TELLINA	*Tellina spp.*	Mollusca	Bivalvia	Tellinidae
563	EUDORELL	*Eudorella spp.*	Arthropoda	Cumacea	Leuconidae
564	MICRATRA	*Microphiopholis atra*	Echinodermata	Ophiuroidea	Amphiuridae
565	MELINNA	*Melinna spp.*	Annelida	Polychaeta	Ampharetidae
566	APHESPEA	*Aphelochaeta sp. A Blake*	Annelida	Polychaeta	Cirratulidae
567	MONTBAPT	*Monticellina baptisteae*	Annelida	Polychaeta	Cirratulidae
568	MONTDORS	*Monticellina dorsobranchialis*	Annelida	Polychaeta	Cirratulidae
569	PHERUSA	*Pherusa spp.*	Annelida	Polychaeta	Flabelligeridae
570	LUMBHEBE	*Scoletoma hebes*	Annelida	Polychaeta	Lumbrineridae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
571	ASYCELON	*Sabaco elongatus*	Annelida	Polychaeta	Maldanidae
572	LEITOSCO	*Leitoscoloplos spp.*	Annelida	Polychaeta	Orbiniidae
573	OWENIA	*Owenia spp.*	Annelida	Polychaeta	Oweniidae
574	PECTINAR	*Pectinaria spp.*	Annelida	Polychaeta	Pectinariidae
575	BRANCLAV	*Brania clavata*	Annelida	Polychaeta	Syllidae
576	BRANSWED	*Brania swedmarki*	Annelida	Polychaeta	Syllidae
577	TYPOALTE	*Typosyllis alternata*	Annelida	Polychaeta	Syllidae
578	TYPOSPE1	*Typosyllis sp. 1 NMFS*	Annelida	Polychaeta	Syllidae
579	AMPHITRI	*Amphitritinae*	Annelida	Polychaeta	Terebellidae
Dropped EMAP-E Taxa (See Text)					
580	NEVEDUPL				
757	ERPODFAM	Erpodellidae	Annelida	Hirudinea	Erpodellidae
758	HIRUDINE	Hirudinea	Annelida	Hirudinea	Unidentified
779	DERO	*Dero* spp.	Annelida	Oligochaeta	Naididae
780	NAIDIDAE	Naididae	Annelida	Oligochaeta	Naididae
781	STEPHENS	*Stephensoniana* spp.	Annelida	Oligochaeta	Naididae
782	TUBIFICO	*Tubificoides* spp.	Annelida	Oligochaeta	Tubificidae
784	AMPHARTD	Ampharetidae	Annelida	Polychaeta	Ampharetidae
785	ARABELLA	*Arabella* spp	Annelida	Polychaeta	Arabellidae
786	ARABELLI	Arabellidae	Annelida	Polychaeta	Arabellidae
787	CAPITELD	Capitellidae	Annelida	Polychaeta	Capitellidae
788	NOTOMAST	*Notomastus* spp	Annelida	Polychaeta	Capitellidae
789	CIRRATUL	Cirratulidae	Annelida	Polychaeta	Cirratulidae
790	EUNICIDA	Eunicidae	Annelida	Polychaeta	Eunicidae
791	FLABELLI	Flabelligeridae	Annelida	Polychaeta	Flabelligeridae
792	GLYCERA	*Glycera* spp	Annelida	Polychaeta	Glyceridae
793	GLYCERID	Glyceridae	Annelida	Polychaeta	Glyceridae
794	GONIADID	Goniadidae	Annelida	Polychaeta	Goniadidae
795	GYPTIS	*Gyptis* spp	Annelida	Polychaeta	Hesionidae
796	HESIONID	Hesionidae	Annelida	Polychaeta	Hesionidae
797	MICROPHT	*Microphthalmus* spp	Annelida	Polychaeta	Hesionidae
798	LUMBRIND	Lumbrineridae	Annelida	Polychaeta	Lumbrineridae
799	LUMBRINE	*Scoletoma* spp	Annelida	Polychaeta	Lumbrineridae
800	MALDANID	Maldanidae	Annelida	Polychaeta	Maldanidae
801	NEPHTYID	Nephtyidae	Annelida	Polychaeta	Nephtyidae
802	NEPHTYS	*Nephtys* spp	Annelida	Polychaeta	Nephtyidae
803	NEREIDAE	Nereididae	Annelida	Polychaeta	Nereididae
804	ONUPHIDA	Onuphidae	Annelida	Polychaeta	Onuphidae
805	OPHELIID	Opheliidae	Annelida	Polychaeta	Opheliidae
806	TRAVISIA	*Travisia* spp	Annelida	Polychaeta	Opheliidae
807	ORBINIA	*Orbinia* spp.	Annelida	Polychaeta	Orbiniidae
808	ORBINIID	Orbiniidae	Annelida	Polychaeta	Orbiniidae
809	SCOLOPLO	*Scoloplos* spp	Annelida	Polychaeta	Orbiniidae
810	OWENIIDA	Oweniidae	Annelida	Polychaeta	Oweniidae
811	ARICIDEA	*Aricidea* spp	Annelida	Polychaeta	Paraonidae
812	PARAONID	Paraonidae	Annelida	Polychaeta	Paraonidae
813	ETEONE	*Hypereteone* spp	Annelida	Polychaeta	Phyllodocidae
814	PHYLLODO	*Phyllodoce* spp	Annelida	Polychaeta	Phyllodocidae
815	PHYLDCDE	Phyllodocidae	Annelida	Polychaeta	Phyllodocidae

No	CODE	Genus spp.	Phylyum	Class	Family
816	PILARGID	Pilargidae	Annelida	Polychaeta	Pilargidae
817	SIGAMBRA	*Sigambra* spp.	Annelida	Polychaeta	Pilargidae
818	HARMOTHO	*Harmothoe* spp.	Annelida	Polychaeta	Polynoidae
819	LEPIDONO	*Lepidonotus* spp.	Annelida	Polychaeta	Polynoidae
820	POLYNOID	Polynoidae	Annelida	Polychaeta	Polynoidae
821	SABELLAR	Sabellariidae	Annelida	Polychaeta	Sabellariidae
822	EUCHONE	*Euchone* spp.	Annelida	Polychaeta	Sabellidae
823	FABRICIN	Fabricinae	Annelida	Polychaeta	Sabellidae
824	SABELLID	Sabellidae	Annelida	Polychaeta	Sabellidae
825	SCALIBRE	Scalibregmatidae	Annelida	Polychaeta	Scalibregmatidae
826	FILOGRAN	Filograninae sp. A Morris	Annelida	Polychaeta	Serpulidae
827	HYDRDIAN	*Hydroides dianthus*	Annelida	Polychaeta	Serpulidae
828	HYDRPROT	*Hydroides protulicola*	Annelida	Polychaeta	Serpulidae
829	HYDROIDE	*Hydroides* spp.	Annelida	Polychaeta	Serpulidae
830	SERPULID	Serpulidae	Annelida	Polychaeta	Serpulidae
831	SIGALION	Sigalionidae	Annelida	Polychaeta	Sigalionidae
832	STENELAI	*Sthenelais* spp.	Annelida	Polychaeta	Sigalionidae
833	POLYDORA	*Polydora* spp.	Annelida	Polychaeta	Spionidae
834	PRIONOSP	*Prionospio* spp.	Annelida	Polychaeta	Spionidae
835	SCOLELEP	*Scolelepis* spp.	Annelida	Polychaeta	Spionidae
836	SPIO	*Spio* spp.	Annelida	Polychaeta	Spionidae
837	SPIONIDA	Spionidae	Annelida	Polychaeta	Spionidae
838	SPIRORBD	Spirorbidae	Annelida	Polychaeta	Spirorbidae
839	SPIRORBI	*Spirorbis* spp.	Annelida	Polychaeta	Spirorbidae
840	AUTOLYNI	Autolyninae	Annelida	Polychaeta	Syllidae
841	AUTOLYTU	*Autolytus* spp.	Annelida	Polychaeta	Syllidae
842	BRANIA	*Brania* spp.	Annelida	Polychaeta	Syllidae
843	EXOGONE	*Exogone* spp.	Annelida	Polychaeta	Syllidae
844	PIONOSYL	*Pionosyllis* spp.	Annelida	Polychaeta	Syllidae
845	SPHAEROS	*Sphaerosyllis* spp.	Annelida	Polychaeta	Syllidae
846	STREPTOS	*Streptosyllis* spp.	Annelida	Polychaeta	Syllidae
847	SYLLIDAE	Syllidae	Annelida	Polychaeta	Syllidae
848	SYLLIDES	Syllides spp.	Annelida	Polychaeta	Syllidae
849	TYPOSYLL	*Typosyllis* spp.	Annelida	Polychaeta	Syllidae
850	PISTA	*Pista* spp.	Annelida	Polychaeta	Terebellidae
851	POLYCIRN	Polycirrinae Unidentified	Annelida	Polychaeta	Terebellidae
852	POLYCIRR	*Polycirrus* spp.	Annelida	Polychaeta	Terebellidae
853	TEREBELL	Terebellidae	Annelida	Polychaeta	Terebellidae
854	POLYCSUB	Polychaeta: Other - Deep Deposit Feeders	Annelida	Polychaeta	Unidentified
855	POLYCCAR	Polychaeta: Other - Omnivores & Carnivore	Annelida	Polychaeta	Unidentified
856	POLYCSUR	Polychaeta: Other - Surface Feeders	Annelida	Polychaeta	Unidentified
857	POLYCHAE	Polychaeta: Other - Unidentified & fragments	Annelida	Polychaeta	Unidentified
581	AMPELISC	*Ampelisca* spp	Arthropoda	Amphipoda	Ampeliscidae
582	AMPITHOE	*Ampithoe* spp.	Arthropoda	Amphipoda	Ampithoidae
583	AMPITHOI	Ampithoidae	Arthropoda	Amphipoda	Ampithoidae
584	AORIDAE	Aoridae	Arthropoda	Amphipoda	Aoridae

No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
585	LEMBOS	Lembos spp.	Arthropoda	Amphipoda	Aoridae
586	LEPTOCHE	Leptocheirus spp.	Arthropoda	Amphipoda	Aoridae
587	MICRODEU	Microdeutopus spp.	Arthropoda	Amphipoda	Aoridae
588	UNCIOLA	Unciola spp.	Arthropoda	Amphipoda	Aoridae
589	AEGILONG	*Aeginina longicornis*	Arthropoda	Amphipoda	Caprellidae
590	CAPRANDR	*Caprella andreae*	Arthropoda	Amphipoda	Caprellidae
591	CAPRPENA	*Caprella penantis*	Arthropoda	Amphipoda	Caprellidae
592	CAPRELLA	*Caprella* spp.	Arthropoda	Amphipoda	Caprellidae
593	CAPRELLI	Caprellidae	Arthropoda	Amphipoda	Caprellidae
594	LUCOINCE	*Luconacia incerta*	Arthropoda	Amphipoda	Caprellidae
595	PARATENU	*Paracaprella tenuis*	Arthropoda	Amphipoda	Caprellidae
596	COROPHIU	*Corophium* spp.	Arthropoda	Amphipoda	Corophiidae
597	GAMMARID	Gammaridae	Arthropoda	Amphipoda	Gammaridae
598	GAMMARUS	*Gammarus* spp.	Arthropoda	Amphipoda	Gammaridae
599	ACANTHOH	*Acanthohaustorius* spp.	Arthropoda	Amphipoda	Haustoriidae
600	HAUSTIDA	Haustoriidae	Arthropoda	Amphipoda	Haustoriidae
601	PARAHAUS	Parahaustorius spp.	Arthropoda	Amphipoda	Haustoriidae
602	PROTOHAU	Protohaustorius spp.	Arthropoda	Amphipoda	Haustoriidae
603	PHOTIS	Photis spp.	Arthropoda	Amphipoda	Isaeidae
604	ERICTHON	Ericthonius spp.	Arthropoda	Amphipoda	Ischyroceridae
605	LILJEBOR	Liljeborgiidae	Arthropoda	Amphipoda	Liljeborgiidae
606	LISTRIEL	Listriella spp.	Arthropoda	Amphipoda	Liljeborgiidae
607	LYSIADAE	Lysianassidae	Arthropoda	Amphipoda	Lysianassidae
608	MELITIDA	Melitidae	Arthropoda	Amphipoda	Melitidae
609	MONOCULO	Monoculodes spp.	Arthropoda	Amphipoda	Oedicerotidae
610	PHOXOCEP	Phoxocephalidae	Arthropoda	Amphipoda	Phoxocephalidae
611	RHEPOXYN	Rhepoxynius spp.	Arthropoda	Amphipoda	Phoxocephalidae
612	PODOCERI	Podoceridae	Arthropoda	Amphipoda	Podoceridae
613	STENOTHO	Stenothoe spp.	Arthropoda	Amphipoda	Stenothoidae
614	AMPHIPOD	Amphipoda: Other	Arthropoda	Amphipoda	Unidentified
625	HOMAAMER	Homarus americanus	Arthropoda	Astacidea	Nephropsidae
674	CHRNMDAE	Chironomidae	Arthropoda	Chironomidae	Chironomidae
675	CHIRONIM	Chironomini	Arthropoda	Chironomidae	Chironomini
676	CRYPTOCH	Cryptochironomus spp.	Arthropoda	Chironomidae	Chironomini
677	POLYPEDI	Polypedilum spp.	Arthropoda	Chironomidae	Chironomini
678	PROCLADI	Procladius spp.	Arthropoda	Chironomidae	Tanypodinae
679	TANYTTRB	Tanytarsini	Arthropoda	Chironomidae	Tanytarsini
680	BALABALA	Balanus balanoides	Arthropoda	Cirripedia	Balanidae
681	BALACREN	Balanus crenatus	Arthropoda	Cirripedia	Balanidae
682	BALAIMPR	Balanus improvisus	Arthropoda	Cirripedia	Balanidae
683	BALANUS	Balanus spp.	Arthropoda	Cirripedia	Balanidae
684	BALAVENU	Balanus venustus	Arthropoda	Cirripedia	Balanidae
685	CLADOCER	Cladocera	Arthropoda	Cladocera	Unidentified
686	COLLEMBO	Collembola	Arthropoda	Collembola	Unidentified
687	CALANOID	Calanoida	Arthropoda	Copepoda	Calanoida
688	CALIGOID	Caligoida	Arthropoda	Copepoda	Caligoida
689	HARPACTI	Harpacticoida	Arthropoda	Copepoda	Harpacticoida
690	BODOTRUN	Bodotriidae	Arthropoda	Cumacea	Bodotriidae
691	CUMACEA	Cumacea	Arthropoda	Cumacea	Unidentified

No	CODE	Genus spp.	Phylyum	Class	Family
692	BRACHYUR	Brachyura	Arthropoda	Decapoda	Brachyura
693	CANCIRRO	Cancer irroratus	Arthropoda	Decapoda	Cancridae
694	CANCER	Cancer spp.	Arthropoda	Decapoda	Cancridae
695	CARIDEA	Caridea	Arthropoda	Decapoda	Caridea
696	HIPPOLYT	Hippolytidae	Arthropoda	Decapoda	Hippolytidae
697	LIBINIA	Libinia spp.	Arthropoda	Decapoda	Majidae
698	MAJIDAE	Majidae	Arthropoda	Decapoda	Majidae
699	PAGURIDA	Paguridae	Arthropoda	Decapoda	Paguridae
700	PAGURUS	Pagurus spp.	Arthropoda	Decapoda	Paguridae
865	PALAPUGI	Palaemonetes pugio	Arthropoda	Decapoda	Palaemonidae
701	PENAEIDA	Penaeidae	Arthropoda	Decapoda	Penaeidae
702	TRACCONS	Trachypenaeus constrictus	Arthropoda	Decapoda	Penaeidae
703	DISSMELL	Dissodactylus mellitae	Arthropoda	Decapoda	Pinnotheridae
704	PINNCHAE	Pinnixa chaetopterana	Arthropoda	Decapoda	Pinnotheridae
705	PINNRETI	Pinnixa retinens	Arthropoda	Decapoda	Pinnotheridae
706	PINNSAYA	Pinnixa sayana	Arthropoda	Decapoda	Pinnotheridae
707	PINNIXA	Pinnixa spp.	Arthropoda	Decapoda	Pinnotheridae
708	PINNOTHR	Pinnotheres spp	Arthropoda	Decapoda	Pinnotheridae
709	PINNOTHE	Pinnotheridae	Arthropoda	Decapoda	Pinnotheridae
710	CALLSAPI	Callinectes sapidus	Arthropoda	Decapoda	Portunidae
711	CALLINEC	Callinectes spp.	Arthropoda	Decapoda	Portunidae
712	CARCMAEN	Carcinus maenas	Arthropoda	Decapoda	Portunidae
713	OVALIPES	Ovalipes spp.	Arthropoda	Decapoda	Portunidae
714	PORTUNID	Portunidae	Arthropoda	Decapoda	Portunidae
715	DECAPODA	Decapoda	Arthropoda	Decapoda	Unidentified
716	XANTHIDA	Xanthidae	Arthropoda	Decapoda	Xanthidae
717	CERATFAM	Ceratopogonidae	Arthropoda	Diptera	Ceratopogonidae
718	DIPTERA	Diptera	Arthropoda	Diptera	Unidentified
724	EPHEMFAM	Ephemeridae	Arthropoda	Ephemeroptera	Ephemeridae
760	HYDRACAR	Hydracarina	Arthropoda	Hydracarina	Unidentified
761	INSECTA	Insecta	Arthropoda	Insecta	Unidentified
762	ANTHURID	Anthuridae	Arthropoda	Isopoda	Anthuridae
763	CYATHURA	Cyathura spp.	Arthropoda	Isopoda	Anthuridae
764	CHIRIDOT	Chiridotea spp.	Arthropoda	Isopoda	Idoteidae
765	ERICHSON	Erichsonella spp	Arthropoda	Isopoda	Idoteidae
766	IDOTEA	Idotea spp.	Arthropoda	Isopoda	Idoteidae
767	IDOTEIDA	Idoteidae	Arthropoda	Isopoda	Idoteidae
768	ISOPODA	Isopoda: Other	Arthropoda	Isopoda	Unidentified
769	LIMUPOLY	Limulus polyphemus	Arthropoda	Merostomata	Limulidae
772	HETEFORM	Heteromysis formosa	Arthropoda	Mysidacea	Mysidae
773	MYSIDAE	Mysidae	Arthropoda	Mysidacea	Mysidae
774	MYSIALMY	Mysidopsis almyra	Arthropoda	Mysidacea	Mysidae
775	MYSIBIGE	Mysidopsis bigelowi	Arthropoda	Mysidacea	Mysidae
776	MYSIDOPS	Mysidopsis spp.	Arthropoda	Mysidacea	Mysidae
777	NEOMAMER	Neomysis americana	Arthropoda	Mysidacea	Mysidae
783	OSTRACOD	Ostracoda	Arthropoda	Ostracoda	Unidentified
861	PYCNOGON	Pycnogonida	Arthropoda	Pycnogonida	Unidentified
862	TANAIDAC	Tanaidacea	Arthropoda	Tanaidacea	Unidentified
863	HYDROFAM	Hydroptilidae	Arthropoda	Trichoptera	Hydroptilidae

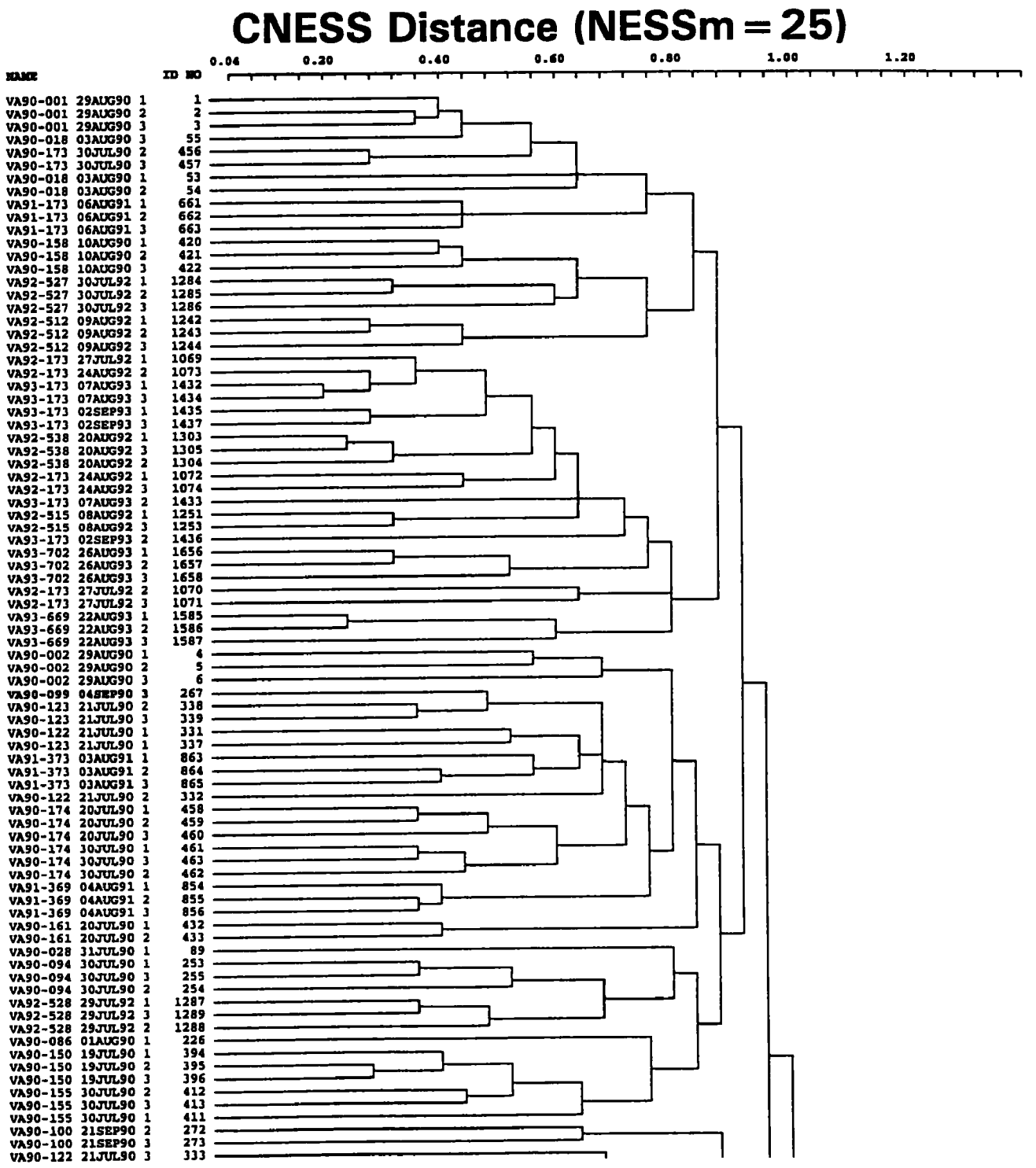
No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
665	ALCYONID	Alcyonidium spp.	Bryozoa	Bryozoa	Alcyonidiidae
666	CALLCRAT	Callopora craticula	Bryozoa	Bryozoa	Calloporidae
667	TURBDICH	Turbicellopora dichotoma	Bryozoa	Bryozoa	Celleporinidae
668	MEMBTENU	Membranipora tenuis	Bryozoa	Bryozoa	Membraniporidae
669	ANGUPALM	Anguinella palmata	Bryozoa	Bryozoa	Nolellidae
670	SCHIUNIC	Schizoporella unicornis	Bryozoa	Bryozoa	Schizoporellidae
671	AMATVIDO	Amathia vidovici	Bryozoa	Bryozoa	Vesicularıidae
617	BOSTPILU	Bostrichobranchus pilularis	Chordata	Ascidiacea	Molgulidae
618	MOLGAREN	Molgula arenata	Chordata	Ascidiacea	Molgulidae
619	MOLGMANH	Molgula manhattensis	Chordata	Ascidiacea	Molgulidae
620	PEROVIRI	Perophora viridis	Chordata	Ascidiacea	Perophoridae
621	AMARSTEL	Amaroucium stellatum	Chordata	Ascidiacea	Polyclinidae
622	BOTRSCHL	Botryllus schlosseri	Chordata	Ascidiacea	Styelidae
623	CNEMMOLL	Cnemidocarpa mollis	Chordata	Ascidiacea	Styelidae
624	ASCIDIAC	Ascidiacea	Chordata	Ascidiacea	Unidentified
673	BRANCARI	Branchiostoma caribaeum	Chordata	Cephalochordata	Branchiostomidae
672	BRANVIRG	Branchiostoma caribaeum	Chordata	Cephalochordata	Branchiostomidae
615	PARARAPI	Paranthus rapiformis	Cnidaria	Anthozoa	Actinostolidae
616	ANTHOZOA	Anthozoa	Cnidaria	Anthozoa	Unidentified
626	ASTERIAS	Asterias spp.	Echinodermata	Asteroidea	Asteriidae
627	ASTEROID	Asteroidea	Echinodermata	Asteroidea	Unidentified
719	ECHINODE	Echinodermata	Echinodermata	Echinodermata	Unidentified
720	ARBAPUNC	Arbacia punctulata	Echinodermata	Echinoidea	Arbaciidae
721	ECHIPARM	Echinarachnius parma	Echinodermata	Echinoidea	Echinarachnidae
722	MELLQUIN	Mellita quinquiesperforata	Echinodermata	Echinoidea	Mellitidae
723	ECHINOID	Echinoidea	Echinodermata	Echinoidea	Unidentified
759	HOLOTHUR	Holothuroidea	Echinodermata	Holothuroidea	Unidentified
756	HEMICHOR	Hemichordata	Hemichordata	Hemichordata	Unidentified
770	MISCELLA	Miscellanea	Miscellanea	Miscellanea	Unidentified
771	NOORGPRS	No Organisms Present	Miscellanea	Miscellanea	Unidentified
628	ANOMSIMP	Anomia simplex	Mollusca	Bivalvia	Anomiidae
629	ANOMIA	Anomia spp	Mollusca	Bivalvia	Anomiidae
630	ANOMSQUA	Anomia squamula	Mollusca	Bivalvia	Anomiidae
631	ARCIDFAM	Arcidae	Mollusca	Bivalvia	Arcidae
632	ASTARTE	Astarte spp	Mollusca	Bivalvia	Astartidae
633	ASTARTID	Astartidae	Mollusca	Bivalvia	Astartidae
634	MYTILEUC	Mytilopsis leucophaeta	Mollusca	Bivalvia	Dreissenidae
635	GALEOMMA	Galeommatacea	Mollusca	Bivalvia	Galeommatacea
636	LYONSIA	Lyonsia spp	Mollusca	Bivalvia	Lyonsiidae
637	MACTRFAM	Mactridae	Mollusca	Bivalvia	Mactridae
638	MYSEPLAN	Mysella planulata	Mollusca	Bivalvia	Montacutidae
639	MYSELLA	Mysella spp.	Mollusca	Bivalvia	Montacutidae
640	CRENDECU	Crenella decussata	Mollusca	Bivalvia	Mytilidae
641	CRENGLAN	Crenella glandula	Mollusca	Bivalvia	Mytilidae
642	CRENELLA	Crenella spp.	Mollusca	Bivalvia	Mytilidae
643	GEUKDEMI	Geukensia demissa	Mollusca	Bivalvia	Mytilidae
644	ISCHRECU	Ischadium recurvum	Mollusca	Bivalvia	Mytilidae
645	MODIOLUS	Modiolus spp	Mollusca	Bivalvia	Mytilidae

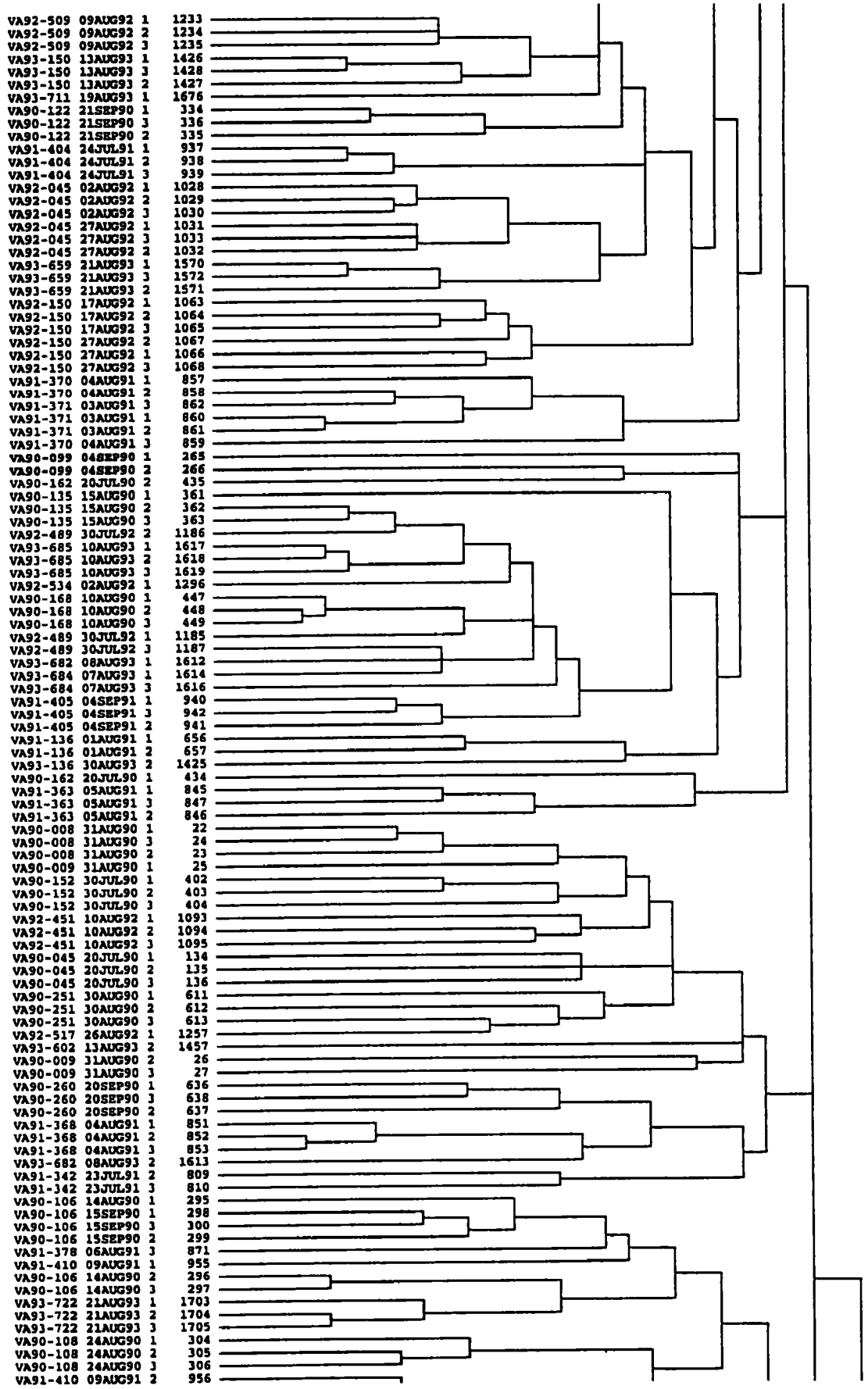
NO	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
646	MUSCNIGE	Musculus niger	Mollusca	Bivalvia	Mytilidae
647	MUSCULUS	Musculus spp.	Mollusca	Bivalvia	Mytilidae
648	MYTILIDA	Mytilidae	Mollusca	Bivalvia	Mytilidae
649	MYTIEDUL	Mytilus edulis	Mollusca	Bivalvia	Mytilidae
650	NUCULANI	Nuculanidae	Mollusca	Bivalvia	Nuculanidae
651	NUCULA	Nucula spp.	Mollusca	Bivalvia	Nuculidae
652	PECTINID	Pectinidae	Mollusca	Bivalvia	Pectinidae
653	BARNTRUN	Barnea truncata	Mollusca	Bivalvia	Pholadidae
654	PHOLADID	Pholadidae	Mollusca	Bivalvia	Pholadidae
655	SOLECFAM	Solecurtidae	Mollusca	Bivalvia	Solecurtidae
656	TAGELUS	*Tagelus* spp.	Mollusca	Bivalvia	Solecurtidae
657	SOLENIDA	Solenidae	Mollusca	Bivalvia	Solenidae
658	TELLINID	Tellinidae	Mollusca	Bivalvia	Tellinidae
659	THRACIID	Thraciidae	Mollusca	Bivalvia	Thraciidae
660	THYASIRI	Thyasiridae	Mollusca	Bivalvia	Thyasiridae
661	BIVALDEP	Bivalvia. Other - Deposit Feeders	Mollusca	Bivalvia	Unidentified
662	BIVALSUS	Bivalvia: Other - Suspension Feeders	Mollusca	Bivalvia	Unidentified
663	BIVALVIA	Bivalvia: Other - Unidentified	Mollusca	Bivalvia	Unidentified
664	UNIONIDA	Unionidae	Mollusca	Bivalvia	Unionidae
725	BUCCINID	Buccinidae	Mollusca	Gastropoda	Buccinidae
726	CAECIDAE	Caecidae	Mollusca	Gastropoda	Caecidae
727	CAECUM	Caecum spp.	Mollusca	Gastropoda	Caecidae
728	CREPCONV	Crepidula convexa	Mollusca	Gastropoda	Calyptraeidae
729	CREPCOFO	*Crepidula convexa-fornicata* complex	Mollusca	Gastropoda	Calyptraeidae
730	CREPFORN	Crepidula fornicata	Mollusca	Gastropoda	Calyptraeidae
731	CREPMACU	Crepidula maculosa	Mollusca	Gastropoda	Calyptraeidae
732	CREPPLAN	Crepidula plana	Mollusca	Gastropoda	Calyptraeidae
733	CREPIDUL	Crepidula spp.	Mollusca	Gastropoda	Calyptraeidae
734	ANACHIS	Anachis spp.	Mollusca	Gastropoda	Columbellidae
735	COLUMBLD	Columbellidae	Mollusca	Gastropoda	Columbellidae
736	CYLICHNE	Cylichnella spp	Mollusca	Gastropoda	Cylichnidae
737	EPITONIU	Epitonium spp.	Mollusca	Gastropoda	Epitoniidae
738	CRATENA	Cratena spp.	Mollusca	Gastropoda	Facelinidae
739	HYDROBIA	Hydrobia spp.	Mollusca	Gastropoda	Hydrobiidae
740	HYDROBII	Hydrobiidae	Mollusca	Gastropoda	Hydrobiidae
741	LYMNAFAM	Lymnaeidae	Mollusca	Gastropoda	Lymnaeidae
742	NASSARIU	*Nassarius* spp.	Mollusca	Gastropoda	Nassariidae
743	NATICA	*Natica* spp.	Mollusca	Gastropoda	Naticidae
744	NATICIDA	Naticidae	Mollusca	Gastropoda	Naticidae
745	NUDIBRAN	Nudibranchia	Mollusca	Gastropoda	Nudibranchia
746	PLANORBI	Planorbidae	Mollusca	Gastropoda	Planorbidae
747	FARGOA	Fargoa spp.	Mollusca	Gastropoda	Pyramidellidae
748	ODOSTOMI	*Odostomia* spp.	Mollusca	Gastropoda	Pyramidellidae
749	PYRAMIDE	Pyramidellidae	Mollusca	Gastropoda	Pyramidellidae
750	TURBONIL	Turbonilla spp.	Mollusca	Gastropoda	Pyramidellidae

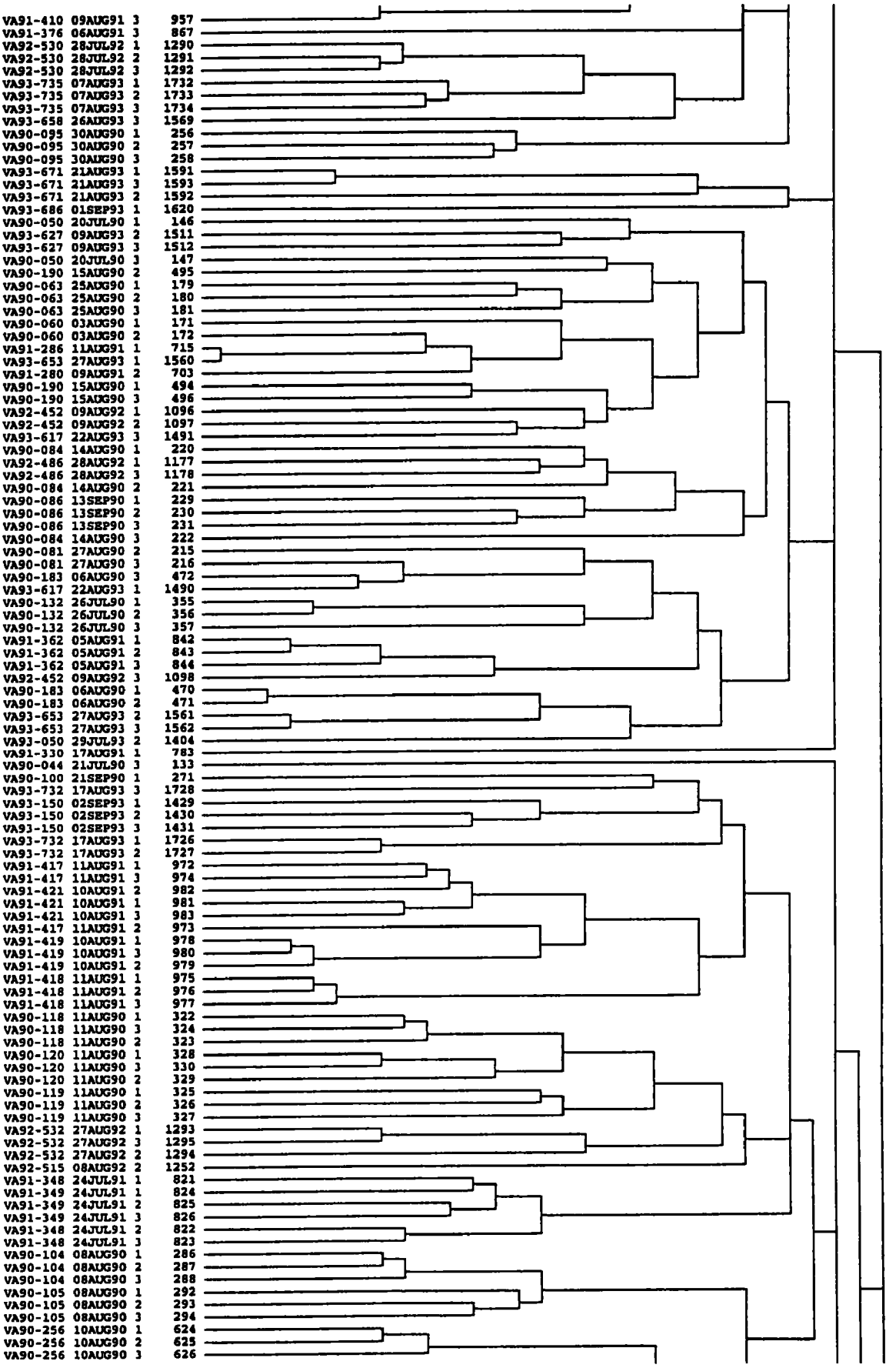
No	CODE	GENUS SPP.	PHYLYUM	CLASS	FAMILY
751	SCAPHFAM	Scaphandridae	Mollusca	Gastropoda	Scaphandridae
752	TURRIFAM	Turridae	Mollusca	Gastropoda	Turridae
753	GASTROPO	Gastropoda: Other	Mollusca	Gastropoda	Unidentified
754	VITRINEL	Vitrinellidae	Mollusca	Gastropoda	Vitrinellidae
755	VIVIPARI	Viviparidae	Mollusca	Gastropoda	Viviparidae
858	CHAEAPIC	Chaetopleura apiculata	Mollusca	Polyplacophora	Chaetopleuridae
859	POLYPLAC	Polyplacophora	Mollusca	Polyplacophora	Unidentified
778	NEMATODA	Nematoda	Nematoda	Nematoda	Unidentified
864	TURBELLA	Turbellaria	Platyhelminthe	Turbellaria	Unidentified
860	PORIFERA	Porifera	Porifera	Porifera	Unidentified
Taxa in the EMAP-E Species List but not present					
868	NAISCOMM	*Nais communis*	Annelida	Oligochaeta	Naididae
866	AMPHABDI	*Amphioplus abdita*	Echinodermata	Ophiuroidea	Amphiuridae
867	HIATARCT	*Hiatella arctica*	Mollusca	Bivalvia	Hiatellidae

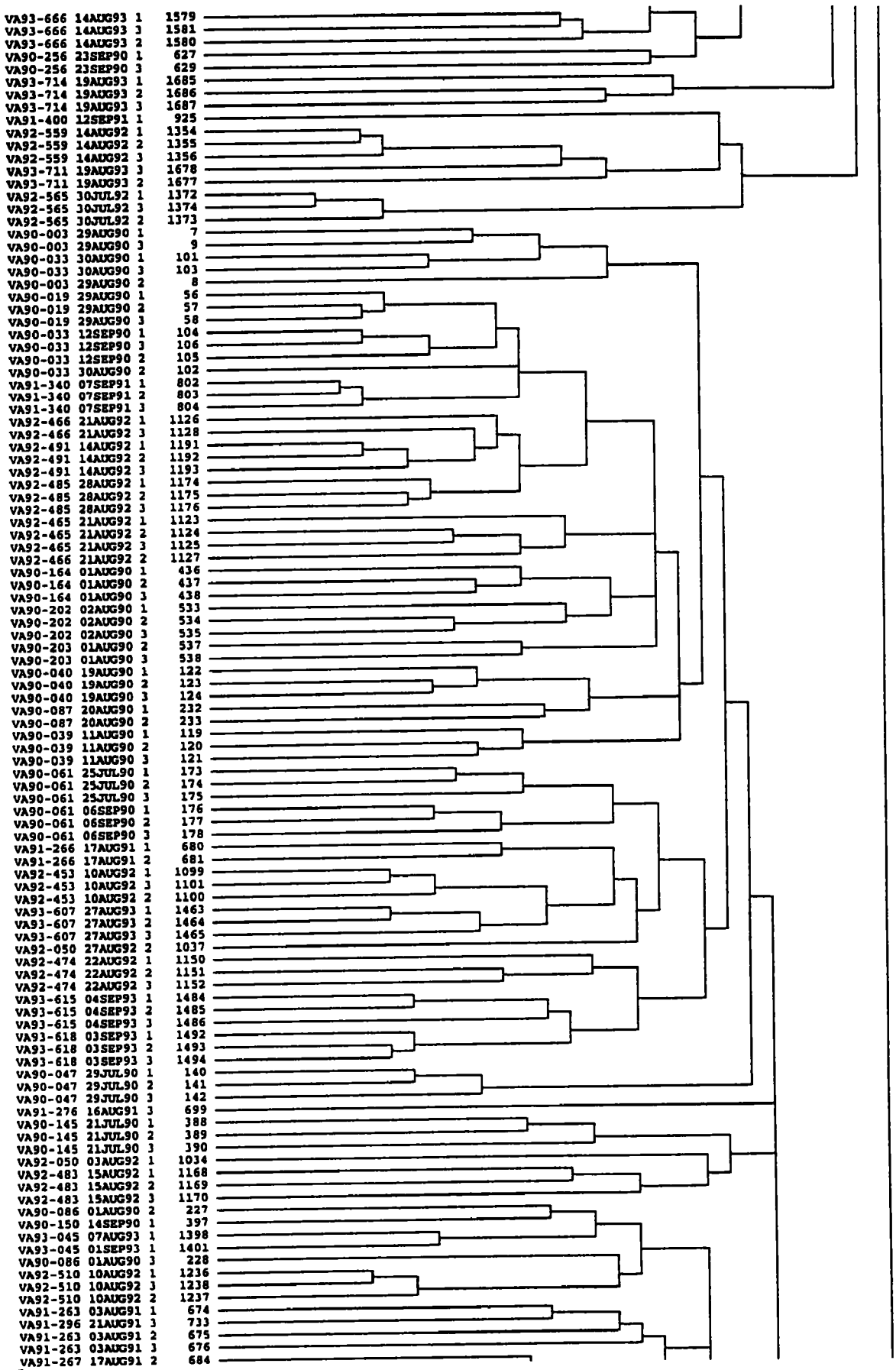
APPENDIX IV SAMPLE CLUSTER ANALYSIS

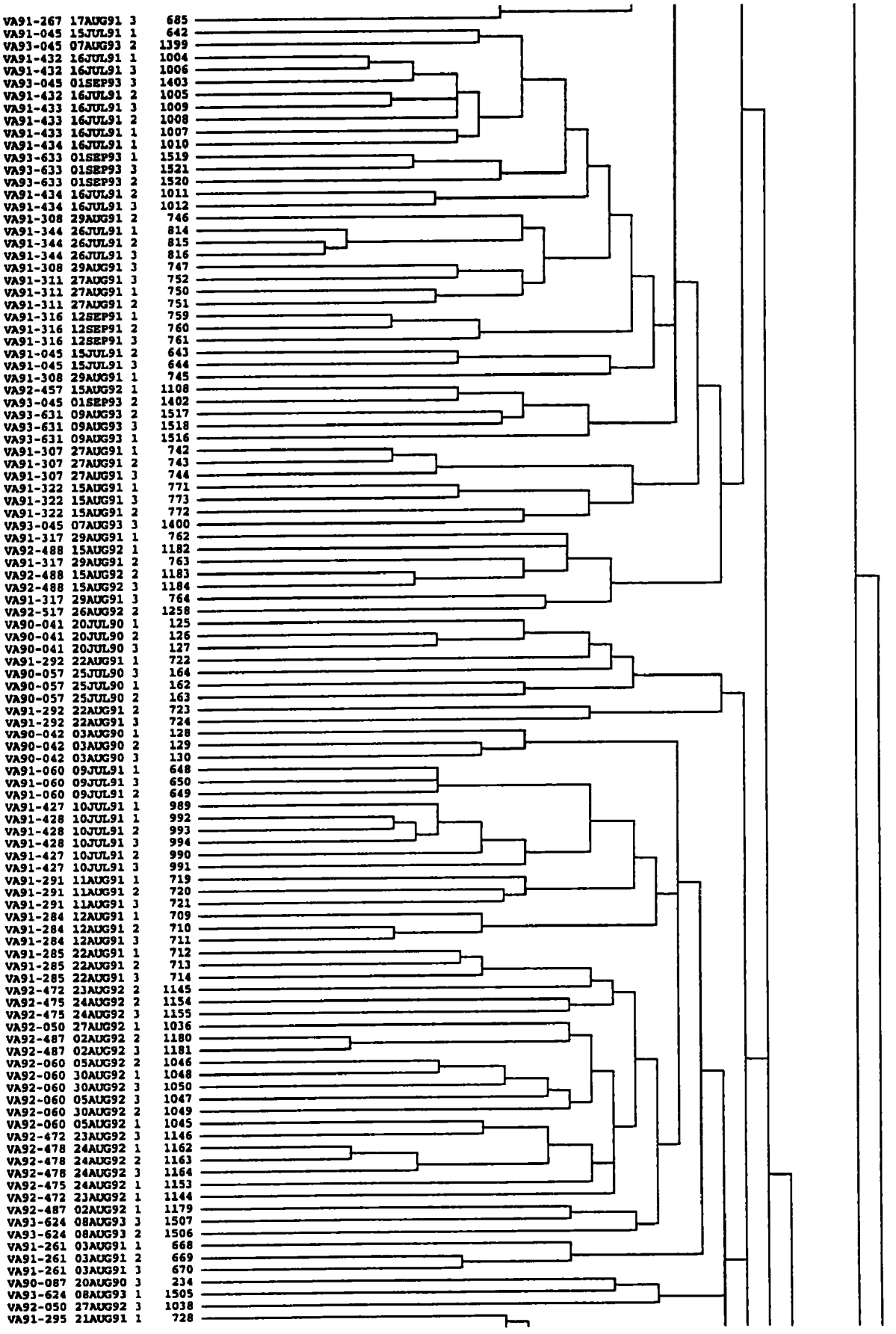
A cluster analysis of the 1918-sample EMAP-E VP benthic data at CNESS (CNESS, m=25, UPGMA Sorting). All samples with fewer than 25 individuals were dropped (a requirement with a random sample size of 25). The pared data set consisted of 1736 samples and 466 species. New Bedford Harbor STA **099**, a degraded estuarine station (Schimmel et al. 1993, Table B-2) is bolded. This degraded EMAP-E VP sampling site exhibits considerable variation among months and years.

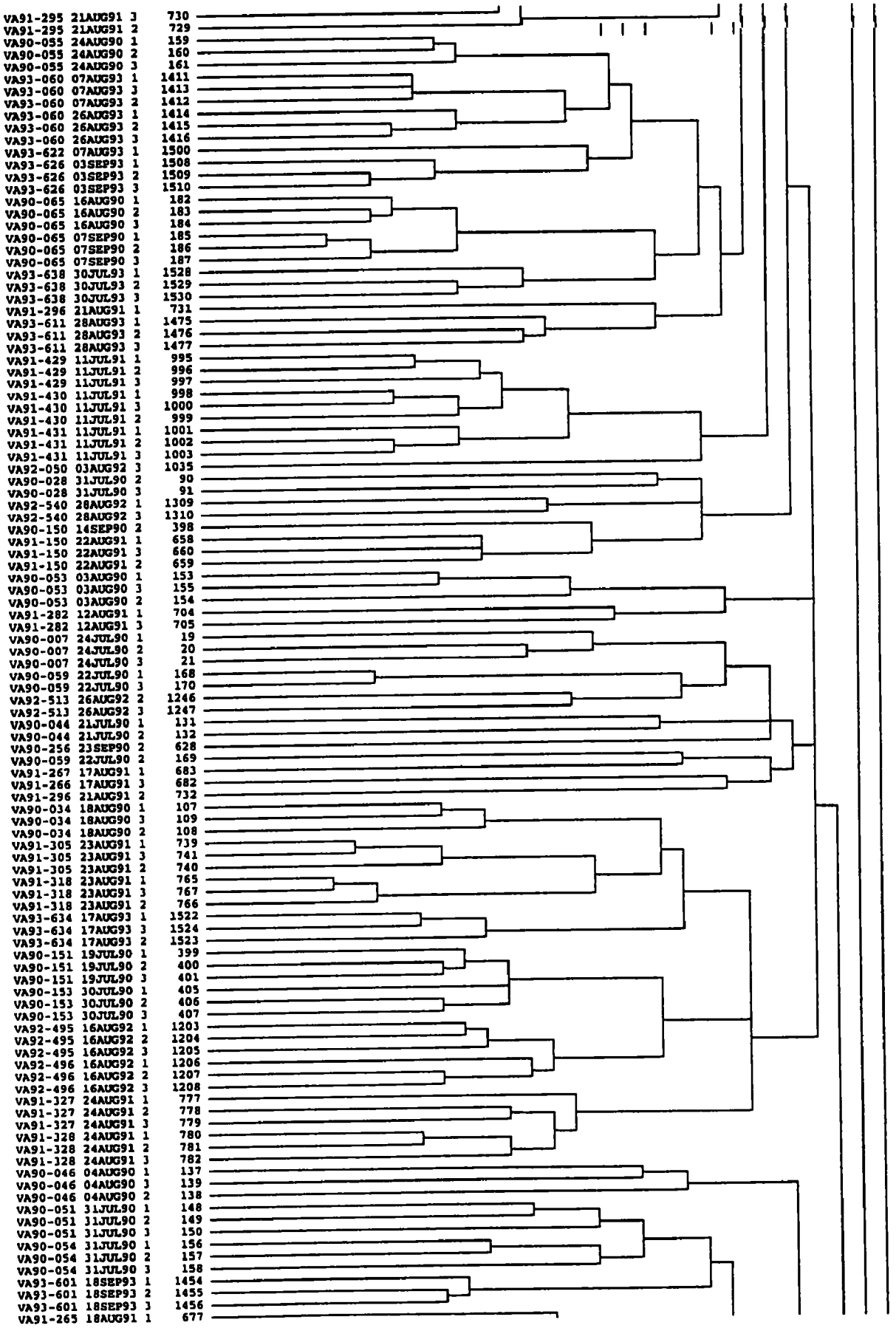


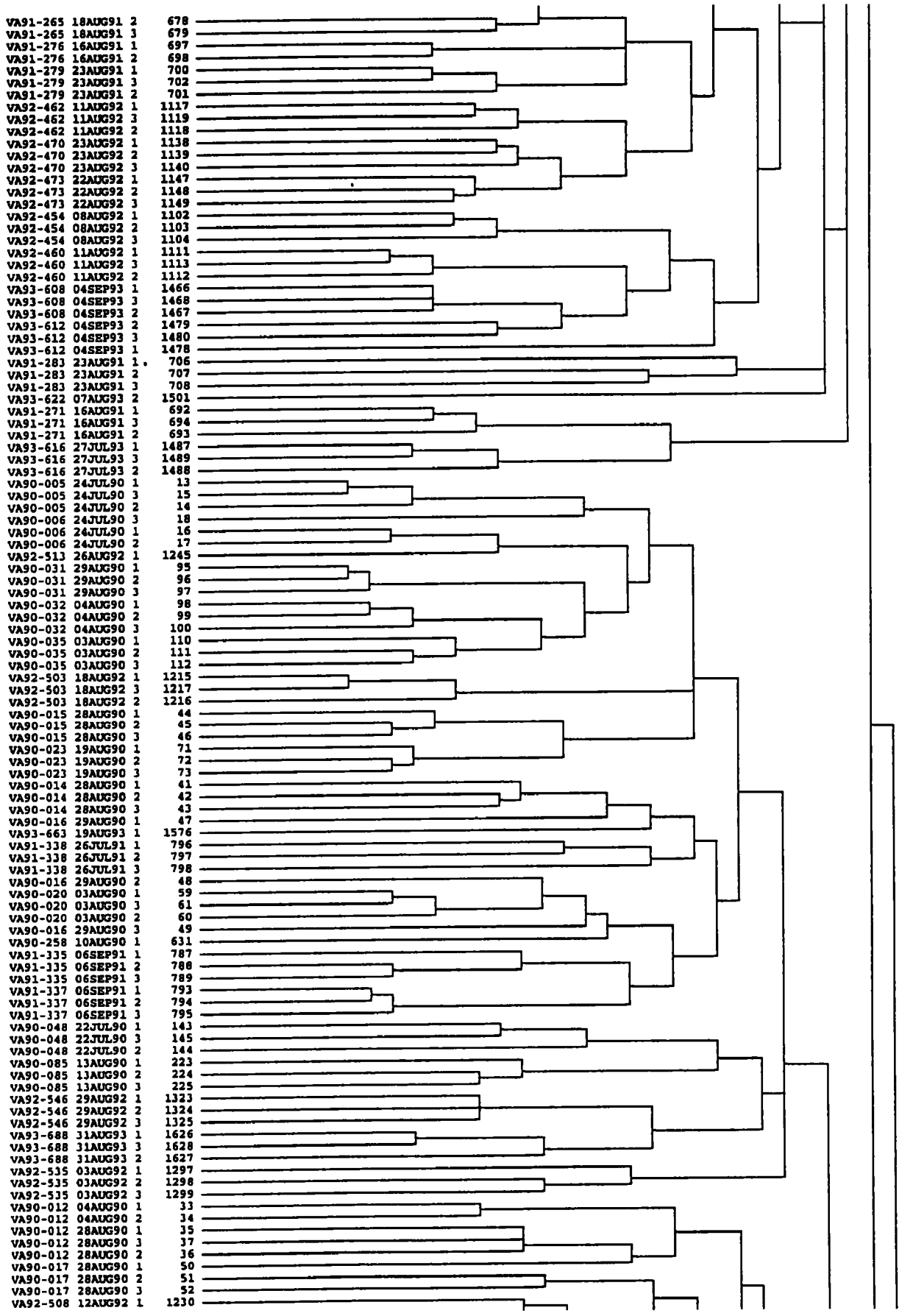

VA92-509 09AUG92 1 1233
VA92-509 09AUG92 2 1234
VA92-509 09AUG92 3 1235
VA93-150 13AUG93 1 1426
VA93-150 13AUG93 3 1428
VA93-150 13AUG93 2 1427
VA93-711 19AUG93 1 1676
VA90-122 21SEP90 1 334
VA90-122 21SEP90 3 336
VA90-122 21SEP90 2 335
VA91-404 24JUL91 1 937
VA91-404 24JUL91 2 938
VA91-404 24JUL91 3 939
VA92-045 02AUG92 1 1028
VA92-045 02AUG92 2 1029
VA92-045 02AUG92 3 1030
VA92-045 27AUG92 1 1031
VA92-045 27AUG92 3 1033
VA92-045 27AUG92 2 1032
VA93-659 21AUG93 1 1570
VA93-659 21AUG93 3 1572
VA93-659 21AUG93 2 1571
VA92-150 17AUG92 1 1063
VA92-150 17AUG92 2 1064
VA92-150 17AUG92 3 1065
VA92-150 27AUG92 2 1067
VA92-150 27AUG92 1 1066
VA92-150 27AUG92 3 1068
VA91-370 04AUG91 1 857
VA91-370 04AUG91 2 858
VA91-371 03AUG91 3 862
VA91-371 03AUG91 1 860
VA91-371 03AUG91 2 861
VA91-370 04AUG91 3 859
VA90-099 04SEP90 1 265
VA90-099 04SEP90 2 266
VA90-162 20JUL90 2 435
VA90-135 15AUG90 1 361
VA90-135 15AUG90 2 362
VA90-135 15AUG90 3 363
VA92-489 30JUL92 2 1186
VA93-685 10AUG93 1 1617
VA93-685 10AUG93 2 1618
VA93-685 10AUG93 3 1619
VA92-534 02AUG92 1 1296
VA90-168 10AUG90 1 447
VA90-168 10AUG90 2 448
VA90-168 10AUG90 3 449
VA92-489 30JUL92 1 1185
VA92-489 30JUL92 3 1187
VA93-682 08AUG93 1 1612
VA93-684 07AUG93 1 1614
VA93-684 07AUG93 3 1616
VA91-405 04SEP91 1 940
VA91-405 04SEP91 3 942
VA91-405 04SEP91 2 941
VA91-136 01AUG91 1 656
VA91-136 01AUG91 2 657
VA93-136 30AUG93 2 1425
VA90-162 20JUL90 1 434
VA91-363 05AUG91 1 845
VA91-363 05AUG91 3 847
VA91-363 05AUG91 2 846
VA90-008 31AUG90 1 22
VA90-008 31AUG90 3 24
VA90-008 31AUG90 2 23
VA90-009 31AUG90 1 25
VA90-152 30JUL90 1 402
VA90-152 30JUL90 2 403
VA90-152 30JUL90 3 404
VA92-451 10AUG92 1 1093
VA92-451 10AUG92 2 1094
VA92-451 10AUG92 3 1095
VA90-045 20JUL90 1 134
VA90-045 20JUL90 2 135
VA90-045 20JUL90 3 136
VA90-251 30AUG90 1 611
VA90-251 30AUG90 2 612
VA90-251 30AUG90 3 613
VA92-517 26AUG92 1 1257
VA93-602 13AUG93 2 1457
VA90-009 31AUG90 2 26
VA90-009 31AUG90 3 27
VA90-260 20SEP90 1 636
VA90-260 20SEP90 3 638
VA90-260 20SEP90 2 637
VA91-368 04AUG91 1 851
VA91-368 04AUG91 2 852
VA91-368 04AUG91 3 853
VA93-682 08AUG93 2 1613
VA91-342 23JUL91 2 809
VA91-342 23JUL91 3 810
VA90-106 14AUG90 1 295
VA90-106 15SEP90 1 298
VA90-106 15SEP90 3 300
VA90-106 15SEP90 2 299
VA91-378 06AUG91 3 871
VA91-410 09AUG91 1 955
VA90-106 14AUG90 2 296
VA90-106 14AUG90 3 297
VA93-722 21AUG93 1 1703
VA93-722 21AUG93 2 1704
VA93-722 21AUG93 3 1705
VA90-108 24AUG90 1 304
VA90-108 24AUG90 2 305
VA90-108 24AUG90 3 306
VA91-410 09AUG91 2 956

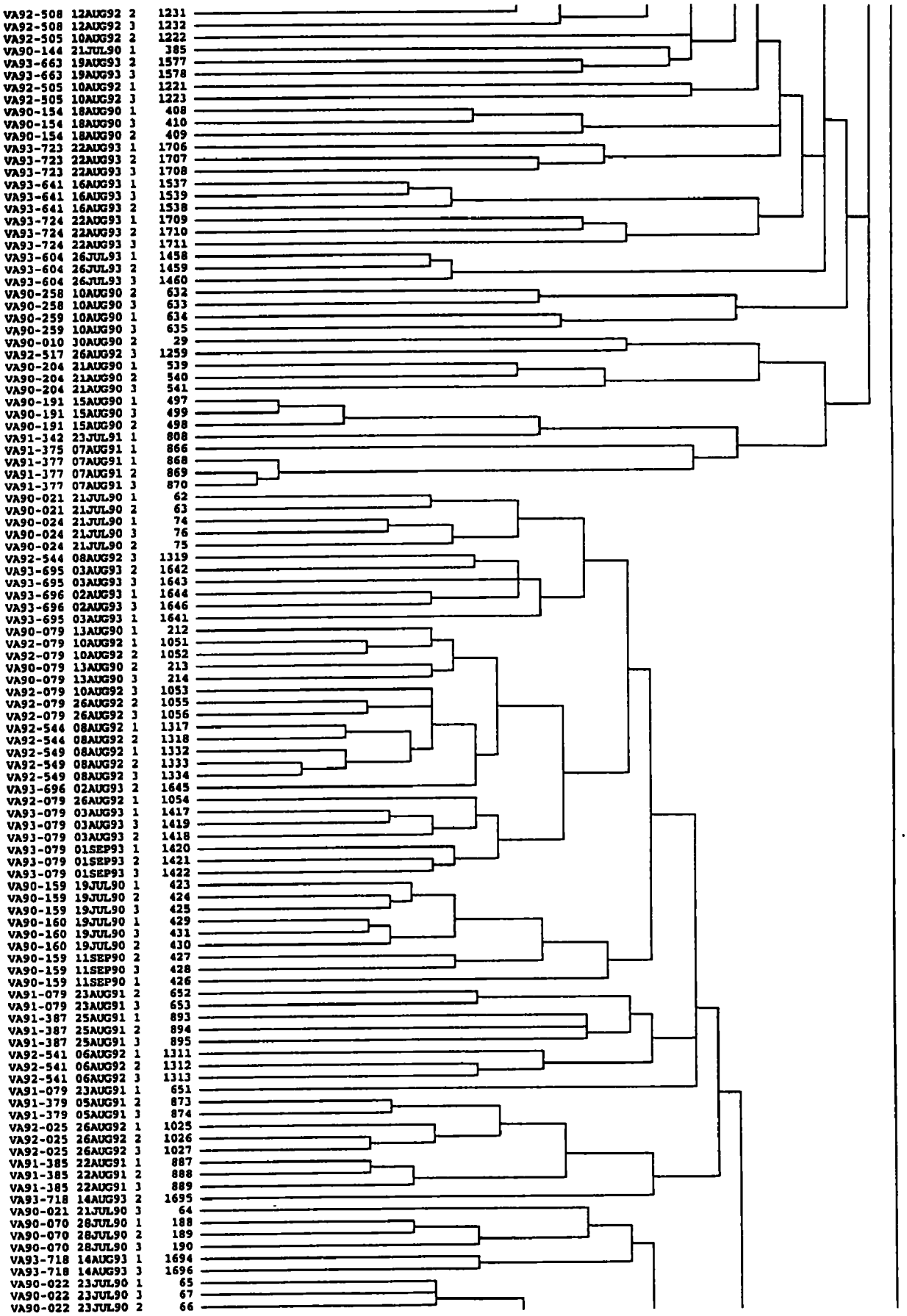

VA91-410 09AUG91 3 957
VA91-376 06AUG91 3 867
VA92-530 28JUL92 1 1290
VA92-530 28JUL92 2 1291
VA92-530 28JUL92 3 1292
VA93-735 07AUG93 1 1732
VA93-735 07AUG93 2 1733
VA93-735 07AUG93 3 1734
VA93-658 26AUG93 3 1569
VA90-095 30AUG90 1 256
VA90-095 30AUG90 2 257
VA90-095 30AUG90 3 258
VA93-671 21AUG93 1 1591
VA93-671 21AUG93 3 1593
VA93-671 21AUG93 2 1592
VA93-686 01SEP93 1 1620
VA90-050 20JUL90 1 146
VA93-627 09AUG93 2 1511
VA93-627 09AUG93 3 1512
VA90-050 20JUL90 3 147
VA90-190 15AUG90 2 495
VA90-063 25AUG90 1 179
VA90-063 25AUG90 2 180
VA90-063 25AUG90 3 181
VA90-060 03AUG90 1 171
VA90-060 03AUG90 2 172
VA91-286 11AUG91 1 715
VA93-653 27AUG93 1 1560
VA91-280 09AUG91 2 703
VA90-190 15AUG90 1 494
VA90-190 15AUG90 3 496
VA92-452 09AUG92 1 1096
VA92-452 09AUG92 2 1097
VA93-617 22AUG93 3 1491
VA90-084 14AUG90 1 220
VA92-486 28AUG92 1 1177
VA92-486 28AUG92 3 1178
VA90-084 14AUG90 2 221
VA90-086 13SEP90 1 229
VA90-086 13SEP90 2 230
VA90-086 13SEP90 3 231
VA90-084 14AUG90 3 222
VA90-081 27AUG90 2 215
VA90-081 27AUG90 3 216
VA90-183 06AUG90 3 472
VA93-617 22AUG93 1 1490
VA90-132 26JUL90 1 355
VA90-132 26JUL90 2 356
VA90-132 26JUL90 3 357
VA91-362 05AUG91 1 842
VA91-362 05AUG91 2 843
VA91-362 05AUG91 3 844
VA92-452 09AUG92 3 1098
VA90-183 06AUG90 1 470
VA90-183 06AUG90 2 471
VA93-653 27AUG93 2 1561
VA93-653 27AUG93 3 1562
VA93-050 29JUL93 2 1404
VA91-330 17AUG91 1 783
VA90-044 21JUL90 3 133
VA90-100 21SEP90 1 271
VA93-732 17AUG93 3 1728
VA93-150 02SEP93 1 1429
VA93-150 02SEP93 2 1430
VA93-150 02SEP93 3 1431
VA93-732 17AUG93 1 1726
VA93-732 17AUG93 2 1727
VA91-417 11AUG91 1 972
VA91-417 11AUG91 3 974
VA91-421 10AUG91 2 982
VA91-421 10AUG91 1 981
VA91-421 10AUG91 3 983
VA91-417 11AUG91 2 973
VA91-419 10AUG91 1 978
VA91-419 10AUG91 3 980
VA91-419 10AUG91 2 979
VA91-418 11AUG91 1 975
VA91-418 11AUG91 2 976
VA91-418 11AUG91 3 977
VA90-118 11AUG90 1 322
VA90-118 11AUG90 3 324
VA90-118 11AUG90 2 323
VA90-120 11AUG90 1 328
VA90-120 11AUG90 3 330
VA90-120 11AUG90 2 329
VA90-119 11AUG90 1 325
VA90-119 11AUG90 2 326
VA90-119 11AUG90 3 327
VA92-532 27AUG92 1 1293
VA92-532 27AUG92 3 1295
VA92-532 27AUG92 2 1294
VA92-515 08AUG92 2 1252
VA91-348 24JUL91 1 821
VA91-349 24JUL91 1 824
VA91-349 24JUL91 2 825
VA91-349 24JUL91 3 826
VA91-348 24JUL91 2 822
VA91-348 24JUL91 3 823
VA90-104 08AUG90 1 286
VA90-104 08AUG90 2 287
VA90-104 08AUG90 3 288
VA90-105 08AUG90 1 292
VA90-105 08AUG90 2 293
VA90-105 08AUG90 3 294
VA90-256 10AUG90 1 624
VA90-256 10AUG90 2 625
VA90-256 10AUG90 3 626

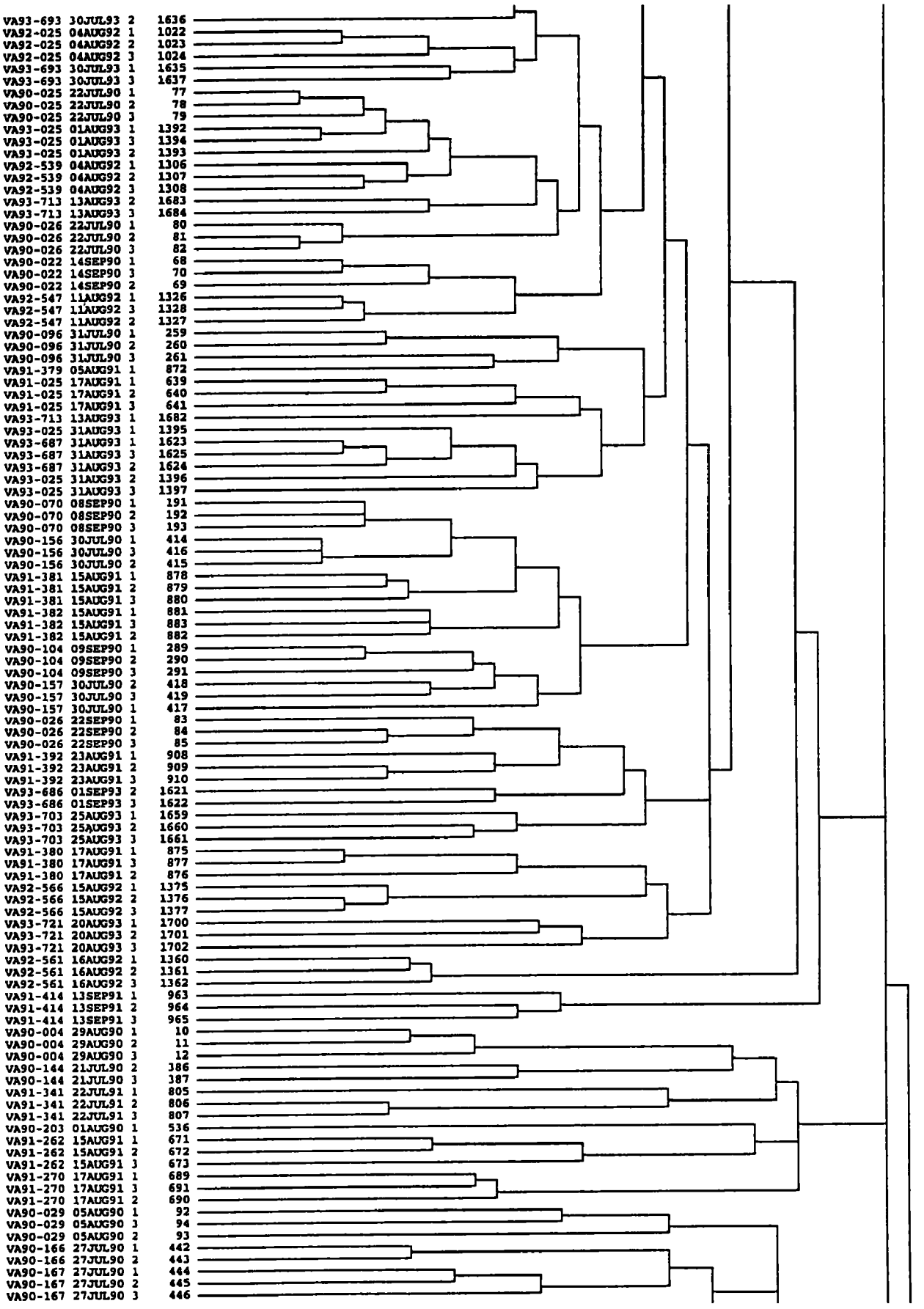

VA93-666 14AUG93 1 1579
VA93-666 14AUG93 3 1581
VA93-666 14AUG93 2 1580
VA90-256 23SEP90 1 627
VA90-256 23SEP90 3 629
VA93-714 19AUG93 1 1685
VA93-714 19AUG93 2 1686
VA93-714 19AUG93 3 1687
VA91-400 12SEP91 1 925
VA92-559 14AUG92 1 1354
VA92-559 14AUG92 2 1355
VA92-559 14AUG92 3 1356
VA93-711 19AUG93 3 1678
VA93-711 19AUG93 2 1677
VA92-565 30JUL92 1 1372
VA92-565 30JUL92 3 1374
VA92-565 30JUL92 2 1373
VA90-003 29AUG90 1 7
VA90-003 29AUG90 3 9
VA90-033 30AUG90 1 101
VA90-033 30AUG90 3 103
VA90-003 29AUG90 2 8
VA90-019 29AUG90 1 56
VA90-019 29AUG90 2 57
VA90-019 29AUG90 3 58
VA90-033 12SEP90 1 104
VA90-033 12SEP90 3 106
VA90-033 12SEP90 2 105
VA90-033 30AUG90 2 102
VA91-340 07SEP91 1 802
VA91-340 07SEP91 2 803
VA91-340 07SEP91 3 804
VA92-466 21AUG92 1 1126
VA92-466 21AUG92 3 1128
VA92-491 14AUG92 1 1191
VA92-491 14AUG92 2 1192
VA92-491 14AUG92 3 1193
VA92-485 28AUG92 1 1174
VA92-485 28AUG92 2 1175
VA92-485 28AUG92 3 1176
VA92-465 21AUG92 1 1123
VA92-465 21AUG92 2 1124
VA92-465 21AUG92 3 1125
VA92-466 21AUG92 2 1127
VA90-164 01AUG90 1 436
VA90-164 01AUG90 2 437
VA90-164 01AUG90 3 438
VA90-202 02AUG90 1 533
VA90-202 02AUG90 2 534
VA90-202 02AUG90 3 535
VA90-203 01AUG90 2 537
VA90-203 01AUG90 3 538
VA90-040 19AUG90 1 122
VA90-040 19AUG90 2 123
VA90-040 19AUG90 3 124
VA90-087 20AUG90 1 232
VA90-087 20AUG90 2 233
VA90-039 11AUG90 1 119
VA90-039 11AUG90 2 120
VA90-039 11AUG90 3 121
VA90-061 25JUL90 1 173
VA90-061 25JUL90 2 174
VA90-061 25JUL90 3 175
VA90-061 06SEP90 1 176
VA90-061 06SEP90 2 177
VA90-061 06SEP90 3 178
VA91-266 17AUG91 1 680
VA91-266 17AUG91 2 681
VA92-453 10AUG92 1 1099
VA92-453 10AUG92 3 1101
VA92-453 10AUG92 2 1100
VA93-607 27AUG93 1 1463
VA93-607 27AUG93 2 1464
VA93-607 27AUG93 3 1465
VA92-050 27AUG92 2 1037
VA92-474 22AUG92 1 1150
VA92-474 22AUG92 2 1151
VA92-474 22AUG92 3 1152
VA93-615 04SEP93 1 1484
VA93-615 04SEP93 2 1485
VA93-615 04SEP93 3 1486
VA93-618 03SEP93 1 1492
VA93-618 03SEP93 2 1493
VA93-618 03SEP93 3 1494
VA90-047 29JUL90 1 140
VA90-047 29JUL90 2 141
VA90-047 29JUL90 3 142
VA91-276 16AUG91 3 699
VA90-145 21JUL90 1 388
VA90-145 21JUL90 2 389
VA90-145 21JUL90 3 390
VA92-050 03AUG92 1 1034
VA92-483 15AUG92 1 1168
VA92-483 15AUG92 2 1169
VA92-483 15AUG92 3 1170
VA90-086 01AUG90 2 227
VA90-150 14SEP90 1 397
VA93-045 07AUG93 1 1398
VA93-045 01SEP93 1 1401
VA90-086 01AUG90 3 228
VA92-510 10AUG92 1 1236
VA92-510 10AUG92 3 1238
VA92-510 10AUG92 2 1237
VA91-263 03AUG91 1 674
VA91-296 21AUG91 3 733
VA91-263 03AUG91 2 675
VA91-263 03AUG91 3 676
VA91-267 17AUG91 2 684

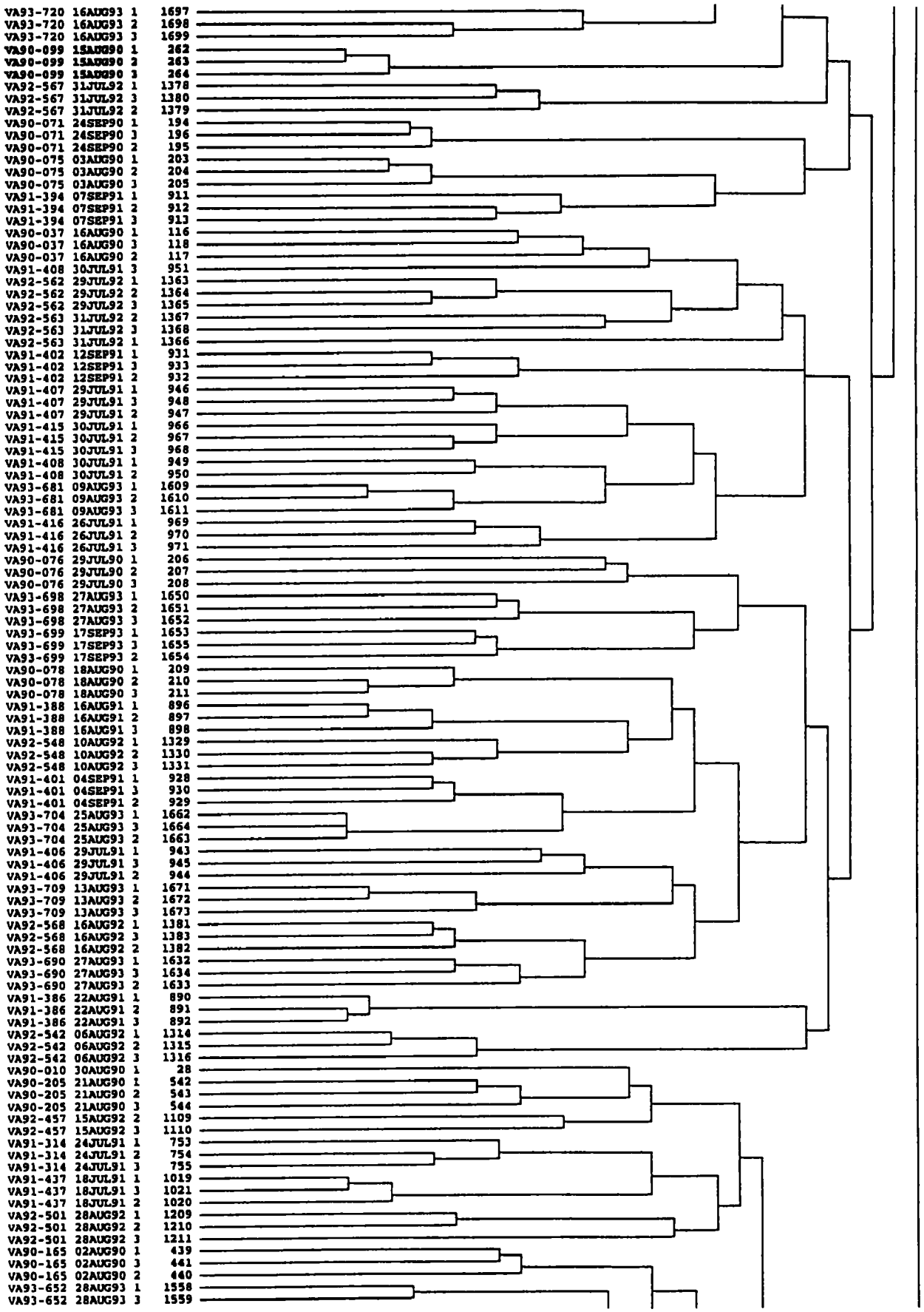

VA91-267 17AUG91 3 685
VA91-045 15JUL91 1 642
VA93-045 07AUG93 2 1399
VA91-432 16JUL91 1 1004
VA91-432 16JUL91 3 1006
VA93-045 01SEP93 3 1403
VA91-432 16JUL91 2 1005
VA91-433 16JUL91 3 1009
VA91-433 16JUL91 2 1008
VA91-433 16JUL91 1 1007
VA91-434 16JUL91 1 1010
VA93-633 01SEP93 1 1519
VA93-633 01SEP93 3 1521
VA93-633 01SEP93 2 1520
VA91-434 16JUL91 2 1011
VA91-434 16JUL91 3 1012
VA91-308 29AUG91 2 746
VA91-344 26JUL91 1 814
VA91-344 26JUL91 2 815
VA91-344 26JUL91 3 816
VA91-308 29AUG91 3 747
VA91-311 27AUG91 3 752
VA91-311 27AUG91 1 750
VA91-311 27AUG91 2 751
VA91-316 12SEP91 1 759
VA91-316 12SEP91 2 760
VA91-316 12SEP91 3 761
VA91-045 15JUL91 2 643
VA91-045 15JUL91 3 644
VA91-308 29AUG91 1 745
VA92-457 15AUG92 1 1108
VA93-045 01SEP93 2 1402
VA93-631 09AUG93 2 1517
VA93-631 09AUG93 3 1518
VA93-631 09AUG93 1 1516
VA91-307 27AUG91 1 742
VA91-307 27AUG91 2 743
VA91-307 27AUG91 3 744
VA91-322 15AUG91 1 771
VA91-322 15AUG91 3 773
VA91-322 15AUG91 2 772
VA93-045 07AUG93 3 1400
VA91-317 29AUG91 1 762
VA92-488 15AUG92 1 1182
VA91-317 29AUG91 2 763
VA92-488 15AUG92 2 1183
VA92-488 15AUG92 3 1184
VA91-317 29AUG91 3 764
VA92-517 26AUG92 2 1258
VA90-041 20JUL90 1 125
VA90-041 20JUL90 2 126
VA90-041 20JUL90 3 127
VA91-292 22AUG91 1 722
VA90-057 25JUL90 3 164
VA90-057 25JUL90 1 162
VA90-057 25JUL90 2 163
VA91-292 22AUG91 2 723
VA91-292 22AUG91 3 724
VA90-042 03AUG90 1 128
VA90-042 03AUG90 2 129
VA90-042 03AUG90 3 130
VA91-060 09JUL91 1 648
VA91-060 09JUL91 3 650
VA91-060 09JUL91 2 649
VA91-427 10JUL91 1 989
VA91-428 10JUL91 1 992
VA91-428 10JUL91 2 993
VA91-428 10JUL91 3 994
VA91-427 10JUL91 2 990
VA91-427 10JUL91 3 991
VA91-291 11AUG91 1 719
VA91-291 11AUG91 2 720
VA91-291 11AUG91 3 721
VA91-284 12AUG91 1 709
VA91-284 12AUG91 2 710
VA91-284 12AUG91 3 711
VA91-285 22AUG91 1 712
VA91-285 22AUG91 2 713
VA91-285 22AUG91 3 714
VA92-472 23AUG92 2 1145
VA92-475 24AUG92 2 1154
VA92-475 24AUG92 3 1155
VA92-050 27AUG92 1 1036
VA92-487 02AUG92 2 1180
VA92-487 02AUG92 3 1181
VA92-060 05AUG92 2 1046
VA92-060 30AUG92 1 1048
VA92-060 30AUG92 3 1050
VA92-060 05AUG92 3 1047
VA92-060 30AUG92 2 1049
VA92-060 05AUG92 1 1045
VA92-472 23AUG92 3 1146
VA92-478 24AUG92 1 1162
VA92-478 24AUG92 2 1163
VA92-478 24AUG92 3 1164
VA92-475 24AUG92 1 1153
VA92-472 23AUG92 1 1144
VA92-487 02AUG92 1 1179
VA93-624 08AUG93 3 1507
VA93-624 08AUG93 2 1506
VA91-261 03AUG91 1 668
VA91-261 03AUG91 2 669
VA91-261 03AUG91 3 670
VA90-087 20AUG90 3 234
VA93-624 08AUG93 1 1505
VA92-050 27AUG92 3 1038
VA91-295 21AUG91 1 728

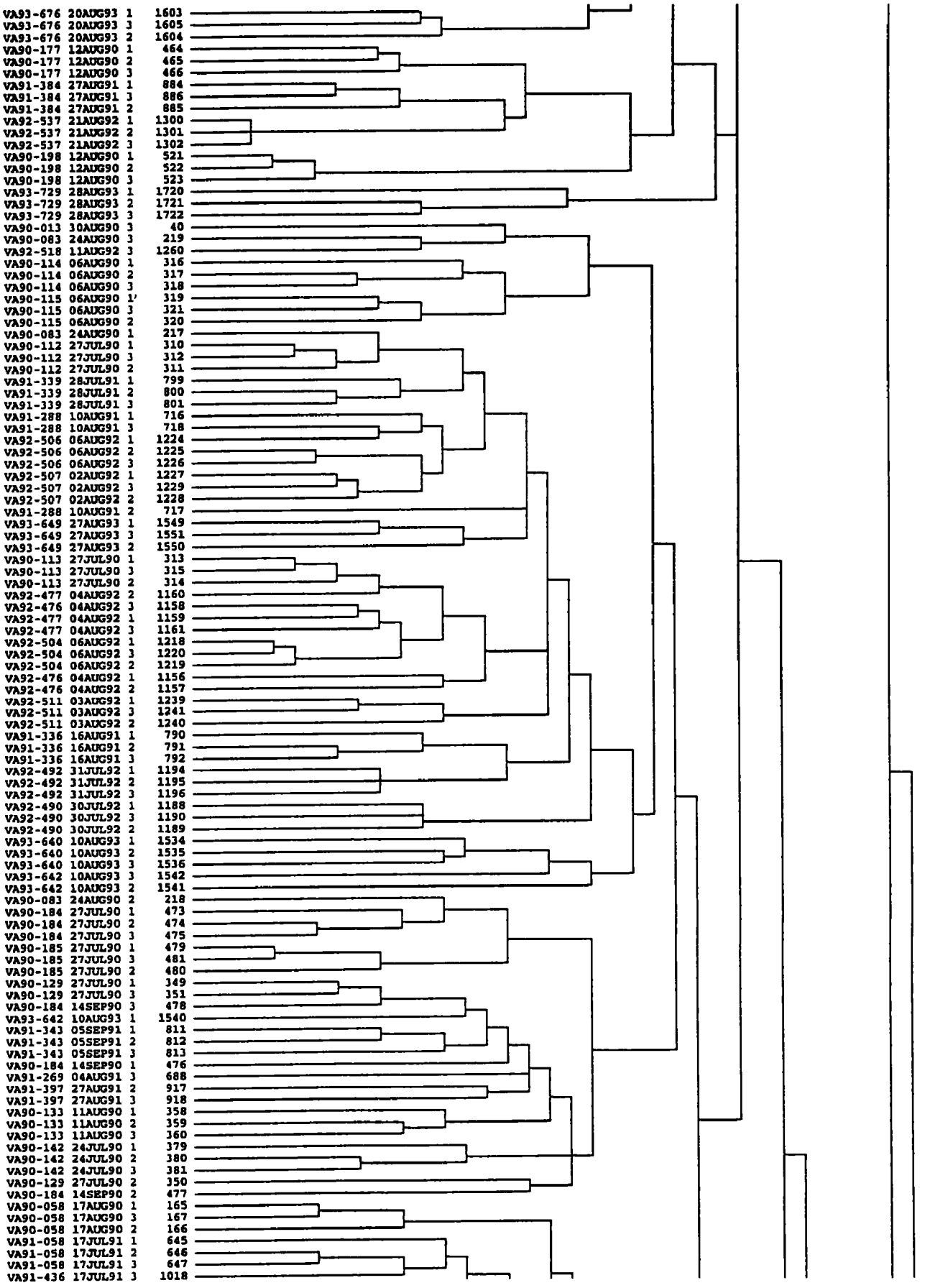

VA91-295 21AUG91 3 730
VA91-295 21AUG91 2 729
VA90-055 24AUG90 1 159
VA90-055 24AUG90 2 160
VA90-055 24AUG90 3 161
VA93-060 07AUG93 1 1411
VA93-060 07AUG93 3 1413
VA93-060 07AUG93 2 1412
VA93-060 26AUG93 1 1414
VA93-060 26AUG93 2 1415
VA93-060 26AUG93 3 1416
VA93-622 07AUG93 1 1500
VA93-626 03SEP93 1 1508
VA93-626 03SEP93 2 1509
VA93-626 03SEP93 3 1510
VA90-065 16AUG90 1 182
VA90-065 16AUG90 2 183
VA90-065 16AUG90 3 184
VA90-065 07SEP90 1 185
VA90-065 07SEP90 2 186
VA90-065 07SEP90 3 187
VA93-638 30JUL93 1 1528
VA93-638 30JUL93 2 1529
VA93-638 30JUL93 3 1530
VA91-296 21AUG91 1 731
VA93-611 28AUG93 1 1475
VA93-611 28AUG93 2 1476
VA93-611 28AUG93 3 1477
VA91-429 11JUL91 1 995
VA91-429 11JUL91 2 996
VA91-429 11JUL91 3 997
VA91-430 11JUL91 1 998
VA91-430 11JUL91 3 1000
VA91-430 11JUL91 2 999
VA91-431 11JUL91 1 1001
VA91-431 11JUL91 2 1002
VA91-431 11JUL91 3 1003
VA92-050 03AUG92 3 1035
VA90-028 31JUL90 2 90
VA90-028 31JUL90 3 91
VA92-540 28AUG92 1 1309
VA92-540 28AUG92 3 1310
VA90-150 14SEP90 2 398
VA91-150 22AUG91 1 658
VA91-150 22AUG91 3 660
VA91-150 22AUG91 2 659
VA90-053 03AUG90 1 153
VA90-053 03AUG90 3 155
VA90-053 03AUG90 2 154
VA91-282 12AUG91 1 704
VA91-282 12AUG91 3 705
VA90-007 24JUL90 1 19
VA90-007 24JUL90 2 20
VA90-007 24JUL90 3 21
VA90-059 22JUL90 1 168
VA90-059 22JUL90 3 170
VA92-513 26AUG92 2 1246
VA92-513 26AUG92 3 1247
VA90-044 21JUL90 1 131
VA90-044 21JUL90 2 132
VA90-256 23SEP90 2 628
VA90-059 22JUL90 2 169
VA91-267 17AUG91 1 683
VA91-266 17AUG91 3 682
VA91-296 21AUG91 2 732
VA90-034 18AUG90 1 107
VA90-034 18AUG90 3 109
VA90-034 18AUG90 2 108
VA91-305 23AUG91 1 739
VA91-305 23AUG91 3 741
VA91-305 23AUG91 2 740
VA91-318 23AUG91 1 765
VA91-318 23AUG91 3 767
VA91-318 23AUG91 2 766
VA93-634 17AUG93 1 1522
VA93-634 17AUG93 3 1524
VA93-634 17AUG93 2 1523
VA90-151 19JUL90 1 399
VA90-151 19JUL90 2 400
VA90-151 19JUL90 3 401
VA90-153 30JUL90 1 405
VA90-153 30JUL90 2 406
VA90-153 30JUL90 3 407
VA92-495 16AUG92 1 1203
VA92-495 16AUG92 2 1204
VA92-495 16AUG92 3 1205
VA92-496 16AUG92 1 1206
VA92-496 16AUG92 2 1207
VA92-496 16AUG92 3 1208
VA91-327 24AUG91 1 777
VA91-327 24AUG91 2 778
VA91-327 24AUG91 3 779
VA91-328 24AUG91 1 780
VA91-328 24AUG91 2 781
VA91-328 24AUG91 3 782
VA90-046 04AUG90 1 137
VA90-046 04AUG90 3 139
VA90-046 04AUG90 2 138
VA90-051 31JUL90 1 148
VA90-051 31JUL90 2 149
VA90-051 31JUL90 3 150
VA90-054 31JUL90 1 156
VA90-054 31JUL90 2 157
VA90-054 31JUL90 3 158
VA93-601 18SEP93 1 1454
VA93-601 18SEP93 2 1455
VA93-601 18SEP93 3 1456
VA91-265 18AUG91 1 677

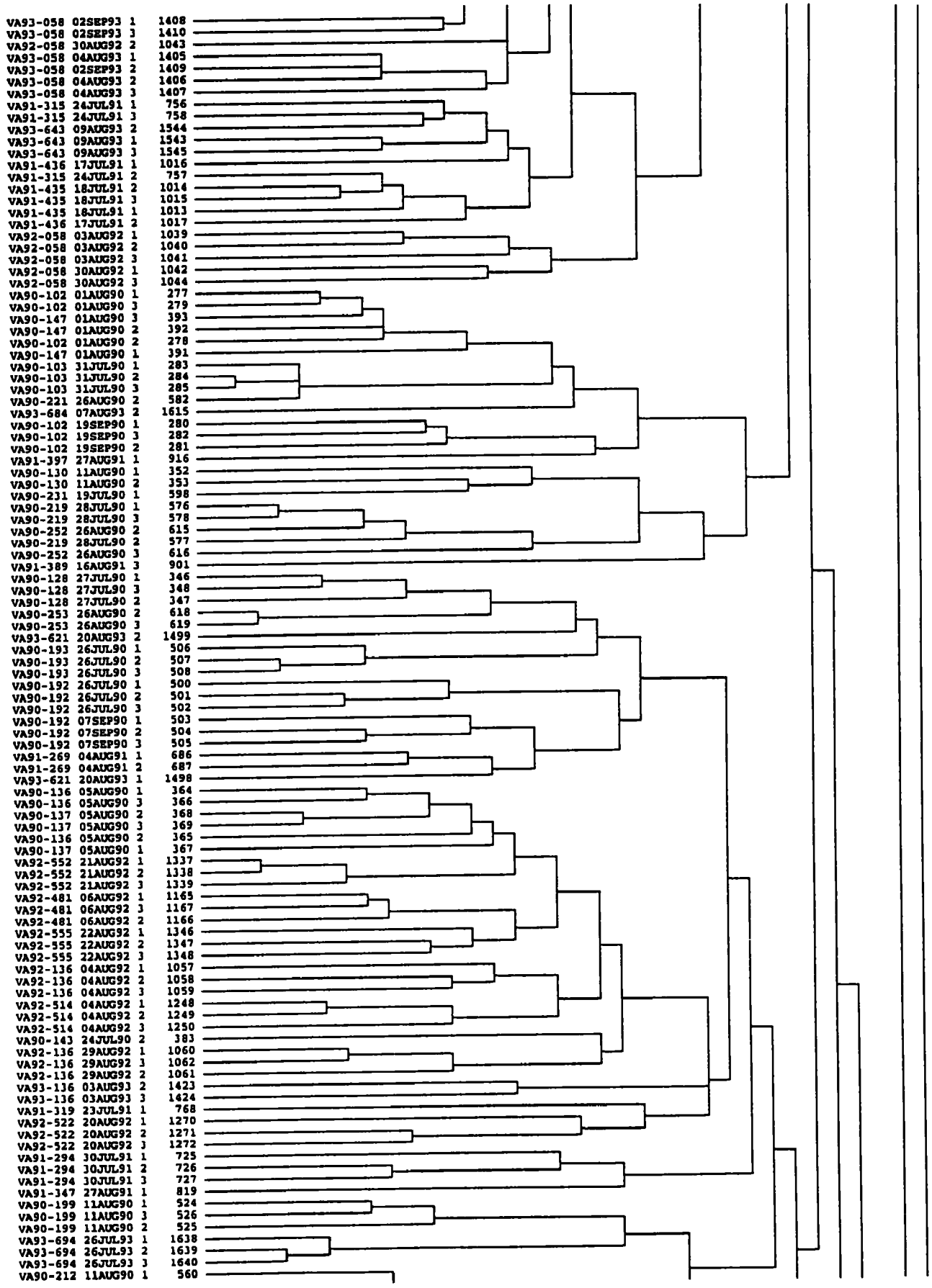

VA91-265 18AUG91 2 678
VA91-265 18AUG91 3 679
VA91-276 16AUG91 1 697
VA91-276 16AUG91 2 698
VA91-279 23AUG91 1 700
VA91-279 23AUG91 3 702
VA91-279 23AUG91 2 701
VA92-462 11AUG92 1 1117
VA92-462 11AUG92 3 1119
VA92-462 11AUG92 2 1118
VA92-470 23AUG92 1 1138
VA92-470 23AUG92 2 1139
VA92-470 23AUG92 3 1140
VA92-473 22AUG92 1 1147
VA92-473 22AUG92 2 1148
VA92-473 22AUG92 3 1149
VA92-454 08AUG92 1 1102
VA92-454 08AUG92 2 1103
VA92-454 08AUG92 3 1104
VA92-460 11AUG92 1 1111
VA92-460 11AUG92 3 1113
VA92-460 11AUG92 2 1112
VA93-608 04SEP93 1 1466
VA93-608 04SEP93 3 1468
VA93-608 04SEP93 2 1467
VA93-612 04SEP93 2 1479
VA93-612 04SEP93 3 1480
VA93-612 04SEP93 1 1478
VA91-283 23AUG91 1 706
VA91-283 23AUG91 2 707
VA91-283 23AUG91 3 708
VA93-622 07AUG93 2 1501
VA91-271 16AUG91 1 692
VA91-271 16AUG91 3 694
VA91-271 16AUG91 2 693
VA93-616 27JUL93 1 1487
VA93-616 27JUL93 3 1489
VA93-616 27JUL93 2 1488
VA90-005 24JUL90 1 13
VA90-005 24JUL90 3 15
VA90-005 24JUL90 2 14
VA90-006 24JUL90 3 18
VA90-006 24JUL90 1 16
VA90-006 24JUL90 2 17
VA92-513 26AUG92 1 1245
VA90-031 29AUG90 1 95
VA90-031 29AUG90 2 96
VA90-031 29AUG90 3 97
VA90-032 04AUG90 1 98
VA90-032 04AUG90 2 99
VA90-032 04AUG90 3 100
VA90-035 03AUG90 1 110
VA90-035 03AUG90 2 111
VA90-035 03AUG90 3 112
VA92-503 18AUG92 1 1215
VA92-503 18AUG92 3 1217
VA92-503 18AUG92 2 1216
VA90-015 28AUG90 1 44
VA90-015 28AUG90 2 45
VA90-015 28AUG90 3 46
VA90-023 19AUG90 1 71
VA90-023 19AUG90 2 72
VA90-023 19AUG90 3 73
VA90-014 28AUG90 1 41
VA90-014 28AUG90 2 42
VA90-014 28AUG90 3 43
VA90-016 29AUG90 1 47
VA93-663 19AUG93 1 1576
VA91-338 26JUL91 1 796
VA91-338 26JUL91 2 797
VA91-338 26JUL91 3 798
VA90-016 29AUG90 2 48
VA90-020 03AUG90 1 59
VA90-020 03AUG90 3 61
VA90-020 03AUG90 2 60
VA90-016 29AUG90 3 49
VA90-258 10AUG90 1 631
VA91-335 06SEP91 1 787
VA91-335 06SEP91 2 788
VA91-335 06SEP91 3 789
VA91-337 06SEP91 1 793
VA91-337 06SEP91 2 794
VA91-337 06SEP91 3 795
VA90-048 22JUL90 1 143
VA90-048 22JUL90 3 145
VA90-048 22JUL90 2 144
VA90-085 13AUG90 1 223
VA90-085 13AUG90 2 224
VA90-085 13AUG90 3 225
VA92-546 29AUG92 1 1323
VA92-546 29AUG92 2 1324
VA92-546 29AUG92 3 1325
VA93-688 31AUG93 1 1626
VA93-688 31AUG93 3 1628
VA93-688 31AUG93 2 1627
VA92-535 03AUG92 1 1297
VA92-535 03AUG92 2 1298
VA92-535 03AUG92 3 1299
VA90-012 04AUG90 1 33
VA90-012 04AUG90 2 34
VA90-012 28AUG90 1 35
VA90-012 28AUG90 3 37
VA90-012 28AUG90 2 36
VA90-017 28AUG90 1 50
VA90-017 28AUG90 2 51
VA90-017 28AUG90 3 52
VA92-508 12AUG92 1 1230

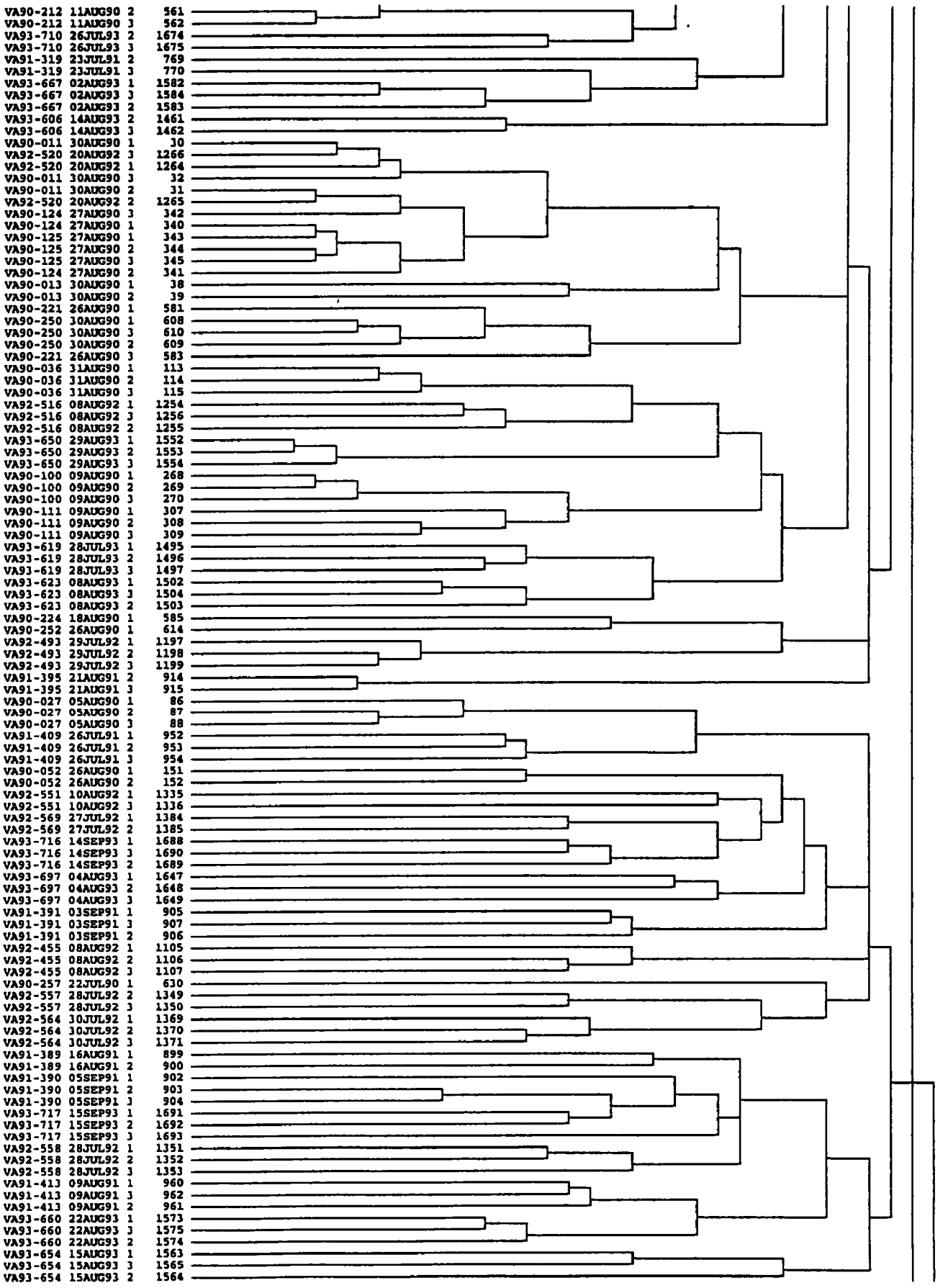

VA92-508 12AUG92 2 1231
VA92-508 12AUG92 3 1232
VA92-505 10AUG92 2 1222
VA90-144 21JUL90 1 385
VA93-663 19AUG93 2 1577
VA93-663 19AUG93 3 1578
VA92-505 10AUG92 1 1221
VA92-505 10AUG92 3 1223
VA90-154 18AUG90 1 408
VA90-154 18AUG90 3 410
VA90-154 18AUG90 2 409
VA93-723 22AUG93 1 1706
VA93-723 22AUG93 2 1707
VA93-723 22AUG93 3 1708
VA93-641 16AUG93 1 1537
VA93-641 16AUG93 3 1539
VA93-641 16AUG93 2 1538
VA93-724 22AUG93 1 1709
VA93-724 22AUG93 2 1710
VA93-724 22AUG93 3 1711
VA93-604 26JUL93 1 1458
VA93-604 26JUL93 2 1459
VA93-604 26JUL93 3 1460
VA90-258 10AUG90 2 632
VA90-258 10AUG90 3 633
VA90-259 10AUG90 1 634
VA90-259 10AUG90 3 635
VA90-010 30AUG90 2 29
VA92-517 26AUG92 3 1259
VA90-204 21AUG90 1 539
VA90-204 21AUG90 2 540
VA90-204 21AUG90 3 541
VA90-191 15AUG90 1 497
VA90-191 15AUG90 3 499
VA90-191 15AUG90 2 498
VA91-342 23JUL91 1 808
VA91-375 07AUG91 1 866
VA91-377 07AUG91 1 868
VA91-377 07AUG91 2 869
VA91-377 07AUG91 3 870
VA90-021 21JUL90 1 62
VA90-021 21JUL90 2 63
VA90-024 21JUL90 1 74
VA90-024 21JUL90 3 76
VA90-024 21JUL90 2 75
VA92-544 08AUG92 3 1319
VA93-695 03AUG93 2 1642
VA93-695 03AUG93 3 1643
VA93-696 02AUG93 1 1644
VA93-696 02AUG93 3 1646
VA93-695 03AUG93 1 1641
VA90-079 13AUG90 1 212
VA92-079 10AUG92 1 1051
VA92-079 10AUG92 2 1052
VA90-079 13AUG90 2 213
VA90-079 13AUG90 3 214
VA92-079 10AUG92 3 1053
VA92-079 26AUG92 2 1055
VA92-079 26AUG92 3 1056
VA92-544 08AUG92 1 1317
VA92-544 08AUG92 2 1318
VA92-549 08AUG92 1 1332
VA92-549 08AUG92 2 1333
VA92-549 08AUG92 3 1334
VA93-696 02AUG93 2 1645
VA92-079 26AUG92 1 1054
VA93-079 03AUG93 1 1417
VA93-079 03AUG93 3 1419
VA93-079 03AUG93 2 1418
VA93-079 01SEP93 1 1420
VA93-079 01SEP93 2 1421
VA93-079 01SEP93 3 1422
VA90-159 19JUL90 1 423
VA90-159 19JUL90 2 424
VA90-159 19JUL90 3 425
VA90-160 19JUL90 1 429
VA90-160 19JUL90 3 431
VA90-160 19JUL90 2 430
VA90-159 11SEP90 2 427
VA90-159 11SEP90 3 428
VA90-159 11SEP90 1 426
VA91-079 23AUG91 2 652
VA91-079 23AUG91 3 653
VA91-387 25AUG91 1 893
VA91-387 25AUG91 2 894
VA91-387 25AUG91 3 895
VA92-541 06AUG92 1 1311
VA92-541 06AUG92 2 1312
VA92-541 06AUG92 3 1313
VA91-079 23AUG91 1 651
VA91-379 05AUG91 2 873
VA91-379 05AUG91 3 874
VA92-025 26AUG92 1 1025
VA92-025 26AUG92 2 1026
VA92-025 26AUG92 3 1027
VA91-385 22AUG91 1 887
VA91-385 22AUG91 2 888
VA91-385 22AUG91 3 889
VA93-718 14AUG93 2 1695
VA90-021 21JUL90 3 64
VA90-070 28JUL90 1 188
VA90-070 28JUL90 2 189
VA90-070 28JUL90 3 190
VA93-718 14AUG93 1 1694
VA93-718 14AUG93 3 1696
VA90-022 23JUL90 1 65
VA90-022 23JUL90 3 67
VA90-022 23JUL90 2 66

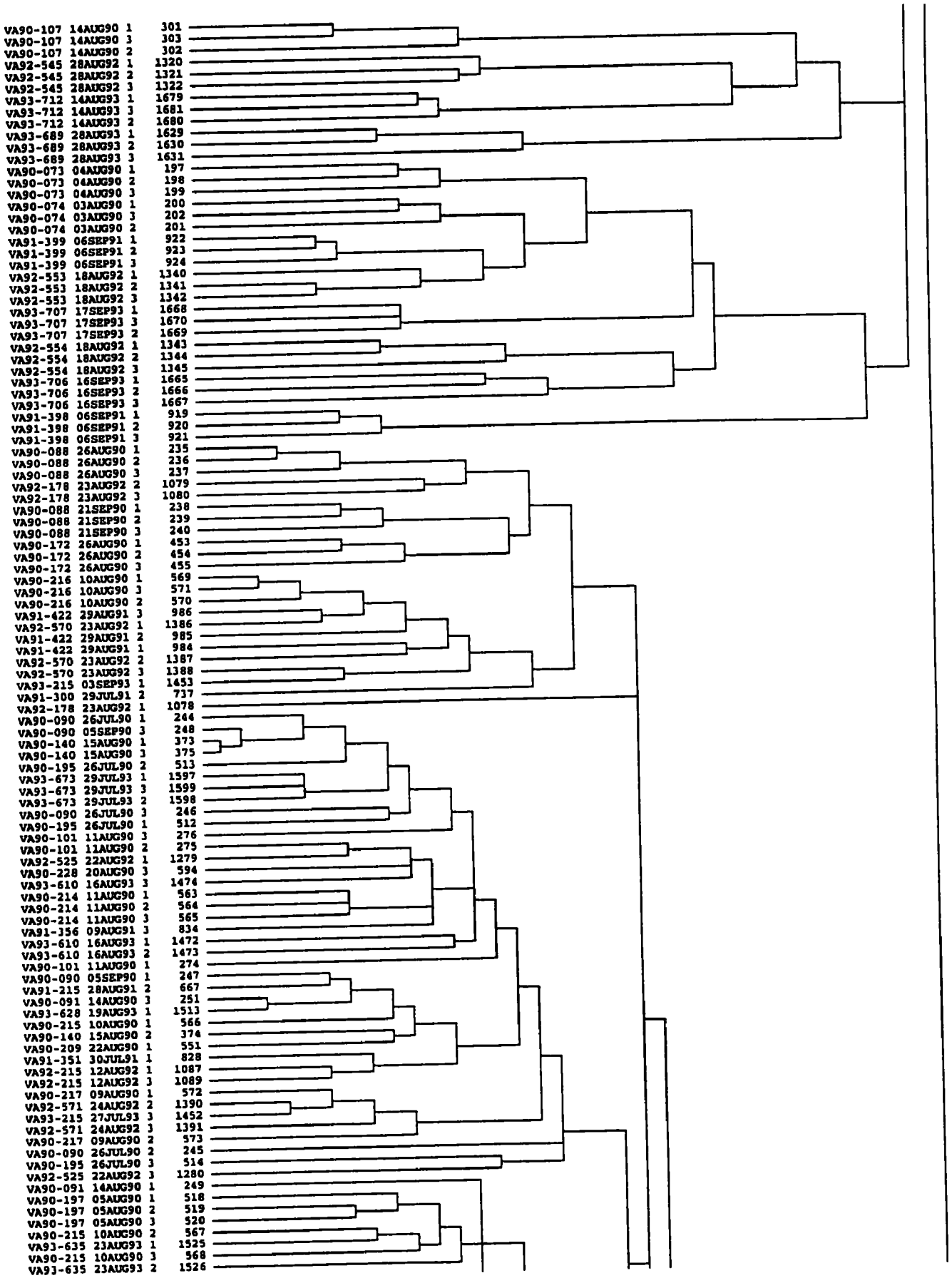

VA93-693 30JUL93 2 1636
VA92-025 04AUG92 1 1022
VA92-025 04AUG92 2 1023
VA92-025 04AUG92 3 1024
VA93-693 30JUL93 1 1635
VA93-693 30JUL93 3 1637
VA90-025 22JUL90 1 77
VA90-025 22JUL90 2 78
VA90-025 22JUL90 3 79
VA93-025 01AUG93 1 1392
VA93-025 01AUG93 3 1394
VA93-025 01AUG93 2 1393
VA92-539 04AUG92 1 1306
VA92-539 04AUG92 2 1307
VA92-539 04AUG92 3 1308
VA93-713 13AUG93 2 1683
VA93-713 13AUG93 3 1684
VA90-026 22JUL90 1 80
VA90-026 22JUL90 2 81
VA90-026 22JUL90 3 82
VA90-022 14SEP90 1 68
VA90-022 14SEP90 3 70
VA90-022 14SEP90 2 69
VA92-547 11AUG92 1 1326
VA92-547 11AUG92 3 1328
VA92-547 11AUG92 2 1327
VA90-096 31JUL90 1 259
VA90-096 31JUL90 2 260
VA90-096 31JUL90 3 261
VA91-379 05AUG91 1 872
VA91-025 17AUG91 1 639
VA91-025 17AUG91 2 640
VA91-025 17AUG91 3 641
VA93-713 13AUG93 1 1682
VA93-025 31AUG93 1 1395
VA93-687 31AUG93 1 1623
VA93-687 31AUG93 3 1625
VA93-687 31AUG93 2 1624
VA93-025 31AUG93 2 1396
VA93-025 31AUG93 3 1397
VA90-070 08SEP90 1 191
VA90-070 08SEP90 2 192
VA90-070 08SEP90 3 193
VA90-156 30JUL90 1 414
VA90-156 30JUL90 3 416
VA90-156 30JUL90 2 415
VA91-381 15AUG91 1 878
VA91-381 15AUG91 2 879
VA91-381 15AUG91 3 880
VA91-382 15AUG91 1 881
VA91-382 15AUG91 3 883
VA91-382 15AUG91 2 882
VA90-104 09SEP90 1 289
VA90-104 09SEP90 2 290
VA90-104 09SEP90 3 291
VA90-157 30JUL90 2 418
VA90-157 30JUL90 3 419
VA90-157 30JUL90 1 417
VA90-026 22SEP90 1 83
VA90-026 22SEP90 2 84
VA90-026 22SEP90 3 85
VA91-392 23AUG91 1 908
VA91-392 23AUG91 2 909
VA91-392 23AUG91 3 910
VA93-686 01SEP93 2 1621
VA93-686 01SEP93 3 1622
VA93-703 25AUG93 1 1659
VA93-703 25AUG93 2 1660
VA93-703 25AUG93 3 1661
VA91-380 17AUG91 1 875
VA91-380 17AUG91 3 877
VA91-380 17AUG91 2 876
VA92-566 15AUG92 1 1375
VA92-566 15AUG92 2 1376
VA92-566 15AUG92 3 1377
VA93-721 20AUG93 1 1700
VA93-721 20AUG93 2 1701
VA93-721 20AUG93 3 1702
VA92-561 16AUG92 1 1360
VA92-561 16AUG92 2 1361
VA92-561 16AUG92 3 1362
VA91-414 13SEP91 1 963
VA91-414 13SEP91 2 964
VA91-414 13SEP91 3 965
VA90-004 29AUG90 1 10
VA90-004 29AUG90 2 11
VA90-004 29AUG90 3 12
VA90-144 21JUL90 2 386
VA90-144 21JUL90 3 387
VA91-341 22JUL91 1 805
VA91-341 22JUL91 2 806
VA91-341 22JUL91 3 807
VA90-203 01AUG90 1 536
VA91-262 15AUG91 1 671
VA91-262 15AUG91 2 672
VA91-262 15AUG91 3 673
VA91-270 17AUG91 1 689
VA91-270 17AUG91 3 691
VA91-270 17AUG91 2 690
VA90-029 05AUG90 1 92
VA90-029 05AUG90 3 94
VA90-029 05AUG90 2 93
VA90-166 27JUL90 1 442
VA90-166 27JUL90 2 443
VA90-167 27JUL90 1 444
VA90-167 27JUL90 2 445
VA90-167 27JUL90 3 446

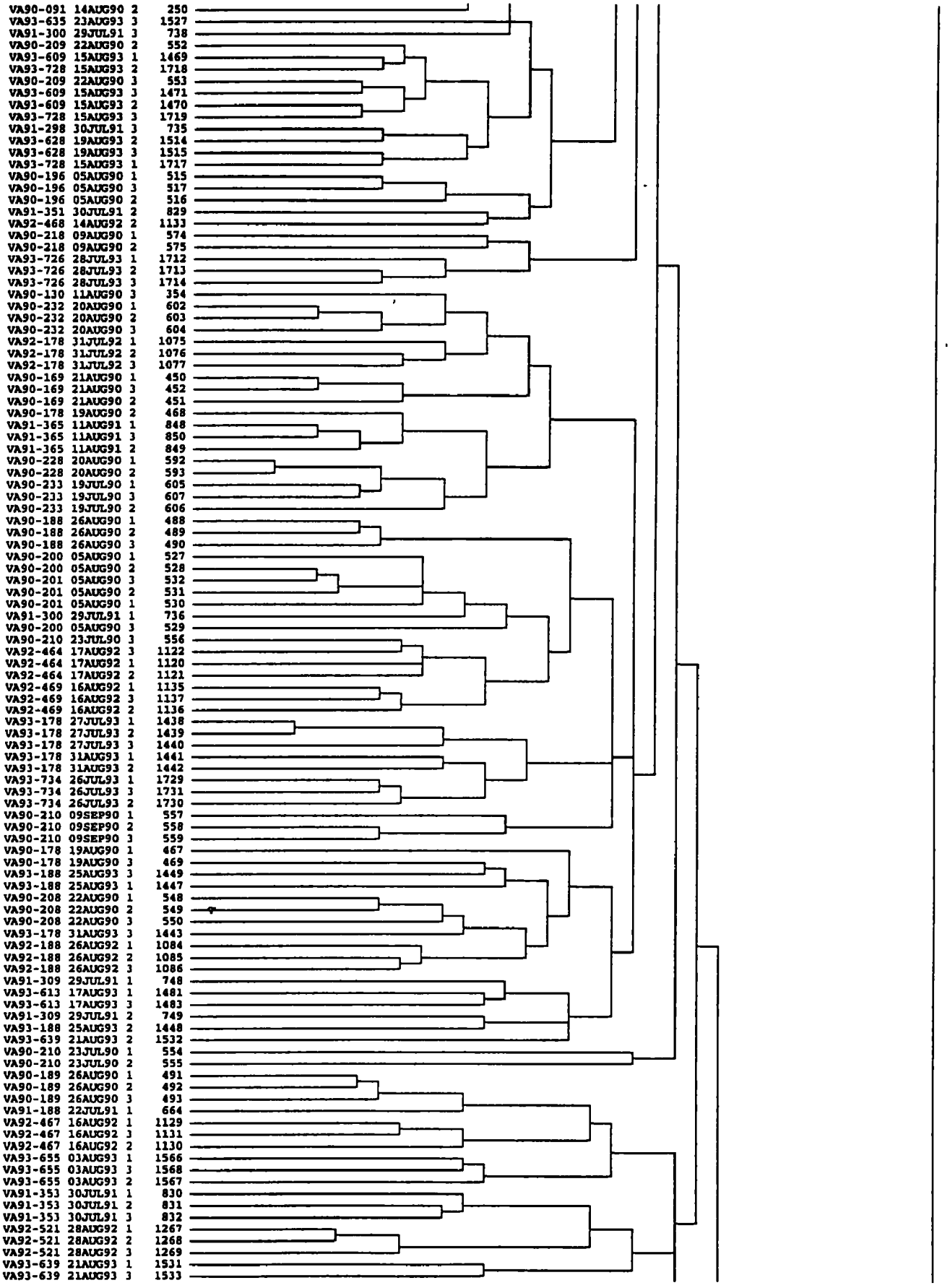

VA93-720 16AUG93 1 1697
VA93-720 16AUG93 2 1698
VA93-720 16AUG93 3 1699
VA90-099 15AUG90 1 262
VA90-099 15AUG90 2 263
VA90-099 15AUG90 3 264
VA92-567 31JUL92 1 1378
VA92-567 31JUL92 3 1380
VA92-567 31JUL92 2 1379
VA90-071 24SEP90 1 194
VA90-071 24SEP90 3 196
VA90-071 24SEP90 2 195
VA90-075 03AUG90 1 203
VA90-075 03AUG90 2 204
VA90-075 03AUG90 3 205
VA91-394 07SEP91 1 911
VA91-394 07SEP91 2 912
VA91-394 07SEP91 3 913
VA90-037 16AUG90 1 116
VA90-037 16AUG90 3 118
VA90-037 16AUG90 2 117
VA91-408 30JUL91 3 951
VA92-562 29JUL92 1 1363
VA92-562 29JUL92 2 1364
VA92-562 29JUL92 3 1365
VA92-563 31JUL92 2 1367
VA92-563 31JUL92 3 1368
VA92-563 31JUL92 1 1366
VA91-402 12SEP91 1 931
VA91-402 12SEP91 3 933
VA91-402 12SEP91 2 932
VA91-407 29JUL91 1 946
VA91-407 29JUL91 3 948
VA91-407 29JUL91 2 947
VA91-415 30JUL91 1 966
VA91-415 30JUL91 2 967
VA91-415 30JUL91 3 968
VA91-408 30JUL91 1 949
VA91-408 30JUL91 2 950
VA93-681 09AUG93 1 1609
VA93-681 09AUG93 2 1610
VA93-681 09AUG93 3 1611
VA91-416 26JUL91 1 969
VA91-416 26JUL91 2 970
VA91-416 26JUL91 3 971
VA90-076 29JUL90 1 206
VA90-076 29JUL90 2 207
VA90-076 29JUL90 3 208
VA93-698 27AUG93 1 1650
VA93-698 27AUG93 2 1651
VA93-698 27AUG93 3 1652
VA93-699 17SEP93 1 1653
VA93-699 17SEP93 3 1655
VA93-699 17SEP93 2 1654
VA90-078 18AUG90 1 209
VA90-078 18AUG90 2 210
VA90-078 18AUG90 3 211
VA91-388 16AUG91 1 896
VA91-388 16AUG91 2 897
VA91-388 16AUG91 3 898
VA92-548 10AUG92 1 1329
VA92-548 10AUG92 2 1330
VA92-548 10AUG92 3 1331
VA91-401 04SEP91 1 928
VA91-401 04SEP91 3 930
VA91-401 04SEP91 2 929
VA93-704 25AUG93 1 1662
VA93-704 25AUG93 3 1664
VA93-704 25AUG93 2 1663
VA91-406 29JUL91 1 943
VA91-406 29JUL91 3 945
VA91-406 29JUL91 2 944
VA93-709 13AUG93 1 1671
VA93-709 13AUG93 2 1672
VA93-709 13AUG93 3 1673
VA92-568 16AUG92 1 1381
VA92-568 16AUG92 3 1383
VA92-568 16AUG92 2 1382
VA93-690 27AUG93 1 1632
VA93-690 27AUG93 3 1634
VA93-690 27AUG93 2 1633
VA91-386 22AUG91 1 890
VA91-386 22AUG91 2 891
VA91-386 22AUG91 3 892
VA92-542 06AUG92 1 1314
VA92-542 06AUG92 2 1315
VA92-542 06AUG92 3 1316
VA90-010 30AUG90 1 28
VA90-205 21AUG90 1 542
VA90-205 21AUG90 2 543
VA90-205 21AUG90 3 544
VA92-457 15AUG92 2 1109
VA92-457 15AUG92 3 1110
VA91-314 24JUL91 1 753
VA91-314 24JUL91 2 754
VA91-314 24JUL91 3 755
VA91-437 18JUL91 1 1019
VA91-437 18JUL91 3 1021
VA91-437 18JUL91 2 1020
VA92-501 28AUG92 1 1209
VA92-501 28AUG92 2 1210
VA92-501 28AUG92 3 1211
VA90-165 02AUG90 1 439
VA90-165 02AUG90 3 441
VA90-165 02AUG90 2 440
VA93-652 28AUG93 1 1558
VA93-652 28AUG93 3 1559

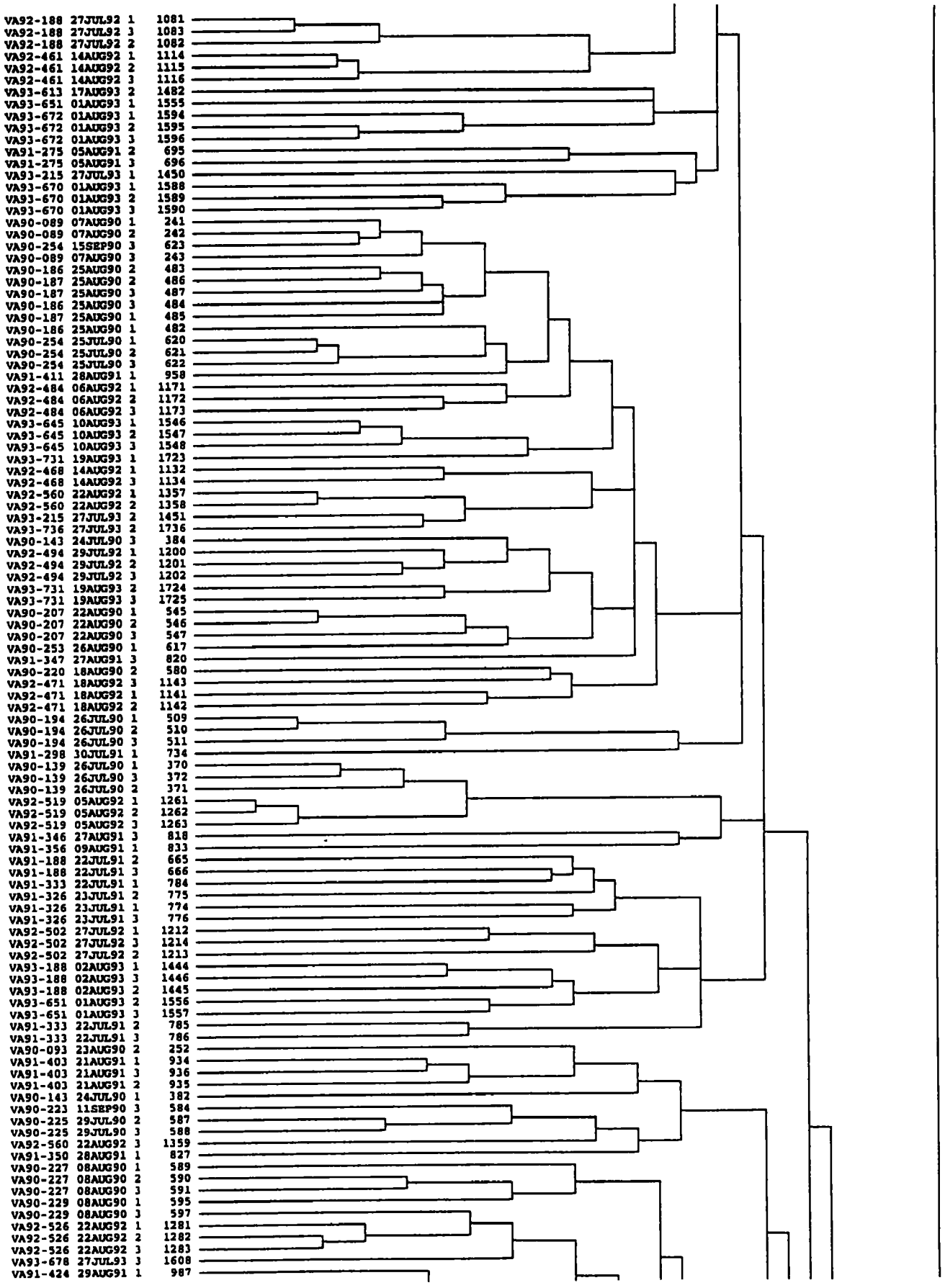

VA93-676 20AUG93 1 1603
VA93-676 20AUG93 3 1605
VA93-676 20AUG93 2 1604
VA90-177 12AUG90 1 464
VA90-177 12AUG90 2 465
VA90-177 12AUG90 3 466
VA91-384 27AUG91 1 884
VA91-384 27AUG91 3 886
VA91-384 27AUG91 2 885
VA92-537 21AUG92 1 1300
VA92-537 21AUG92 2 1301
VA92-537 21AUG92 3 1302
VA90-198 12AUG90 1 521
VA90-198 12AUG90 2 522
VA90-198 12AUG90 3 523
VA93-729 28AUG93 1 1720
VA93-729 28AUG93 2 1721
VA93-729 28AUG93 3 1722
VA90-013 30AUG90 3 40
VA90-083 24AUG90 3 219
VA92-518 11AUG92 3 1260
VA90-114 06AUG90 1 316
VA90-114 06AUG90 2 317
VA90-114 06AUG90 3 318
VA90-115 06AUG90 1' 319
VA90-115 06AUG90 3 321
VA90-115 06AUG90 2 320
VA90-083 24AUG90 1 217
VA90-112 27JUL90 1 310
VA90-112 27JUL90 3 312
VA90-112 27JUL90 2 311
VA91-339 28JUL91 1 799
VA91-339 28JUL91 2 800
VA91-339 28JUL91 3 801
VA91-288 10AUG91 1 716
VA91-288 10AUG91 3 718
VA92-506 06AUG92 1 1224
VA92-506 06AUG92 2 1225
VA92-506 06AUG92 3 1226
VA92-507 02AUG92 1 1227
VA92-507 02AUG92 3 1229
VA92-507 02AUG92 2 1228
VA91-288 10AUG91 2 717
VA93-649 27AUG93 1 1549
VA93-649 27AUG93 3 1551
VA93-649 27AUG93 2 1550
VA90-113 27JUL90 1 313
VA90-113 27JUL90 3 315
VA90-113 27JUL90 2 314
VA92-477 04AUG92 2 1160
VA92-476 04AUG92 3 1158
VA92-477 04AUG92 1 1159
VA92-477 04AUG92 3 1161
VA92-504 06AUG92 1 1218
VA92-504 06AUG92 3 1220
VA92-504 06AUG92 2 1219
VA92-476 04AUG92 1 1156
VA92-476 04AUG92 2 1157
VA92-511 03AUG92 1 1239
VA92-511 03AUG92 3 1241
VA92-511 03AUG92 2 1240
VA91-336 16AUG91 1 790
VA91-336 16AUG91 2 791
VA91-336 16AUG91 3 792
VA92-492 31JUL92 1 1194
VA92-492 31JUL92 2 1195
VA92-492 31JUL92 3 1196
VA92-490 30JUL92 1 1188
VA92-490 30JUL92 3 1190
VA92-490 30JUL92 2 1189
VA93-640 10AUG93 1 1534
VA93-640 10AUG93 2 1535
VA93-640 10AUG93 3 1536
VA93-642 10AUG93 3 1542
VA93-642 10AUG93 2 1541
VA90-083 24AUG90 2 218
VA90-184 27JUL90 1 473
VA90-184 27JUL90 2 474
VA90-184 27JUL90 3 475
VA90-185 27JUL90 1 479
VA90-185 27JUL90 3 481
VA90-185 27JUL90 2 480
VA90-129 27JUL90 1 349
VA90-129 27JUL90 3 351
VA90-184 14SEP90 3 478
VA93-642 10AUG93 1 1540
VA91-343 05SEP91 1 811
VA91-343 05SEP91 2 812
VA91-343 05SEP91 3 813
VA90-184 14SEP90 1 476
VA91-269 04AUG91 3 688
VA91-397 27AUG91 2 917
VA91-397 27AUG91 3 918
VA90-133 11AUG90 1 358
VA90-133 11AUG90 2 359
VA90-133 11AUG90 3 360
VA90-142 24JUL90 1 379
VA90-142 24JUL90 2 380
VA90-142 24JUL90 3 381
VA90-129 27JUL90 2 350
VA90-184 14SEP90 2 477
VA90-058 17AUG90 1 165
VA90-058 17AUG90 3 167
VA90-058 17AUG90 2 166
VA91-058 17JUL91 1 645
VA91-058 17JUL91 2 646
VA91-058 17JUL91 3 647
VA91-436 17JUL91 3 1018

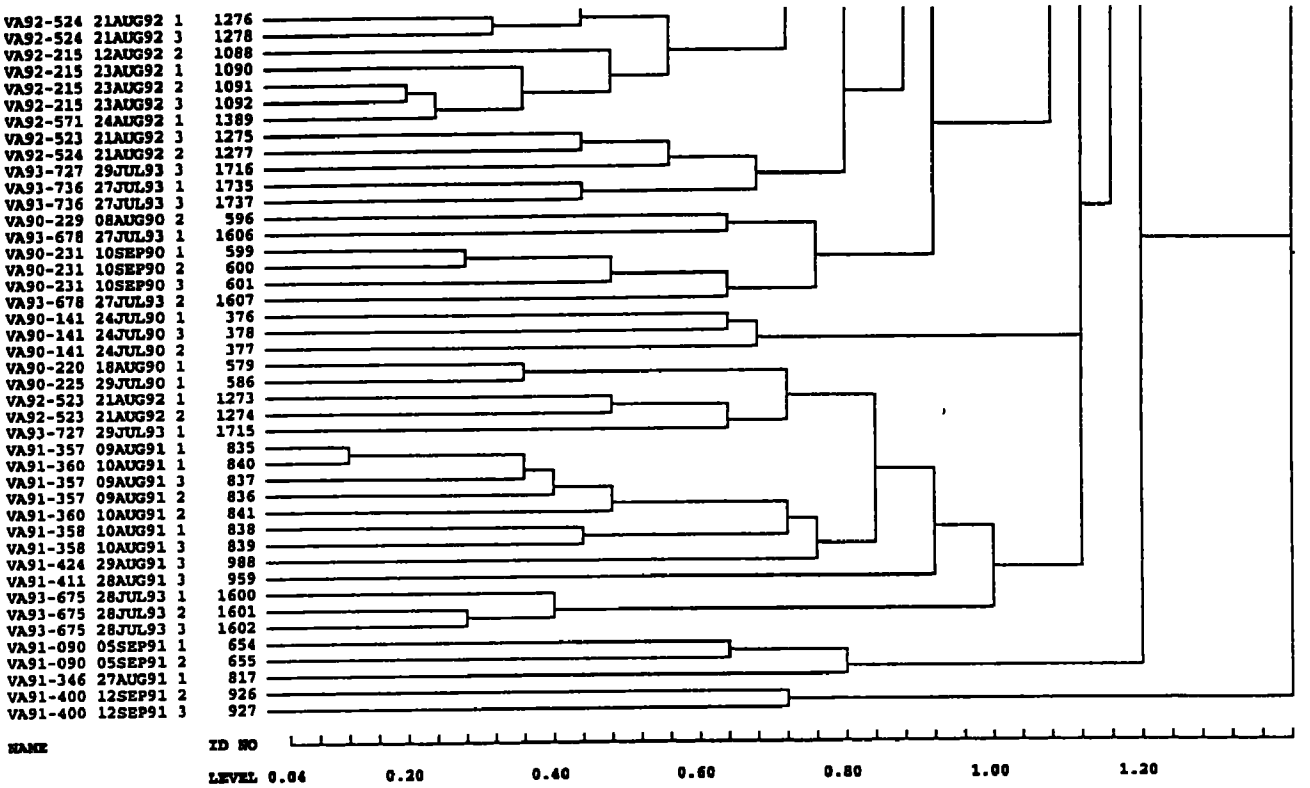

VA93-058 02SEP93 1 1408
VA93-058 02SEP93 3 1410
VA92-058 30AUG92 2 1043
VA93-058 04AUG93 1 1405
VA93-058 02SEP93 2 1409
VA93-058 04AUG93 2 1406
VA93-058 04AUG93 3 1407
VA91-315 24JUL91 1 756
VA91-315 24JUL91 3 758
VA93-643 09AUG93 2 1544
VA93-643 09AUG93 1 1543
VA93-643 09AUG93 3 1545
VA91-436 17JUL91 1 1016
VA91-315 24JUL91 2 757
VA91-435 18JUL91 2 1014
VA91-435 18JUL91 3 1015
VA91-435 18JUL91 1 1013
VA91-436 17JUL91 2 1017
VA92-058 03AUG92 1 1039
VA92-058 03AUG92 2 1040
VA92-058 03AUG92 3 1041
VA92-058 30AUG92 1 1042
VA92-058 30AUG92 3 1044
VA90-102 01AUG90 1 277
VA90-102 01AUG90 3 279
VA90-147 01AUG90 3 393
VA90-147 01AUG90 2 392
VA90-102 01AUG90 2 278
VA90-147 01AUG90 1 391
VA90-103 31JUL90 1 283
VA90-103 31JUL90 2 284
VA90-103 31JUL90 3 285
VA90-221 26AUG90 2 582
VA93-684 07AUG93 2 1615
VA90-102 19SEP90 1 280
VA90-102 19SEP90 3 282
VA90-102 19SEP90 2 281
VA91-397 27AUG91 1 916
VA90-130 11AUG90 1 352
VA90-130 11AUG90 2 353
VA90-231 19JUL90 1 598
VA90-219 28JUL90 1 576
VA90-219 28JUL90 3 578
VA90-252 26AUG90 2 615
VA90-219 28JUL90 2 577
VA90-252 26AUG90 3 616
VA91-389 16AUG91 3 901
VA90-128 27JUL90 1 346
VA90-128 27JUL90 3 348
VA90-128 27JUL90 2 347
VA90-253 26AUG90 2 618
VA90-253 26AUG90 3 619
VA93-621 20AUG93 2 1499
VA90-193 26JUL90 1 506
VA90-193 26JUL90 2 507
VA90-193 26JUL90 3 508
VA90-192 26JUL90 1 500
VA90-192 26JUL90 2 501
VA90-192 26JUL90 3 502
VA90-192 07SEP90 1 503
VA90-192 07SEP90 2 504
VA90-192 07SEP90 3 505
VA91-269 04AUG91 1 686
VA91-269 04AUG91 2 687
VA93-621 20AUG93 1 1498
VA90-136 05AUG90 1 364
VA90-136 05AUG90 3 366
VA90-137 05AUG90 2 368
VA90-137 05AUG90 3 369
VA90-136 05AUG90 2 365
VA90-137 05AUG90 1 367
VA92-552 21AUG92 1 1337
VA92-552 21AUG92 2 1338
VA92-552 21AUG92 3 1339
VA92-481 06AUG92 1 1165
VA92-481 06AUG92 3 1167
VA92-481 06AUG92 2 1166
VA92-555 22AUG92 1 1346
VA92-555 22AUG92 2 1347
VA92-555 22AUG92 3 1348
VA92-136 04AUG92 1 1057
VA92-136 04AUG92 2 1058
VA92-136 04AUG92 3 1059
VA92-514 04AUG92 1 1248
VA92-514 04AUG92 2 1249
VA92-514 04AUG92 3 1250
VA90-143 24JUL90 2 383
VA92-136 29AUG92 1 1060
VA92-136 29AUG92 3 1062
VA92-136 29AUG92 2 1061
VA93-136 03AUG93 2 1423
VA93-136 03AUG93 3 1424
VA91-319 23JUL91 1 768
VA92-522 20AUG92 1 1270
VA92-522 20AUG92 2 1271
VA92-522 20AUG92 3 1272
VA91-294 30JUL91 1 725
VA91-294 30JUL91 2 726
VA91-294 30JUL91 3 727
VA91-347 27AUG91 1 819
VA90-199 11AUG90 1 524
VA90-199 11AUG90 3 526
VA90-199 11AUG90 2 525
VA93-694 26JUL93 1 1638
VA93-694 26JUL93 2 1639
VA93-694 26JUL93 3 1640
VA90-212 11AUG90 1 560


VA90-212 11AUG90 2 561
VA90-212 11AUG90 3 562
VA93-710 26JUL93 2 1674
VA93-710 26JUL93 3 1675
VA91-319 23JUL91 2 769
VA91-319 23JUL91 3 770
VA93-667 02AUG93 1 1582
VA93-667 02AUG93 3 1584
VA93-667 02AUG93 2 1583
VA93-606 14AUG93 2 1461
VA93-606 14AUG93 3 1462
VA90-011 30AUG90 1 30
VA92-520 20AUG92 3 1266
VA92-520 20AUG92 1 1264
VA90-011 30AUG90 3 32
VA90-011 30AUG90 2 31
VA92-520 20AUG92 2 1265
VA90-124 27AUG90 3 342
VA90-124 27AUG90 1 340
VA90-125 27AUG90 1 343
VA90-125 27AUG90 2 344
VA90-125 27AUG90 3 345
VA90-124 27AUG90 2 341
VA90-013 30AUG90 1 38
VA90-013 30AUG90 2 39
VA90-221 26AUG90 1 581
VA90-250 30AUG90 1 608
VA90-250 30AUG90 3 610
VA90-250 30AUG90 2 609
VA90-221 26AUG90 3 583
VA90-036 31AUG90 1 113
VA90-036 31AUG90 2 114
VA90-036 31AUG90 3 115
VA92-516 08AUG92 1 1254
VA92-516 08AUG92 3 1256
VA92-516 08AUG92 2 1255
VA93-650 29AUG93 1 1552
VA93-650 29AUG93 2 1553
VA93-650 29AUG93 3 1554
VA90-100 09AUG90 1 268
VA90-100 09AUG90 2 269
VA90-100 09AUG90 3 270
VA90-111 09AUG90 1 307
VA90-111 09AUG90 2 308
VA90-111 09AUG90 3 309
VA93-619 28JUL93 1 1495
VA93-619 28JUL93 2 1496
VA93-619 28JUL93 3 1497
VA93-623 08AUG93 1 1502
VA93-623 08AUG93 3 1504
VA93-623 08AUG93 2 1503
VA90-224 18AUG90 1 585
VA90-252 26AUG90 1 614
VA92-493 29JUL92 1 1197
VA92-493 29JUL92 2 1198
VA92-493 29JUL92 3 1199
VA91-395 21AUG91 2 914
VA91-395 21AUG91 3 915
VA90-027 05AUG90 1 86
VA90-027 05AUG90 2 87
VA90-027 05AUG90 3 88
VA91-409 26JUL91 1 952
VA91-409 26JUL91 2 953
VA91-409 26JUL91 3 954
VA90-052 26AUG90 1 151
VA90-052 26AUG90 2 152
VA92-551 10AUG92 1 1335
VA92-551 10AUG92 3 1336
VA92-569 27JUL92 1 1384
VA92-569 27JUL92 2 1385
VA93-716 14SEP93 1 1688
VA93-716 14SEP93 3 1690
VA93-716 14SEP93 2 1689
VA93-697 04AUG93 1 1647
VA93-697 04AUG93 2 1648
VA93-697 04AUG93 3 1649
VA91-391 03SEP91 1 905
VA91-391 03SEP91 3 907
VA91-391 03SEP91 2 906
VA92-455 08AUG92 1 1105
VA92-455 08AUG92 2 1106
VA92-455 08AUG92 3 1107
VA90-257 22JUL90 1 630
VA92-557 28JUL92 2 1349
VA92-557 28JUL92 3 1350
VA92-564 30JUL92 1 1369
VA92-564 30JUL92 2 1370
VA92-564 30JUL92 3 1371
VA91-389 16AUG91 1 899
VA91-389 16AUG91 2 900
VA91-390 05SEP91 1 902
VA91-390 05SEP91 2 903
VA91-390 05SEP91 3 904
VA93-717 15SEP93 1 1691
VA93-717 15SEP93 2 1692
VA93-717 15SEP93 3 1693
VA92-558 28JUL92 1 1351
VA92-558 28JUL92 2 1352
VA92-558 28JUL92 3 1353
VA91-413 09AUG91 1 960
VA91-413 09AUG91 3 962
VA91-413 09AUG91 2 961
VA93-660 22AUG93 1 1573
VA93-660 22AUG93 3 1575
VA93-660 22AUG93 2 1574
VA93-654 15AUG93 1 1563
VA93-654 15AUG93 3 1565
VA93-654 15AUG93 2 1564


VA90-107 14AUG90 1 301
VA90-107 14AUG90 3 303
VA90-107 14AUG90 2 302
VA92-545 28AUG92 1 1320
VA92-545 28AUG92 2 1321
VA92-545 28AUG92 3 1322
VA93-712 14AUG93 1 1679
VA93-712 14AUG93 3 1681
VA93-712 14AUG93 2 1680
VA93-689 28AUG93 1 1629
VA93-689 28AUG93 2 1630
VA93-689 28AUG93 3 1631
VA90-073 04AUG90 1 197
VA90-073 04AUG90 2 198
VA90-073 04AUG90 3 199
VA90-074 03AUG90 1 200
VA90-074 03AUG90 3 202
VA90-074 03AUG90 2 201
VA91-399 06SEP91 1 922
VA91-399 06SEP91 2 923
VA91-399 06SEP91 3 924
VA92-553 18AUG92 1 1340
VA92-553 18AUG92 2 1341
VA92-553 18AUG92 3 1342
VA93-707 17SEP93 1 1668
VA93-707 17SEP93 3 1670
VA93-707 17SEP93 2 1669
VA92-554 18AUG92 1 1343
VA92-554 18AUG92 2 1344
VA92-554 18AUG92 3 1345
VA93-706 16SEP93 1 1665
VA93-706 16SEP93 2 1666
VA93-706 16SEP93 3 1667
VA91-398 06SEP91 1 919
VA91-398 06SEP91 2 920
VA91-398 06SEP91 3 921
VA90-088 26AUG90 1 235
VA90-088 26AUG90 2 236
VA90-088 26AUG90 3 237
VA92-178 23AUG92 2 1079
VA92-178 23AUG92 3 1080
VA90-088 21SEP90 1 238
VA90-088 21SEP90 2 239
VA90-088 21SEP90 3 240
VA90-172 26AUG90 1 453
VA90-172 26AUG90 2 454
VA90-172 26AUG90 3 455
VA90-216 10AUG90 1 569
VA90-216 10AUG90 3 571
VA90-216 10AUG90 2 570
VA91-422 29AUG91 3 986
VA92-570 23AUG92 1 1386
VA91-422 29AUG91 2 985
VA91-422 29AUG91 1 984
VA92-570 23AUG92 2 1387
VA92-570 23AUG92 3 1388
VA93-215 03SEP93 1 1453
VA91-300 29JUL91 2 737
VA92-178 23AUG92 1 1078
VA90-090 26JUL90 1 244
VA90-090 05SEP90 3 248
VA90-140 15AUG90 1 373
VA90-140 15AUG90 3 375
VA90-195 26JUL90 2 513
VA93-673 29JUL93 1 1597
VA93-673 29JUL93 3 1599
VA93-673 29JUL93 2 1598
VA90-090 26JUL90 3 246
VA90-195 26JUL90 1 512
VA90-101 11AUG90 3 276
VA90-101 11AUG90 2 275
VA92-525 22AUG92 1 1279
VA90-228 20AUG90 3 594
VA93-610 16AUG93 3 1474
VA90-214 11AUG90 1 563
VA90-214 11AUG90 2 564
VA90-214 11AUG90 3 565
VA91-356 09AUG91 3 834
VA93-610 16AUG93 1 1472
VA93-610 16AUG93 2 1473
VA90-101 11AUG90 1 274
VA90-090 05SEP90 1 247
VA91-215 28AUG91 2 667
VA90-091 14AUG90 3 251
VA93-628 19AUG93 1 1513
VA90-215 10AUG90 1 566
VA90-140 15AUG90 2 374
VA90-209 22AUG90 1 551
VA91-351 30JUL91 1 828
VA92-215 12AUG92 1 1087
VA92-215 12AUG92 3 1089
VA90-217 09AUG90 1 572
VA92-571 24AUG92 2 1390
VA93-215 27JUL93 3 1452
VA92-571 24AUG92 3 1391
VA90-217 09AUG90 2 573
VA90-090 26JUL90 2 245
VA90-195 26JUL90 3 514
VA92-525 22AUG92 3 1280
VA90-091 14AUG90 1 249
VA90-197 05AUG90 1 518
VA90-197 05AUG90 2 519
VA90-197 05AUG90 3 520
VA90-215 10AUG90 2 567
VA93-635 23AUG93 1 1525
VA90-215 10AUG90 3 568
VA93-635 23AUG93 2 1526


VA90-091 14AUG90 2 250
VA93-635 23AUG93 3 1527
VA91-300 29JUL91 3 738
VA90-209 22AUG90 2 552
VA93-609 15AUG93 1 1469
VA93-728 15AUG93 2 1718
VA90-209 22AUG90 3 553
VA93-609 15AUG93 3 1471
VA93-609 15AUG93 2 1470
VA93-728 15AUG93 3 1719
VA91-298 30JUL91 3 735
VA93-628 19AUG93 2 1514
VA93-628 19AUG93 3 1515
VA93-728 15AUG93 1 1717
VA90-196 05AUG90 1 515
VA90-196 05AUG90 3 517
VA90-196 05AUG90 2 516
VA91-351 30JUL91 2 829
VA92-468 14AUG92 2 1133
VA90-218 09AUG90 1 574
VA90-218 09AUG90 2 575
VA93-726 28JUL93 1 1712
VA93-726 28JUL93 2 1713
VA93-726 28JUL93 3 1714
VA90-130 11AUG90 3 354
VA90-232 20AUG90 1 602
VA90-232 20AUG90 2 603
VA90-232 20AUG90 3 604
VA92-178 31JUL92 1 1075
VA92-178 31JUL92 2 1076
VA92-178 31JUL92 3 1077
VA90-169 21AUG90 1 450
VA90-169 21AUG90 3 452
VA90-169 21AUG90 2 451
VA90-178 19AUG90 2 468
VA91-365 11AUG91 1 848
VA91-365 11AUG91 3 850
VA91-365 11AUG91 2 849
VA90-228 20AUG90 1 592
VA90-228 20AUG90 2 593
VA90-233 19JUL90 1 605
VA90-233 19JUL90 3 607
VA90-233 19JUL90 2 606
VA90-188 26AUG90 1 488
VA90-188 26AUG90 2 489
VA90-188 26AUG90 3 490
VA90-200 05AUG90 1 527
VA90-200 05AUG90 2 528
VA90-201 05AUG90 3 532
VA90-201 05AUG90 2 531
VA90-201 05AUG90 1 530
VA91-300 29JUL91 1 736
VA90-200 05AUG90 3 529
VA90-210 23JUL90 3 556
VA92-464 17AUG92 3 1122
VA92-464 17AUG92 1 1120
VA92-464 17AUG92 2 1121
VA92-469 16AUG92 1 1135
VA92-469 16AUG92 3 1137
VA92-469 16AUG92 2 1136
VA93-178 27JUL93 1 1438
VA93-178 27JUL93 2 1439
VA93-178 27JUL93 3 1440
VA93-178 31AUG93 1 1441
VA93-178 31AUG93 2 1442
VA93-734 26JUL93 1 1729
VA93-734 26JUL93 3 1731
VA93-734 26JUL93 2 1730
VA90-210 09SEP90 1 557
VA90-210 09SEP90 2 558
VA90-210 09SEP90 3 559
VA90-178 19AUG90 1 467
VA90-178 19AUG90 3 469
VA93-188 25AUG93 3 1449
VA93-188 25AUG93 1 1447
VA90-208 22AUG90 1 548
VA90-208 22AUG90 2 549
VA90-208 22AUG90 3 550
VA93-178 31AUG93 3 1443
VA92-188 26AUG92 1 1084
VA92-188 26AUG92 2 1085
VA92-188 26AUG92 3 1086
VA91-309 29JUL91 1 748
VA93-613 17AUG93 1 1481
VA93-613 17AUG93 3 1483
VA91-309 29JUL91 2 749
VA93-188 25AUG93 2 1448
VA93-639 21AUG93 2 1532
VA90-210 23JUL90 1 554
VA90-210 23JUL90 2 555
VA90-189 26AUG90 1 491
VA90-189 26AUG90 2 492
VA90-189 26AUG90 3 493
VA91-188 22JUL91 1 664
VA92-467 16AUG92 1 1129
VA92-467 16AUG92 3 1131
VA92-467 16AUG92 2 1130
VA93-655 03AUG93 1 1566
VA93-655 03AUG93 3 1568
VA93-655 03AUG93 2 1567
VA91-353 30JUL91 1 830
VA91-353 30JUL91 2 831
VA91-353 30JUL91 3 832
VA92-521 28AUG92 1 1267
VA92-521 28AUG92 2 1268
VA92-521 28AUG92 3 1269
VA93-639 21AUG93 1 1531
VA93-639 21AUG93 3 1533

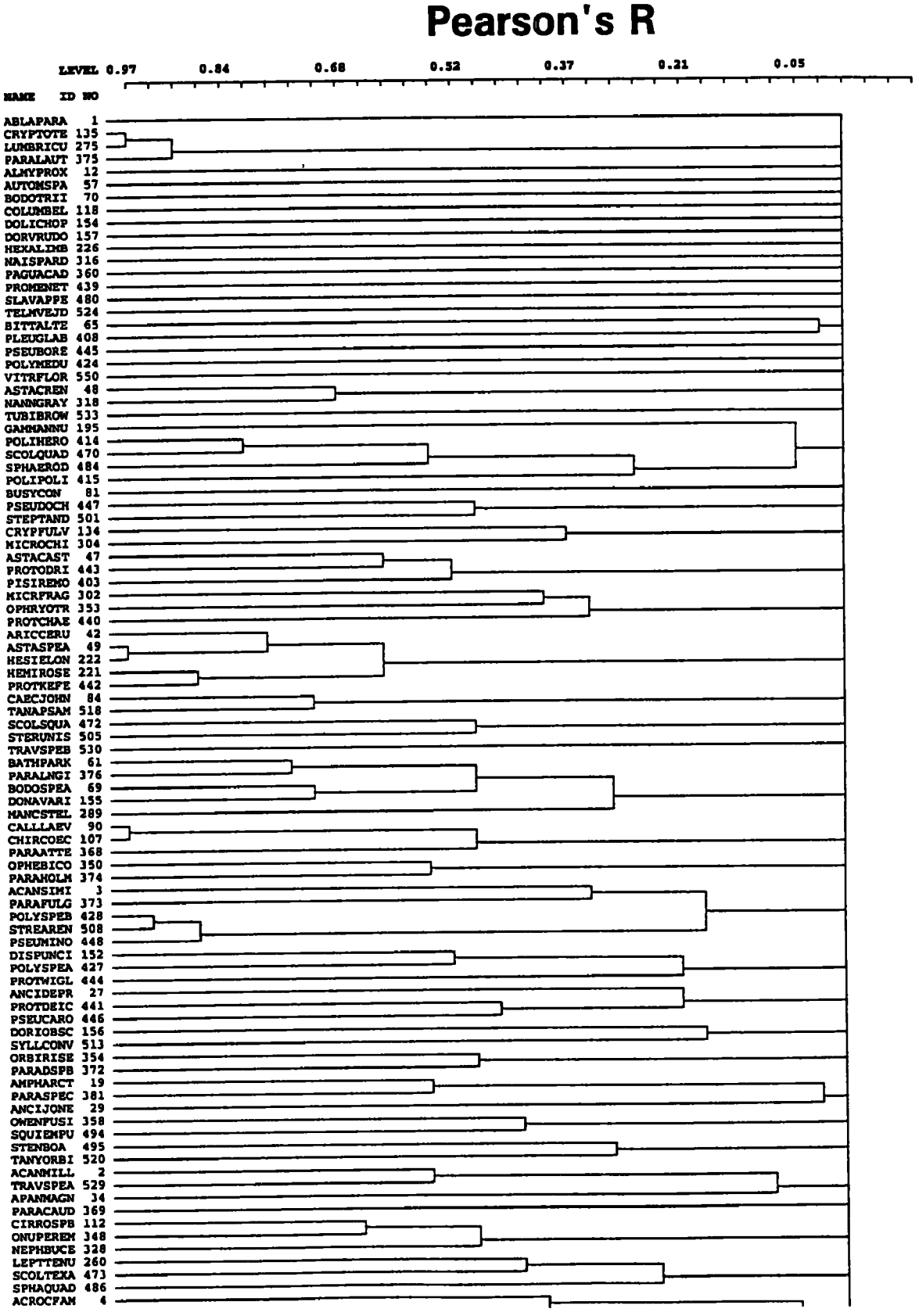

VA92-188 27JUL92 1 1081
VA92-188 27JUL92 3 1083
VA92-188 27JUL92 2 1082
VA92-461 14AUG92 1 1114
VA92-461 14AUG92 2 1115
VA92-461 14AUG92 3 1116
VA93-613 17AUG93 2 1482
VA93-651 01AUG93 1 1555
VA93-672 01AUG93 1 1594
VA93-672 01AUG93 2 1595
VA93-672 01AUG93 3 1596
VA91-275 05AUG91 2 695
VA91-275 05AUG91 3 696
VA93-215 27JUL93 1 1450
VA93-670 01AUG93 1 1588
VA93-670 01AUG93 2 1589
VA93-670 01AUG93 3 1590
VA90-089 07AUG90 1 241
VA90-089 07AUG90 2 242
VA90-254 15SEP90 3 623
VA90-089 07AUG90 3 243
VA90-186 25AUG90 2 483
VA90-187 25AUG90 2 486
VA90-187 25AUG90 3 487
VA90-186 25AUG90 3 484
VA90-187 25AUG90 1 485
VA90-186 25AUG90 1 482
VA90-254 25JUL90 1 620
VA90-254 25JUL90 2 621
VA90-254 25JUL90 3 622
VA91-411 28AUG91 1 958
VA92-484 06AUG92 1 1171
VA92-484 06AUG92 2 1172
VA92-484 06AUG92 3 1173
VA93-645 10AUG93 1 1546
VA93-645 10AUG93 2 1547
VA93-645 10AUG93 3 1548
VA93-731 19AUG93 1 1723
VA92-468 14AUG92 1 1132
VA92-468 14AUG92 3 1134
VA92-560 22AUG92 1 1357
VA92-560 22AUG92 2 1358
VA93-215 27JUL93 2 1451
VA93-736 27JUL93 2 1736
VA90-143 24JUL90 3 384
VA92-494 29JUL92 1 1200
VA92-494 29JUL92 2 1201
VA92-494 29JUL92 3 1202
VA93-731 19AUG93 2 1724
VA93-731 19AUG93 3 1725
VA90-207 22AUG90 1 545
VA90-207 22AUG90 2 546
VA90-207 22AUG90 3 547
VA90-253 26AUG90 1 617
VA91-347 27AUG91 3 820
VA90-220 18AUG90 2 580
VA92-471 18AUG92 3 1143
VA92-471 18AUG92 1 1141
VA92-471 18AUG92 2 1142
VA90-194 26JUL90 1 509
VA90-194 26JUL90 2 510
VA90-194 26JUL90 3 511
VA91-298 30JUL91 1 734
VA90-139 26JUL90 1 370
VA90-139 26JUL90 3 372
VA90-139 26JUL90 2 371
VA92-519 05AUG92 1 1261
VA92-519 05AUG92 2 1262
VA92-519 05AUG92 3 1263
VA91-346 27AUG91 3 818
VA91-356 09AUG91 1 833
VA91-188 22JUL91 2 665
VA91-188 22JUL91 3 666
VA91-333 22JUL91 1 784
VA91-326 23JUL91 2 775
VA91-326 23JUL91 1 774
VA91-326 23JUL91 3 776
VA92-502 27JUL92 1 1212
VA92-502 27JUL92 3 1214
VA92-502 27JUL92 2 1213
VA93-188 02AUG93 1 1444
VA93-188 02AUG93 3 1446
VA93-188 02AUG93 2 1445
VA93-651 01AUG93 2 1556
VA93-651 01AUG93 3 1557
VA91-333 22JUL91 2 785
VA91-333 22JUL91 3 786
VA90-093 23AUG90 2 252
VA91-403 21AUG91 1 934
VA91-403 21AUG91 3 936
VA91-403 21AUG91 2 935
VA90-143 24JUL90 1 382
VA90-223 11SEP90 3 584
VA90-225 29JUL90 2 587
VA90-225 29JUL90 3 588
VA92-560 22AUG92 3 1359
VA91-350 28AUG91 1 827
VA90-227 08AUG90 1 589
VA90-227 08AUG90 2 590
VA90-227 08AUG90 3 591
VA90-229 08AUG90 1 595
VA90-229 08AUG90 3 597
VA92-526 22AUG92 1 1281
VA92-526 22AUG92 2 1282
VA92-526 22AUG92 3 1283
VA93-678 27JUL93 3 1608
VA91-424 29AUG91 1 987

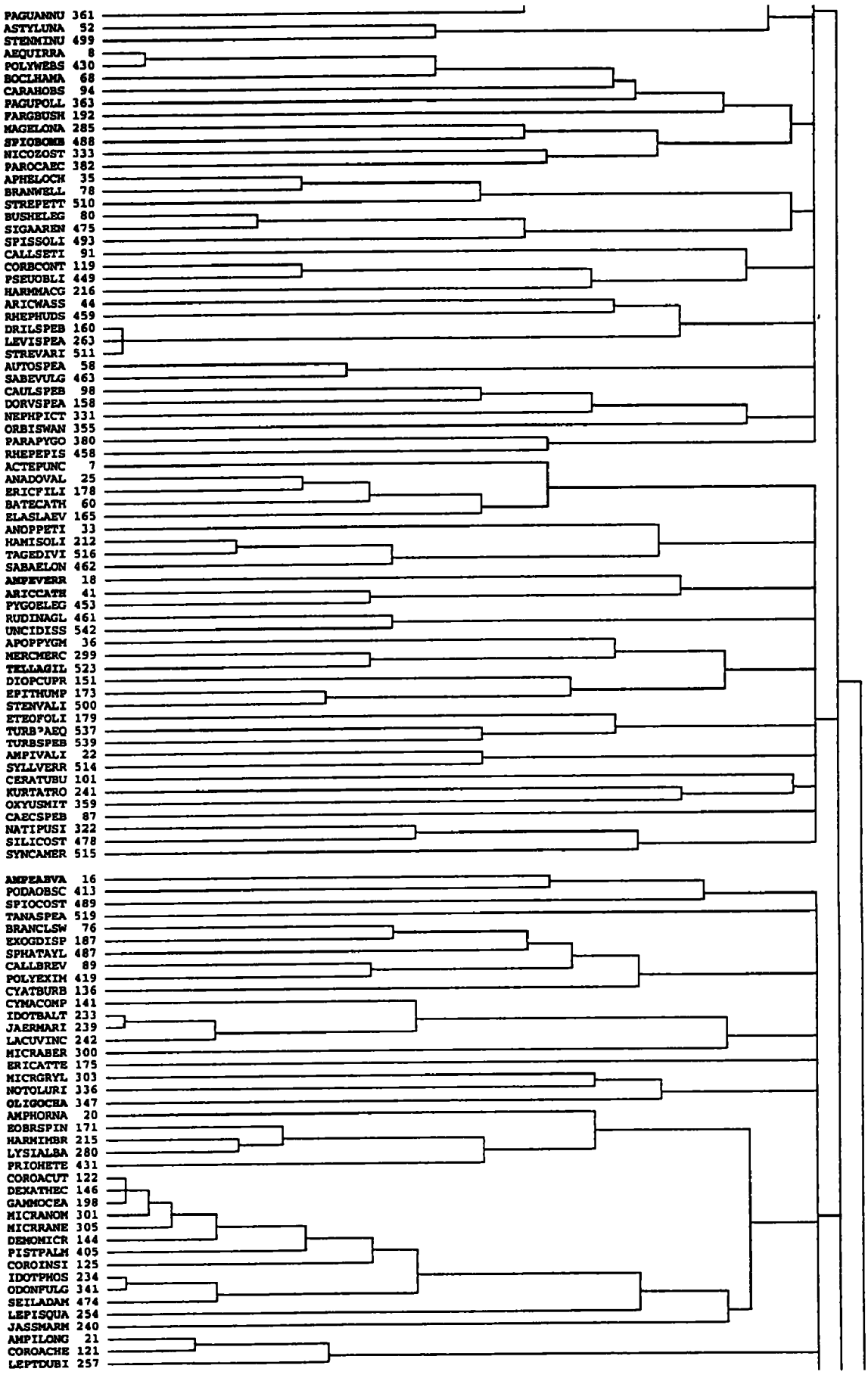


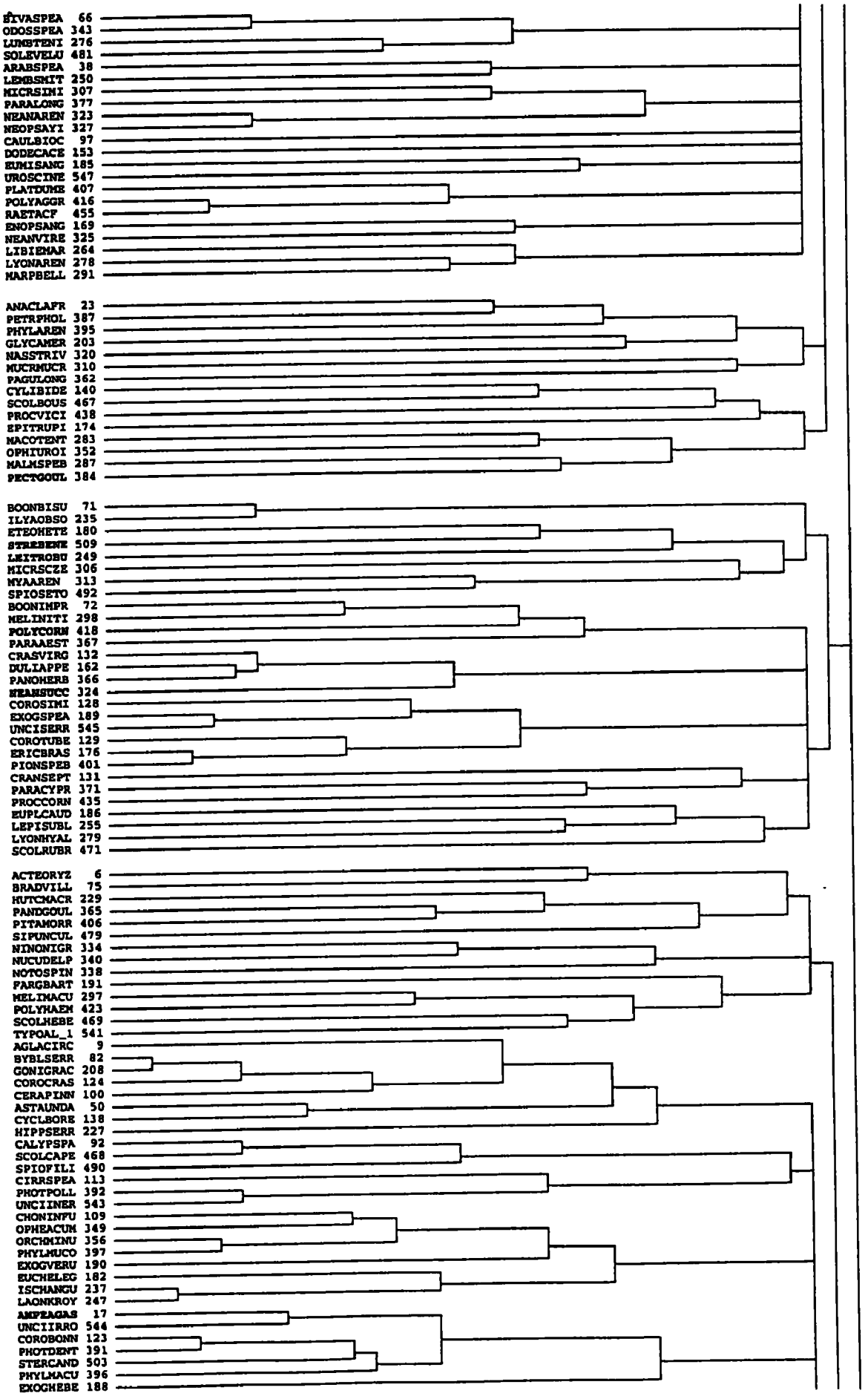
CNESS Distance (NESSm = 25)

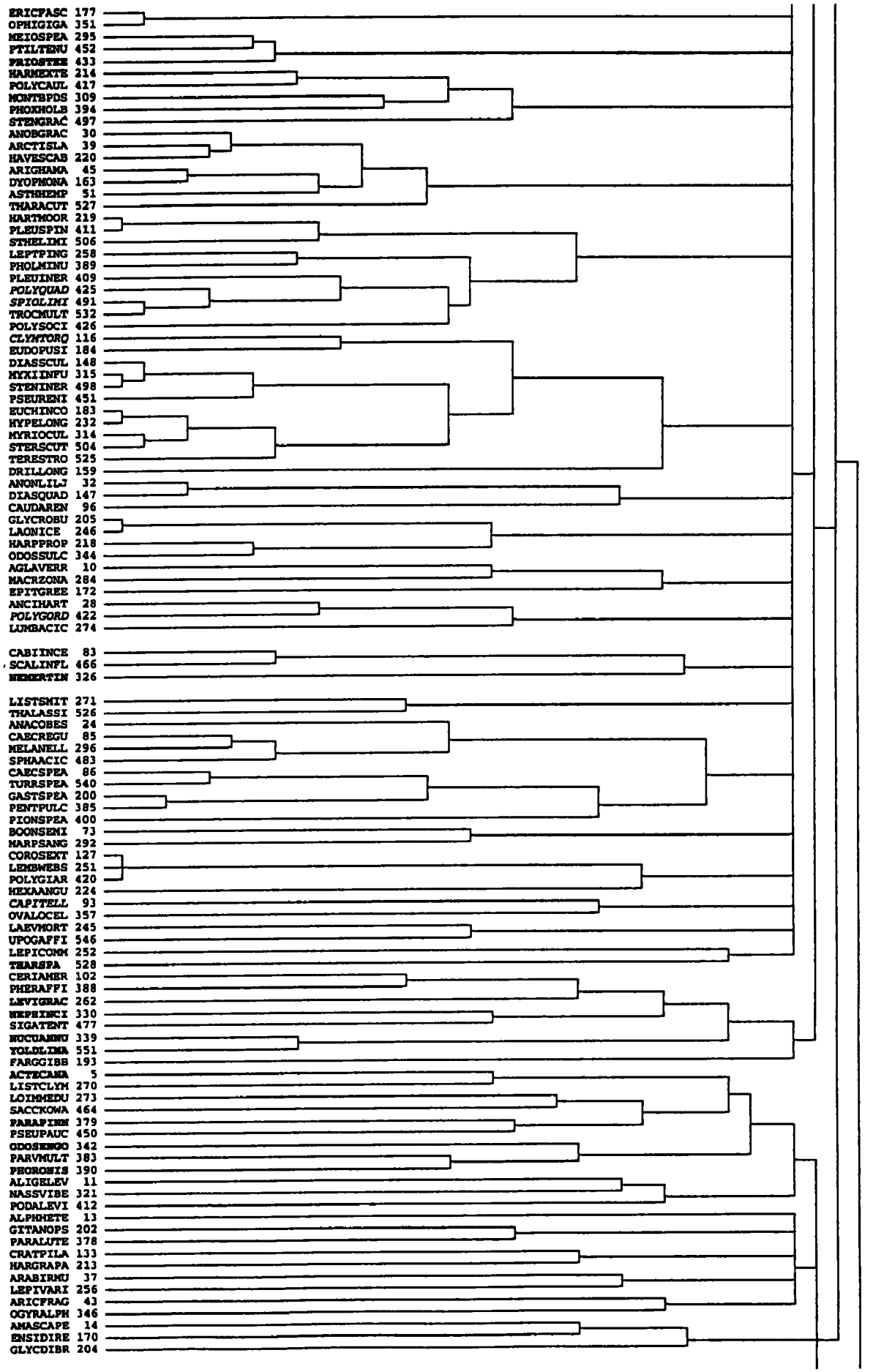
APPENDIX V SPECIES CLUSTERS FOR ALL 551 EMAP-E VP TAXA

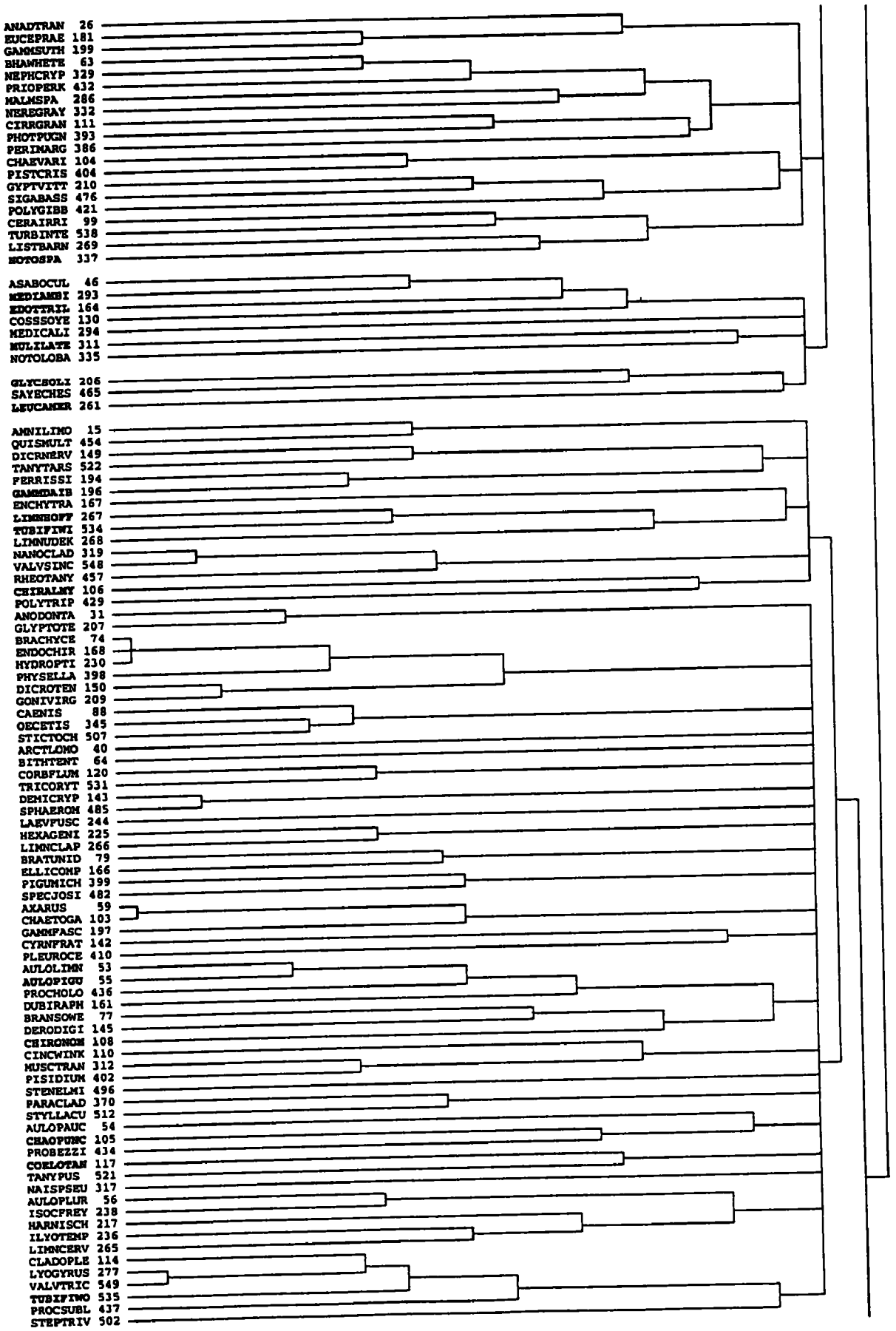
All EMAP-E VP taxa were clustered using the species-clustering methods described in Trueblood *et al.* (1994). Species are clustered using single linkage clustering of cos θ, where θ is the angle between pairs of species vectors in the Gabriel covariance biplot (Figure 15).

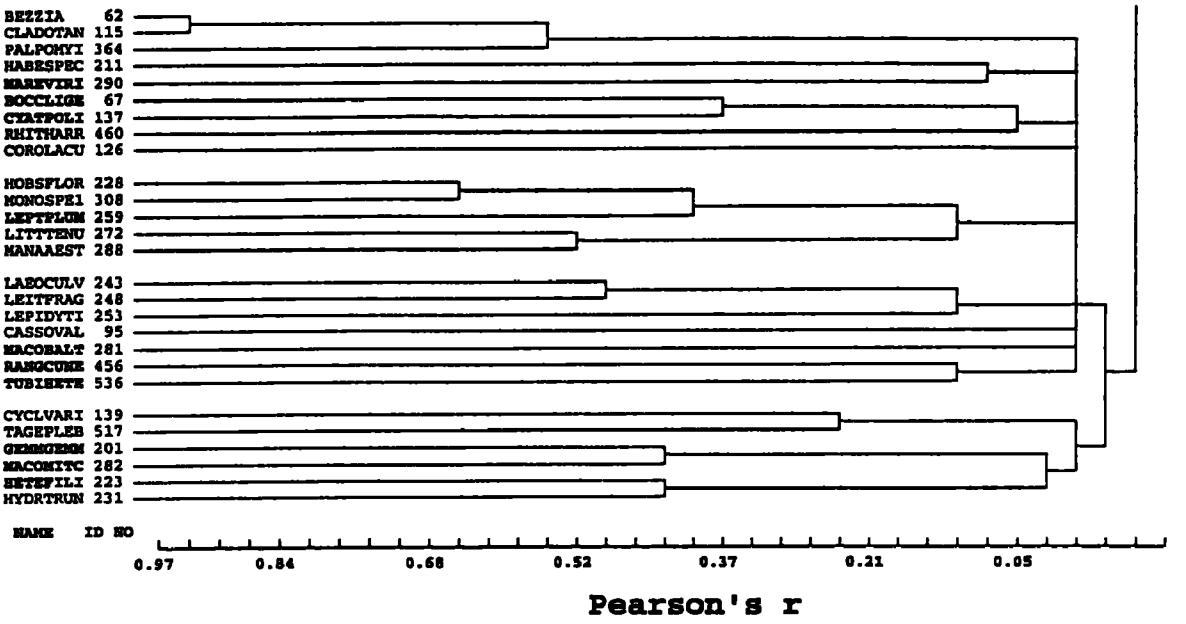



PAGUANNU 361
ASTYLUNA 52
STENMINU 499
AEQUIRRA 8
POLYWEBS 430
BOCLHAMA 68
CARAHOBS 94
PAGUPOLL 363
FARGBUSH 192
MAGELONA 285
SPIOBOMB 488
NICOZOST 333
PAROCAEC 382
APHELOCH 35
BRANWELL 78
STREPETT 510
BUSHELEG 80
SIGAAREN 475
SPISSOLI 493
CALLSETI 91
CORBCONT 119
PSEUOBLI 449
HARMMACG 216
ARICWASS 44
RHEPHUDS 459
DRILSPEB 160
LEVISPEA 263
STREVARI 511
AUTOSPEA 58
SABEVULG 463
CAULSPEB 98
DORVSPEA 158
NEPHPICT 331
ORBISWAN 355
PARAPYGO 380
RHEPEPIS 458
ACTEPUNC 7
ANADOVAL 25
ERICFILI 178
BATECATH 60
ELASLAEV 165
ANOPPETI 33
HAMISOLI 212
TAGEDIVI 516
SABAELON 462
AMPEVERR 18
ARICCATH 41
PYGOELEG 453
RUDINAGL 461
UNCIDISS 542
APOPPYGM 36
MERCMERC 299
TELLAGIL 523
DIOPCUPR 151
EPITHUMP 173
STENVALI 500
ETEOFOLI 179
TURB'AEQ 537
TURBSPEB 539
AMPIVALI 22
SYLLVERR 514
CERATUBU 101
KURTATRO 241
OXYUSMIT 359
CAECSPEB 87
NATIPUSI 322
SILICOST 478
SYNCAMER 515
AMPEABVA 16
PODAOBSC 413
SPIOCOST 489
TANASPEA 519
BRANCLSW 76
EXOGDISP 187
SPHATAYL 487
CALLBREV 89
POLYEXIM 419
CYATBURB 136
CYMACOMP 141
IDOTBALT 233
JAERMARI 239
LACUVINC 242
MICRABER 300
ERICATTE 175
MICRGRYL 303
NOTOLURI 336
OLIGOCBA 347
AMPHORNA 20
EOBRSPIN 171
HARMIMBR 215
LYSIALBA 280
PRIOHETE 431
COROACUT 122
DEXATHEC 146
GAMMOCEA 198
MICRANOM 301
MICRRANE 305
DEMOMICR 144
PISTPALM 405
COROINSI 125
IDOTPHOS 234
ODONFULG 341
SEILADAM 474
LEPISQUA 254
JASSMARM 240
AMPILONG 21
COROACHE 121
LEPTDUBI 257


ETVASPEA 66
ODOSSPEA 343
LUMBTENI 276
SOLEVELU 481
ARABSPEA 38
LEMBSMIT 250
MICRSIMI 307
PARALONG 377
NEANAREN 323
NEOPSAYI 327
CAULBIOC 97
DODECACE 153
EUMISANG 185
UROSCINE 547
PLATDUME 407
POLYAGGR 416
RAETACF 455
ENOPSANG 169
NEANVIRE 325
LIBIEMAR 264
LYONAREN 278
MARPBELL 291
ANACLAFR 23
PETRPHOL 387
PHYLAREN 395
GLYCAMER 203
NASSTRIV 320
MUCRMUCR 310
PAGULONG 362
CYLIBIDE 140
SCOLBOUS 467
PROCVICI 438
EPITRUPI 174
NACOTENT 283
OPHIUROI 352
MALMSPEB 287
PECTGOUL 384
BOONBISU 71
ILYAOBSO 235
ETEOHETE 180
STREBENE 509
LEITROBU 249
MICRSCZE 306
MYAAREN 313
SPIOSETO 492
BOONIMPR 72
MELINITI 298
POLYCORN 418
PARAAEST 367
CRASVIRG 132
DULIAPPE 162
PANOHERB 366
NEANSUCC 324
COROSIMI 128
EXOGSPEA 189
UNCISERR 545
COROTUBE 129
ERICBRAS 176
PIONSPEB 401
CRANSEPT 131
PARACYPR 371
PROCCORN 435
EUPLCAUD 186
LEPISUBL 255
LYONHYAL 279
SCOLRUBR 471
ACTEORYZ 6
BRADVILL 75
HUTCMACR 229
PANDGOUL 365
PITAMORR 406
SIPUNCUL 479
NINONIGR 334
NUCUDELP 340
NOTOSPIN 338
FARGBART 191
MELIMACU 297
POLYHAEM 423
SCOLNEBE 469
TYPOAL_1 541
AGLACIRC 9
BYBLSERR 82
GONIGRAC 208
COROCRAS 124
CERAPINN 100
ASTAUNDA 50
CYCLBORE 138
HIPPSERR 227
CALYPSPA 92
SCOLCAPE 468
SPIOFILI 490
CIRRSPEA 113
PHOTPOLL 392
UNCIINER 543
CHONINFU 109
OPHEACUM 349
ORCHMINU 356
PHYLHUCO 197
EXOGVERU 190
EUCHELEG 182
ISCHANGU 237
LAONKROY 247
AMPEAGAS 17
UNCIIRRO 544
COROBONN 123
PHOTDENT 391
STERCAND 503
PHYLMACU 396
EXOGNEBE 188


ERICPASC 177
OPHIGIGA 351
MEIOSPEA 295
PTILTENU 452
PRIOSTEE 433
HARMEXTE 214
POLYCAUL 417
MONTSPDS 309
PHOXHOLB 394
STENGRAC 497
ANOBGRAC 30
ARCTISLA 39
HAVESCAB 220
ARIGHAMA 45
DYOPMONA 163
ASTHHEMP 51
THARACUT 527
HARTMOOR 219
PLEUSPIN 411
STHELIMI 506
LEPTPING 258
PHOLMINU 389
PLEUINER 409
POLYQUAD 425
SPIOLIMI 491
TROCMULT 532
POLYSOCI 426
CLYMTORQ 116
EUDOPUSI 184
DIASSCUL 148
MYXIINFU 315
STENINER 498
PSEURENI 451
EUCHINCO 183
HYPELONG 232
MYRIOCUL 314
STERSCUT 504
TERESTRO 525
DRILLONG 159
ANONLILJ 32
DIASQUAD 147
CAUDAREN 96
GLYCROBU 205
LAONICE 246
HARPPROP 218
ODOSSULC 344
AGLAVERR 10
MACRZONA 284
EPITGREE 172
ANCIHART 28
POLYGORD 422
LUMBACIC 274
CABIINCE 83
SCALINFL 466
NEMERTIN 326
LISTSMIT 271
THALASSI 526
ANACOBES 24
CAECREGU 85
MELANELL 296
SPHAACIC 483
CAECSPEA 86
TURRSPEA 540
GASTSPEA 200
PENTPULC 385
PIONSPEA 400
BOONSEMI 73
HARPSANG 292
COROSEXT 127
LEMBWEBS 251
POLYGIAR 420
HEXAANGU 224
CAPITELL 93
OVALOCEL 357
LAEVMORT 245
UPOGAFFI 546
LEPICOMM 252
THARSPA 528
CERIAMER 102
PHERAFFI 388
LEVIGRAC 262
NEPHINCI 330
SIGATENT 477
NUCUANNU 339
YOLDLIMA 551
FARGGIBB 193
ACTECAMA 5
LISTCLYM 270
LOIMMEDU 273
SACCKOWA 464
PARAPINN 379
PSEUPAUC 450
ODOSNNGO 342
PARVMULT 383
PHORONIS 390
ALIGELEV 11
NASSVIBE 321
PODALEVI 412
ALPHHETE 13
GITANOPS 202
PARALITE 378
CRATPILA 133
HARGRAPA 213
ARABIRMU 37
LEPTVARI 256
ARICFRAG 43
OGYRALPH 346
AMASCAPE 14
ENSIDIRE 170
GLYCDIBR 204


ANADTRAN 26
EUCEPRAE 181
GAMMSUTH 199
BHAWHETE 63
NEPHCRYP 329
PRIOPERK 432
MALMSPA 286
NEREGRAY 332
CIRRGRAN 111
PHOTPUGN 393
PERIMARG 386
CHAEVARI 104
PISTCRIS 404
GYPTVITT 210
SIGABASS 476
POLYGIBB 421
CERAIRRI 99
TURBINTE 538
LISTBARN 269
NOTOSPA 337
ASABOCUL 46
MEDIAMBI 293
EDOTTRIL 164
COSSSOYE 130
MEDICALI 294
MULILATE 311
NOTOLOBA 335
GLYCSOLI 206
SAYECHES 465
LEUCAMER 261
AMNILIMO 15
QUISMULT 454
DICRNERV 149
TANYTARS 522
FERRISSI 194
GAMMDAIB 196
ENCHYTRA 167
LIMNHOFF 267
TUBIFIWI 534
LIMNUDEK 268
NANOCLAD 319
VALVSINC 548
RHEOTANY 457
CHIRALMY 106
POLYTRIP 429
ANODONTA 31
GLYPTOTE 207
BRACHYCE 74
ENDOCHIR 168
HYDROPTI 230
PHYSELLA 398
DICROTEN 150
GONIVIRG 209
CAENIS 88
OECETIS 345
STICTOCH 507
ARCTLOMO 40
BITHTENT 64
CORBFLUM 120
TRICORYT 531
DEMICRYP 143
SPHAEROM 485
LAEVFUSC 244
HEXAGENI 225
LIMNCLAP 266
BRATUNID 79
ELLICOMP 166
PIGUMICH 399
SPECJOSI 482
AXARUS 59
CHAETOGA 103
GAMMFASC 197
CYRNFRAT 142
PLEUROCE 410
AULOLIMN 53
AULOPIGU 55
PROCHOLO 436
DUBIRAPH 161
BRANSOWE 77
DERODIGI 145
CHIRONOM 108
CINCWINK 110
MUSCTRAN 312
PISIDIUM 402
STENELMI 496
PARACLAD 370
STYLLACU 512
AULOPAUC 54
CHAOPUNC 105
PROBEZZI 434
COELOTAN 117
TANYPUS 521
NAISPSEU 317
AULOPLUR 56
ISOCFREY 238
HARNISCH 217
ILYOTEMP 236
LIMNCERV 265
CLADOPLE 114
LYOGYRUS 277
VALVTRIC 549
TUBIFIWO 535
PROCSUBL 437
STEPTRIV 502


BEZZIA 62
CLADOTAN 115
PALPOMYI 364
HABESPEC 211
[illegible] 290
[illegible] 67
CYATPOLI 137
RHITHARR 460
COROLACU 126
HOBSFLOR 228
[illegible] 308
[illegible] 259
LITTTENU 272
MANAAEST 288
LAEOCULV 243
LEITFRAG 248
LEPIDYTI 253
CASSOVAL 95
[illegible] 281
[illegible] 456
TUBIBETE 536
CYCLVARI 139
TAGEPLEB 517
[illegible] 201
[illegible] 282
[illegible] 223
HYDRTRUN 231
NAME ID NO
0.97
0.84
0.68
0.52
0.37
0.21
0.05
Pearson's r