

**MARINE WETLAND BOUNDARY DEFINITION:
EVALUATION OF METHODOLOGY**

by

**H. Peter Eilers
Alan Taylor
William Sanville**

**ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CORVALLIS, OREGON 97333**

June 1981

**MARILYN POTTS GUIN LIBRARY
HATFIELD MARINE SCIENCE CENTER
OREGON STATE UNIVERSITY
NEWPORT, OREGON 97365**

**MARINE WETLAND BOUNDARY DEFINITION:
EVALUATION OF METHODOLOGY**

**H. Peter Eilers
Alan Taylor
William Sanville**

**CERL - 054
June 1981**

ABSTRACT

With legislation to protect wetlands and current pressures to convert them to other uses, it is often necessary to accurately determine a wetland-upland boundary. We investigated 6 methods to establish such a boundary based on vegetation. Each method was applied to a common data set obtained from 295 quadrats along 22 transects between marsh and upland in 13 Oregon and Washington intertidal wetlands. The multiple occurrence, joint occurrence, and five percent methods required plant species to be classified as wetland, upland, and non-indicator; cluster and similarity methods required no initial classification. Close agreement between wetland-upland boundaries determined by the 6 methods suggests that preclassification of plants and collection of plant cover data may not be necessary to arrive at a defensible boundary determination. Examples of each method and lists of indicator plant species for coastal California, Oregon, and Washington are provided.

TABLE OF CONTENTS

Abstract.	
Figures	
Tables.	
Acknowledgements.	
Introduction.	
Methods for Boundary Determination.	
Indicator Species.	
Five Percent	
Joint Occurrence	
Multiple Occurrence.	
Cluster.	
Similarity ISJ and ISE	
Lists of Indicator Species.	
Comparison of Methods	
Discussion and Recommendations.	
Literature Cited.	
Appendices	
A. Examples of vegetation methods to determine wetland boundaries. .	
B. Salt marsh, non-indicator, and upland plant species of California, Oregon, and Washington.	
C. Upper limit of marsh and lower limit of transition zone determined by 6 methods applied to 22 transects	
D. Sample field data sheet	
E. Computer software available at the U.S. Environmental Protection Agency, Corvallis, Oregon	

FIGURES

- Figure 1. Flow diagram to facilitate choice of vegetation method to determine upper limit of wetland

TABLES

- Table 1. Lower transition zone limit (LTZ) and upper limit of marsh (ULM) as determined by 6 methods applied to 22 transects from Frenkel et al. (1978). Limits expressed as distance (M) along transect where distance increases from marsh to upland.

ACKNOWLEDGEMENTS

The refinement of indicator species lists was possible through the effort of numerous scholars: Michael G. Barbour, University of California, Davis; Lawrence C. Bliss, University of Washington; Kenton L. Chambers, Oregon State University; Wayne R. Ferren, University of California, Santa Barbara; Keith Macdonald, Woodward-Clyde Consultants; Robert Ornduff, University of California, Berkeley; David H. Wagner, University of Oregon; and Joy Zedler, San Diego State University. We greatly appreciate their time and effort.

We also thank Theodore Boss for comments and criticism, and Jo Oshiro for help with computer graphics.

INTRODUCTION

Two decades of intensive research following the suggestions of Odum (1961) and the work of Teal (1962) have firmly established values attributed to undisturbed coastal salt marshes. These intertidal wetlands were noted for high macrophyte production and for export of energy-rich organic detritus and dissolved organic carbon to estuarine waters. They serve as juvenile fish and wildlife habitat, as buffer to erosion of sediment, and have potential for water purification.

Accompanying the increase in awareness of salt marsh values and potentials, however, has been the rapid conversion of coastal marsh to urban, suburban, and agricultural uses through diking, filling, and construction activities (Darnell 1976). Recent federal legislation is designed to retard this rapid conversion and thereby protect what now remains of the nation's wetland resources. Most notable are the Federal Water Pollution Control Act Amendments of 1972 and 1977 (Water Act) which, in Section 404 provide for a permit review process to regulate dredge and fill projects.

To fully implement Section 404 requires that those involved in the review process be equipped to: (1) identify wetland; and (2) determine boundaries, especially that between the marsh and upland. Yet, while the identification of wetlands may be accomplished by noting the presence of standing water and plants adapted to growth in saturated soil conditions, the determination of the upper limit of wetland is difficult. Instead of exhibiting a sharp break, the characteristics of wetland are more likely to gradually shift to those of upland along a transition. In salt marsh, the influence of the tide gradually

diminishes with increasing surface elevation, soils become better drained, and vegetation gradually changes to that of non-wetland. An ecotone with inter-digitation of marsh and upland plant species occurs between the two systems.

To better understand the nature of the marsh-upland ecotone and to develop methodologies to delineate a defensible intertidal marsh boundary, the U.S. Environmental Protection Agency in conjunction with the U.S. Army Corps of Engineers began a major research effort in 1976. Following the completion of two pilot projects (Frenkel and Eilers 1976, Jefferson 1976), five groups were funded to investigate transition zones and upper limits. Individually they covered salt marshes along the coasts of California (Harvey et al. 1978); Oregon and Washington (Frenkel et al. 1978); Alaska (Batten et al. 1978); Delaware, Maryland, Virginia, and North Carolina (Boon et al. 1978); and freshwater marsh along the shores of the Lake Superior, Lake Michigan, and Lake Huron (Jefferson 1978). The reports provide an excellent floristic description of marsh-upland ecotones and they identify major approaches to boundary determination based on vegetation.

The purpose of this report is to: (1) evaluate the methods applied by these researchers; (2) present alternative methods; (3) recommend the best approach to wetland boundary delineation based on vegetation; and (4) provide appropriate plant lists and computer software to apply methodology to Pacific Coast intertidal marshes. We consider the methods presented as applicable to wetland-upland boundary determination in general, not to marine wetlands alone. We acknowledge, however, that vegetation should not be the only criteria considered. The best approach will incorporate vegetation, soils, and hydrology. The methods provided here are a first approximation. As our knowledge of physical factors across the wetland-upland ecotone is increased,

methods will be enlarged and refined. At the moment we must rely primarily on a vegetation approach.

METHODS FOR BOUNDARY DETERMINATION

Methods to determine wetland boundaries presented by these researchers listed above vary from those with an emphasis on indicator species and little quantitative data to those requiring classification of all plant species recorded and intensive quantitative treatment. We will consider the less quantitative approach favored by Batten et al. (1978) and Jefferson (1978), then the more quantitative methods of other researchers. To this we will add other quantitative approaches.

Indicator Species

Batten et al. (1978) investigated Alaskan coastal salt marshes and collected information on plant species percent cover from quadrats located along the elevation gradient between marsh and upland. Based on their data and knowledge of plant species habitat preference, they developed lists of indicator species that signal the shift from salt marsh to terrestrial upland or freshwater marsh. The lower limit of the transition zone (LTZ) was established at a point where species abundant in upland or freshwater wetland first become "abundant" in the marsh and the upper limit of marsh (ULM) was reached when all the species characteristic of the vegetation type bordering the marsh are present in "appropriate amounts." No definition of "abundant" or "appropriate amounts" is given and thus the placement of a boundary in the field following this approach would be highly subjective and ill-suited to cases involving close legal scrutiny.

Jefferson (1978) likewise developed indicator plant species lists from the study of freshwater marshes along the shores of the Great Lakes. Her treatment of the marsh-upland ecotone is exhaustive, yet little attention is given to boundary delineation. She states that "by using the community descriptions and lists of dominant, prevalent, and differential species, detection of the ecotone and its limits should be facilitated." As with Batten et al. (1978), this approach requires much subjective judgment and may be expected to yield only an approximate boundary determination.

Five Percent

The initial approach of Boon et al. (1978) and Harvey et al. (1978) was similar to those above but carried further. Following acquisition of plant cover estimates from transects along the transition from marsh to upland, a "five percent" method was utilized such that the upper limit of the transition zone was defined as the point "at which the amount of ground coverage by upland plants is at least five percent and is contiguous with the upland proper" (Boon et al. (1978). The lower transition limit is defined similarly with coverage of upland plants less than five percent. Both research groups classified plant species as to marsh, transition, upland (Boon et al. 1978); or marsh, upland, non-indicator (Harvey et al. 1978) and present results graphically. Harvey et al. (1978) applied the following procedures: (1) when a five percent cover value of the appropriate cover type, either marsh or upland, occurred in a quadrat and no trace occurred in the adjacent, more distal quadrat, the quadrat with five percent cover was marked as the transition; (2) if the adjacent quadrat distal to the five percent cover plot had a trace of the vegetation type in question, the adjacent quadrat was marked as the transition limit; (3) if two plots in sequence had a trace of either type

vegetation, the more distal quadrat was marked as the limit; (4) if the five percent cover level fell between two quadrats, the limit was located by interpolation; (5) if no overlap of upland and marsh species occurred either due to bare ground and/or cover by non-indicator species, a point midway between quadrats in which each type was represented was chosen. Appendices A and C contain examples of this and other methods described.

Joint Occurrence

After applying the five percent method, Harvey et al. (1978) sought a "quicker, easier, but equally accurate approach." Their choice was a modification of Fager's (1957) measure of joint occurrence which takes the form

$$I_{MU} = \frac{2J}{nM + nU}$$

where, for any single quadrat, J is the number of joint occurrences of marsh and upland species, nM is the number of marsh species, and nU is the number of upland species. Non-indicator species are disregarded.

Plotting I_{MU} for quadrats along a transect shows a series of zeros for pure wetland followed by a rise to a peak in the transition and a fall to zero again in pure upland. In practice, however, Harvey et al. (1978) found it difficult to interpret such a graph when natural or man-made "patchiness" was present. This problem was largely eliminated by computing and plotting a standardized cumulative index (SCI) for each quadrat

$$SCI_i = \frac{I_{MU}}{\sum_{i=1}^n \frac{I_{MU_i}}{n}} \text{ and } SCI_n = 1.0$$

where \underline{n} is the total number of quadrats. After plotting index values, Harvey et al. (1978) identified the lower and upper limits of the transition as 0.5 m above the rise of the data line from the abscissa and 0.5 m above $SCI = 1.0$, respectively (given 1 m distance between sample quadrats or one-half the distance between quadrats if greater than 1 m). Close agreement between the SCI and the five percent method transition boundaries was observed.

Multiple Occurrence

Frenkel et al. (1978) applied an expanded plant classification with four categories--low marsh, high marsh, non-indicator, and upland--and computed a score for quadrat data collected along transects between marsh and upland. The "multiple occurrence method" (MOM) score (M) required the assignment of a weighting coefficient:

<u>Species Type</u>	<u>Weighting Coefficient</u>
Low marsh	2
High marsh	1
Upland	-2
Non-Indicator	0

The quadrat score was calculated as

$$M = \sum_{i=1}^n W_i C_i,$$

where \underline{W}_i is the weighting coefficient for species, \underline{i} , \underline{C}_i is cover value for species \underline{i} , and \underline{n} is total number of species in the quadrat sample. Cover values were after the classes of Daubenmire (1959): 0-5% = 1, 5-25% = 2, 25-50% = 3, 50-75% = 4, 75-95% = 5, 95-100% = 6. Species present but with negligible cover were disregarded.

Positive M values were interpreted as marsh, the upper limit of marsh was defined as $M = 0$, and $M < 0$ denoted upland. However, further interpretation was necessary because M values did not always descend to a single $M = 0$ and thereafter remain negative. Two additional cases were noted. One contained more than one $M = 0$ in succession, and the other with M scores alternating above and below zero. In both cases, the portion of the transect between first and last $M = 0$ were considered as the transition zone and the upper limit of marsh was placed midway through this zone. In our interpretation of this method we have assigned the upper limit of the transition zone as the ULM, a shift agreed to by Frenkel (personal communication).

Cluster

We reasoned that if marsh and upland are floristically different, cluster analysis (Boesch 1977) of data collected from quadrats along transects between the two systems might be used to identify wetland limits. Such an approach would have the advantage of not requiring preclassification of plant species into "marsh," "upland," "non-indicator," and would provide a more objective instrument. We chose the Bray-Curtis dissimilarity measure (Clifford and Stephenson, 1975),

$$D_{jk} = \frac{\sum_{i=1}^n x_{ij} - x_{ik}}{\sum_{i=1}^n (x_{ij} + x_{ik})},$$

where x is cover value for species i in quadrats j and k , and n is the total number of species. A "flexible" fusion strategy with Beta = -0.25 (Boesch, 1977) was utilized. The end product is a dendrogram showing quadrat clusters

which form at decreasing levels of dissimilarity. We identified the upland cluster as that containing the highest numbered quadrats (when quadrats were numbered from wetland to upland). The upper limit of marsh was interpreted as being half the distance (on the transect) between the lowest numbered member of the upland cluster and the next lowest group of quadrats.

Similarity ISJ and ISE

By computing the similarity in species content of adjacent quadrat samples along a transect and graphing these values, we expected to observe a decrease in similarity at the marsh-upland border. In this case, we chose two measures. One was Jaccard's index (Mueller-Dombois and Ellenburg, 1974) which requires binary data (presence-absence):

$$ISJ = \frac{c}{a + b + c} \times 100,$$

where c is the number of species common to two quadrats, a is the number of species unique to the first quadrat, and b is the number of species unique to the second quadrat. The other was Ellenberg's (1956 in Mueller-Dombois and Ellenberg, 1974) modification of Jaccard's index which accepts species quantities:

$$ISE = \frac{Mc:2}{Ma + Mb + Mc:2} \times 100.$$

Here, Mc is the sum of cover values of species common to both quadrats, Ma is the sum of the cover values of the species restricted to the first quadrat, and Mb is the corresponding sum for species restricted to a second quadrat. Species noted as present but with negligible cover were assigned a value of 0.25.

LISTS OF INDICATOR SPECIES

Lists of indicator species for California, Oregon, and Washington coastal marshes are found in Appendix B. They represent a consensus of EPA researchers and local authorities. We sent tentative plant lists to recognized authorities in botany and wetland ecology for review (see Acknowledgements) and made numerous adjustments. The lists are still evolving, but they provide a good approximation in present form. In addition, the U.S. Fish and Wildlife Service is now compiling nationwide lists of wetland plant species through the National Wetlands Inventory program.

COMPARISON OF METHODS

To compare the results obtained by the quantitative methods presented above (excluding the indicator species method), we applied each to a common data set. We chose 22 transects (12%) at random from the 190 sampled by Frenkel et al. (1978). The data were collected from 50 x 50 cm quadrats. Transects were located with the foot well into wetland, the head well into upland, and the orientation parallel to the elevation gradient. Plant species in each quadrat were recorded as to cover class (Daubenmire 1959) except that those with negligible cover were assigned "present" status only. As we calculated LTZ and ULM by each method, we kept careful note of time involved and ease of application. We concentrated our efforts on comparison of ULM identification because of its direct relationship to jurisdictional questions. We considered the ULM to be synonymous with the upper limit of the transition zone and thus the true limit of wetland.

Table 1 and Appendix C reveal close agreement in LTZ and ULM positions obtained by the six methods. ULM location agreed within 1.0 m on 9 transects (45%) and within 2.5 m on 13 transects (65%). ULM for two transects (0808 and

1606) was not identified by all methods, suggesting that the transects did not extend far enough to include marsh and upland quadrats. The range of ULM estimates was greatest for transect 1703 (25.5 m), but cluster and similarity plots for this transect show discontinuities at positions in agreement with other methods that could be interpreted as ULM. In general, methods with species classification built in (five percent, joint occurrence, and multiple occurrence) exhibit low intragroup variability, as do those without species classification.

All methods, with the exception of cluster, involve simple calculations that can be done by hand. Cluster requires a computer. We found little time difference involved in applying each method given basic field data and plant classifications, so that the choice of method should be attuned to time available for field work and the availability of a valid list of indicator species.

Perhaps the most important result of this comparative treatment is that use of species presence-absence yields ULM positions identical or nearly identical to those requiring species percent cover. Thus, the extended field effort required to obtain plant cover is not necessary and the greatest return for time spent might be expected from utilizing species occurrence only.

DISCUSSION AND RECOMMENDATIONS

The above methods fall into two basic groups. The first comprises five percent, joint occurrence, and multiple occurrence and is characterized by reliance on pre-established lists of wetland and upland indicator species. A consensus of ecological thought as it pertains to plant species is built into these methods. The field researcher must have botanical expertise but, theoretically, a valid ULM determination could be made without in-depth knowledge

of wetland ecology. We caution, however, that results from all methods reviewed must remain valid under evaluation by wetland specialists.

The second group--cluster, similarity ISJ and similarity ISE--does not require preclassification of plant species. Instead, it is assumed that species are distributed along transects in such a way as to form groups characteristic of wetland, transition, and upland, and that these groups can be identified objectively. We have demonstrated that this is a viable approach and that results are comparable to those obtained by preclassification methods. We consider cluster and similarity methods to be very sophisticated and caution should be given to inexperienced users. Transect 1703 (Table 1, Appendix C) provides an illustration of this point. A ULM of 31.5 m is suggested by strict adherence to procedure, but it is likely that a position closer to 7.0 m as indicated by five percent, joint occurrence, and multiple occurrence would have been the selected ULM given on-site review by trained personnel. All six methods should be viewed as tools with strong indicator value and whether classification of plant species is involved or not, the final boundary placement should involve the judgment of trained personnel.

We recommend the general vegetation approach to wetland boundary identification outlined in Figure 1. If classification of plants is available, the joint occurrence method is the best approach because it reduces field time and yields results close to the five percent and multiple occurrence methods. If accepted plant classifications are unavailable, as is the present case for most freshwater wetlands, the cluster method or similarity ISJ applied to presence-absence data provide defensible boundaries and have the added advantage of helping to establish a classification. Cluster and similarity methods are very sensitive to zonal vegetation patterns but, as stated above, it is the task of trained personnel to interpret results to obtain the ULM.

If the requisite information to apply the joint occurrence method is available, it is still advisable to employ either cluster or similarity ISJ or both to support the initial decision.

Even though a vegetation approach to ULM determination is likely to be satisfactory, because plant distributions reflect environmental conditions, our present knowledge of physical factors, such as soils and hydrological regimes, across the transition is very limited. We assume that certain plants indicate physical conditions of wetland, transition, and upland, but we do not know tolerance limits for species so classified. Research underway at the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers is designed to provide a more holistic treatment of the wetland boundary problem. Physical factors between wetland and upland are being intensively monitored at numerous wetland sites; greenhouse studies are testing species tolerance to various field conditions, such as inundation and soil saturation, and methods are being devised which incorporate both vegetation and physical factors to identify wetland limits. In the near future, our ability to establish boundaries will be enhanced beyond the tenuous reliance on vegetation indicators alone.

LITERATURE CITED

- Batten, A. R., S. Murphy, and D. F. Murray. 1978. Definition of Alaskan wetlands by floristic criteria. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Boesch, D. F. 1977. Application of numerical classification in ecological investigations of water pollution. Special Scientific Report No. 77, Virginia Institute of Marine Science.
- Boon, J. D., D. M. Ware, and G. M. Silberhorn. 1978. Survey of vegetation and elevational relationships within coastal marsh transition zones in the central Atlantic coastal region. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Clifford, H. T. and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York.
- Darnell, R. M. 1976. Impacts of construction activities in wetlands of the United States. U.S. EPA, Corvallis, Oregon. Publ. No. EPA-600/3-76-045.
- Daubenmire, R. F. 1959. Canopy coverage method of vegetation analysis. Northwest Sci. 33:43-64.
- Fager, E. W. 1957. Determination and analysis of recurrent groups. Ecology 38:586-595.
- Frenkel, R. E. and H. P. Eilers. 1976. Tidal datums and characteristics of the upper limits of coastal marshes in selected Oregon estuaries. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.

- Frenkel, R. E., T. Boss, and S. R. Schuller. 1978. Transition zone vegetation between intertidal marsh and upland in Oregon and Washington. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Harvey, H. T., M. J. Kutilek and K. M. DiVittorio. 1978. Determination of transition zone limits in coastal California wetlands. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Hitchcock, A. S. 1950. Manual of the grasses of the United States. U.S. Department of Agriculture Misc. Publ. No. 200.
- Hitchcock, C. L. and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle.
- Jefferson, C. A. 1976. Relationship of vegetation and elevation at upper and lower limits of the transition zone between wetland and upland in Oregon's estuaries. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Jefferson, C. A. 1978. Vegetative delineation of the upper limit of coastal wetlands of the upper Great Lakes. Report to the U.S. Environmental Protection Agency, Corvallis, Oregon.
- Munz, P. A. and D. D. Keck. 1963. A California flora with supplement, 1968. University of California Press, Berkeley.
- Odum, E. P. 1961. The role of tidal marshes in estuarine production. The Conservationist 15:12-13.
- Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

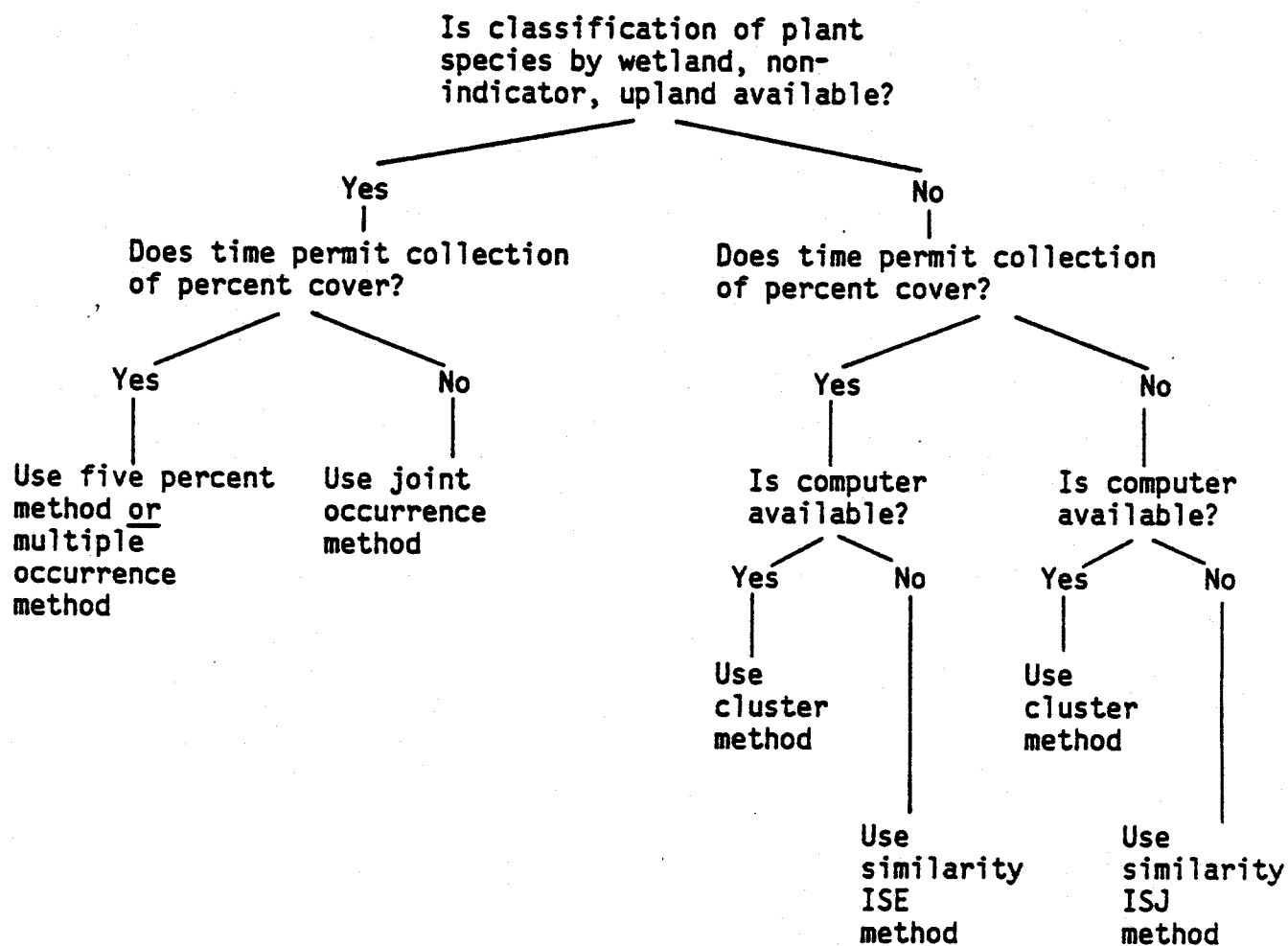


Figure 1. Flow diagram to facilitate choice of vegetation method to determine upper limit of wetland.

Table 1. Lower transition zone limit (LTZ) and upper limit of marsh (ULM) as determined by 6 methods applied to 22 transects from Frenkel *et al.* (1978). Limits expressed as distance (m) along transect where distance increases from marsh to upland.

Transect Number	Location	Five Percent		Joint Occurrence		Multiple Occurrence		Cluster		Similarity ISJ		Similarity ISE		ULM Mean	ULM S.D.	ULM Range
		LTZ	ULM	LTZ	ULM	LTZ	ULM	LTZ	ULM	LTZ	ULM	LTZ	ULM			
OREGON																
0105	Coquille Estuary	11.0	14.5	9.0	14.5	11.5	13.0	9.0	14.5	11.5	15.5	12.5	14.5	14.4	0.8	2.5
0208	Coos Bay	16.5	19.5	16.5	21.5	---	21.0	---	19.5	---	21.5	---	21.5	20.8	1.0	2.0
0301	Alsea Bay	9.0	15.5	---	15.5	10.0	15.0	9.0	15.5	9.0	15.5	9.0	15.5	15.4	0.2	0.5
0310	Alsea Bay	---	13.0	---	13.5	10.0	12.0	9.0	13.5	7.0	13.5	9.0	13.5	13.2	0.6	1.5
0402	Yaquina Bay	---	19.5	---	19.5	---	18.5	13.5	19.5	13.5	19.5	13.5	19.5	19.3	0.4	1.0
0407	Yaquina Bay	4.5	19.5	4.5	19.5	7.5	19.5	1.5	19.5	10.5	19.5	10.5	19.5	19.5	0.0	0.0
0704	Nehalem Bay	1.0	11.0	1.0	11.5	---	8.0	7.0	15.5	---	9.0	---	9.0	10.7	2.7	7.5
0706	Nehalem Bay	10.5	13.0	10.5	13.5	10.5	11.1	10.5	15.5	7.0	16.5	12.5	16.5	14.4	2.2	5.4
0710	Nehalem Bay	---	16.0	---	15.5	---	15.0	---	15.5	---	15.5	---	15.5	15.5	0.3	1.0
WASHINGTON																
0804	Willapa Bay	14.5	15.5	14.5	16.5	11.0	15.0	9.0	15.5	9.0	15.5	9.0	15.5	15.6	0.5	1.5
0808	Willapa Bay	---	---	---	---	8.0	---	5.0	15.5	---	---	---	---	---	---	---
0809	Willapa Bay	15.0	22.5	---	22.5	15.0	22.0	19.0	22.5	20.5	22.5	19.0	22.5	22.4	0.2	0.5
0910	Willapa Bay	84.5	87.5	---	87.5	63.5	87.5	---	87.5	65.0	87.5	65.0	87.5	87.5	0.0	0.0
1001	Willapa Bay	256.0	265.0	---	265.0	248.0	259.0	---	259.0	---	249.0	---	249.0	257.7	7.2	16.0
1103	Grays Harbor	105.5	146.0	105.5	147.5	117.5	129.5	117.5	147.5	117.5	147.5	98.0	147.5	144.3	7.3	18.0
1201	Grays Harbor	18.5	19.5	---	19.5	---	19.0	17.0	19.5	17.0	19.5	17.0	19.5	19.4	0.2	0.5
1606	Thorndyke Bay	---	---	---	---	---	---	---	---	---	10.5	---	10.5	---	---	---
1610	Thorndyke Bay	---	6.0	3.5	7.5	---	3.0	---	10.5	---	10.5	---	10.5	8.0	3.1	7.5
1611	Thorndyke Bay	9.0	12.5	---	12.5	6.0	12.0	---	10.5	4.5	10.5	4.5	10.5	11.4	1.0	2.0
1612	Thorndyke Bay	---	21.5	---	21.5	1.0	20.0	12.0	23.5	---	12.0	12.0	23.5	20.3	4.3	11.5
1703	Snohomish Estuary	---	7.5	---	7.5	---	6.0	---	31.5	---	31.5	---	31.5	19.3	13.4	25.5
1802	Oak Bay	---	26.0	---	25.5	---	25.5	---	25.5	10.5	25.5	19.5	25.5	25.6	0.2	0.5

APPENDIX A

Examples of Vegetation Methods to Determine Wetland Boundaries

FIVE PERCENT

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plants occurring in quadrats and assign percent cover (nearest 5%) to each species in each quadrat



Classify plants recorded as to

- *Marsh species
- *Non-indicator
- *Upland species



Compute total percent cover of marsh species and upland species in each quadrat



Plot totals for marsh and upland species against distance along transect (in bar graph form)



Locate LTZ and ULM**

- *LTZ is point at which upland species = 5%
- *ULM is point at which wetland species = 5%

**See text for rules.

CALCULATION FOR QUADRAT 5:

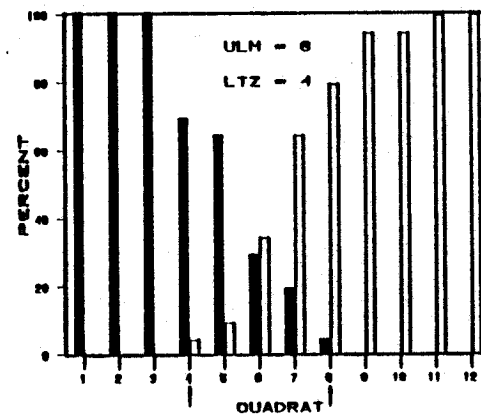
Species	%Cover	Classification
A	30	marsh
B	15	non-indicator
C	20	marsh
D	5	marsh
E	10	non-indicator
F	10	marsh
G	10	upland

marsh % cover = 65

upland % cover = 10

TRANSECT SUMMARY:

Quadrat	%Marsh	%Upland
1	100	0
2	100	0
3	100	0
4	70	5
5	65	10
6	30	35
7	20	65
8	5	80
9	0	95
10	0	95
11	0	100
12	0	100



JOINT OCCURRENCE

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plants occurring in quadrats



Classification of plants recorded as to

- *Marsh species
- *Non-indicator
- *Upland species



Compute joint occurrence score for each quadrat



Compute Standardized Cumulative Index for quadrats



Plot Standardized Cumulative Index against distance along transect



Locate LTZ and ULM

- *LTZ is one half quadrat interval on transect above (toward upland) quadrat where SCI initially > 0
- *ULM is one half quadrat interval on transect above (toward upland) quadrat where SCI initially = 1.00

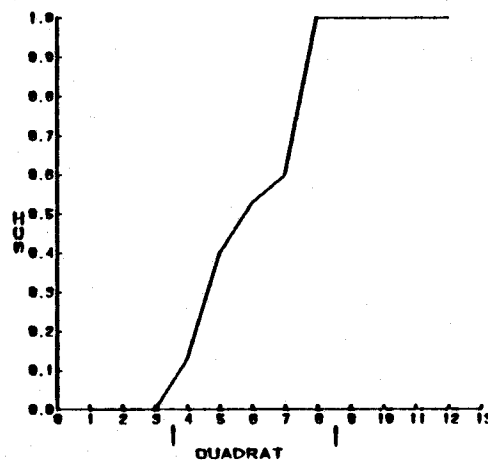
CALCULATION FOR QUADRAT 5:

Species	Classification
A	marsh
B	non-indicator
C	marsh
D	marsh
E	non-indicator
F	marsh
G	upland

$$I_{MU} = \frac{2J}{nM + nU} = \frac{2}{5} = .40$$

TRANSECT SUMMARY:

Quadrat	I _{MU}	SI	SCI
1	0	0	0
2	0	0	0
3	0	0	0
4	.20	.13	.13
5	.40	.27	.40
6	.20	.13	.53
7	.10	.07	.60
8	.60	.40	1.00
9	0	0	1.00
10	0	0	1.00
11	0	0	1.00
12	0	0	1.00



MULTIPLE OCCURRENCE

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plants occurring in quadrats and assign cover class value to each species in each quadrat



Classify plants recorded as to

- *Marsh species
- *Non-indicator
- *Upland species



Compute M score for each quadrat



Plot M score against distance along transect



Locate LTZ and ULM

- *LTZ is first M = 0 (if > 1 M = 0) on transect from wetland to upland
- *ULM is last or only M = 0 on transect from wetland to upland

CALCULATION FOR QUADRAT 5:

Species	Cover Class**	Classification	Weight
A	3	marsh (low)***	2
B	2	non-indicator	0
C	2	marsh (low)	2
D	1	marsh (low)	2
E	2	non-indicator	0
F	2	marsh (high)	1
G	2	upland	-2

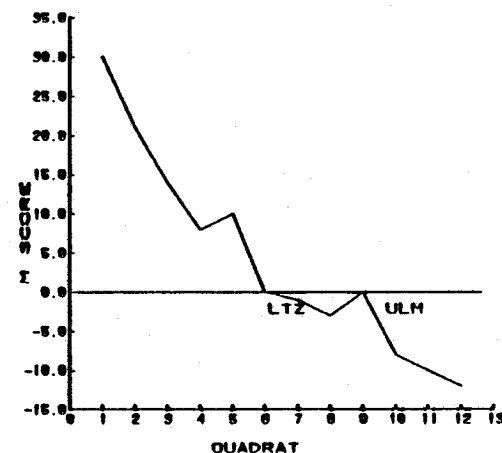
$$M = \sum_{i=1}^n W_i C_i$$

$$= (3 \times 2) + (2 \times 0) + (2 \times 2) + (1 \times 2) + (2 \times 0) + (2 \times 1) + (2 \times (-2))$$

$$= 10$$

TRANSECT SUMMARY:

Quadrat	M
1	30
2	21
3	14
4	8
5	10
6	0
7	-1
8	-3
9	0
10	-8
11	-10
12	-12



** Frenkel et al (1978) used cover class, but we recommend using percent cover rather than class.

***We recommend assignment of a weight of 2 to all plants classified as marsh.

CLUSTER

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plants occurring in quadrats and assign percent cover (nearest 5%) to each species in each quadrat**

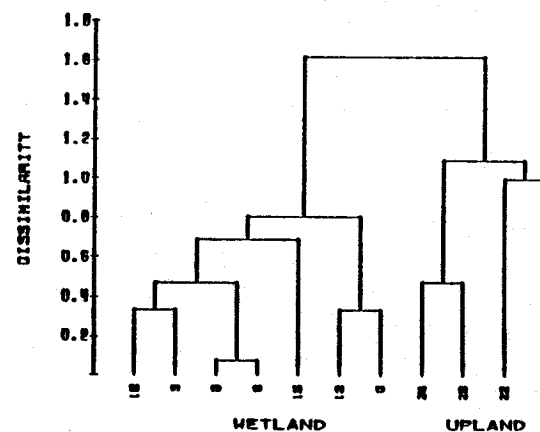


Create computer data file for each transect and run program Cluster***



Locate LTZ and ULM

- *LTZ is break between marsh and transition clusters
- *ULM is break between transition and upland cluster



** Collection of cover is optional

***Available at EPA Corvallis

SIMILARITY ISJ

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plant species occurring in each quadrat



Compute similarity coefficient ISJ for all adjacent quadrat pairs along transect



Plot similarity values against distance along transect (values located at mid-point between quadrats)



Locate LTZ and ULM

- *LTZ is point of low similarity on transect below ULM
- *ULM is point of low similarity on transect closest to upland

CLASSIFICATION FOR QUADRATS 5 AND 6:

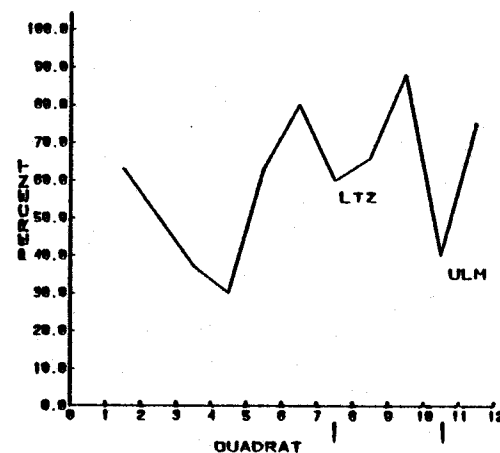
Species	Quadrat 5	Quadrat 6
A	x	x
B	x	x
C	x	x
D	x	x
E	x	x
F	x	x
G	x	
H	x	x
I	x	
J		x
K	x	

TRANSECT SUMMARY:

Quadrats	ISJ
1 & 2	63
2 & 3	50
3 & 4	37
4 & 5	30
5 & 6	63
6 & 7	80
7 & 8	60
8 & 9	66
9 & 10	88
10 & 11	40
11 & 12	75

$$ISJ = \frac{c}{a+b+c} \times 100 = \frac{7}{3+1+7} \times 100$$

$$= \frac{7}{11} \times 100 = 63$$



SIMILARITY ISE

Field data collection

- *Quadrats at regular intervals (i.e., 1 m) along transects between marsh and upland
- *Record all plant species occurring in quadrats and assign percent cover (nearest 5%) to each species in each quadrat



Compute similarity coefficient ISE for all adjacent quadrat pairs along transect



Plot similarity values against distance along transect (values located at mid-point between quadrats)



Locate LTZ and ULM

- *LTZ is point of low similarity on transect below ULM
- *ULM is point of low similarity on transect closest to upland

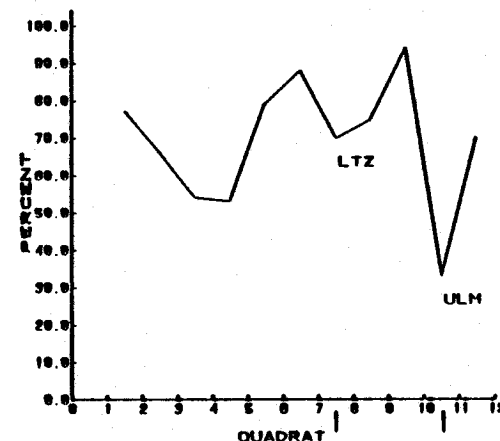
CALCULATION FOR QUADRATS 5 AND 6:

Species	Quadrat 5	Quadrat 6
A	.25	5.00
B	5.00	5.00
C	35.00	35.00
D	5.00	.25
E	5.00	.25
F	35.00	15.00
G	5.00	
H	5.00	15.00
I	15.00	
J		.25
K	5.00	
	115.25	75.75

$$\begin{aligned}
 ISE &= \frac{Mc:2}{Ma+Mb+Mc:2} \times 100 \\
 &= \frac{191:2}{25+.25+191:2} \times 100 \\
 &= \frac{95.5}{120.75} \times 100 = 79
 \end{aligned}$$

TRANSECT SUMMARY:

Quadrats	ISE
1 & 2	77
2 & 3	66
3 & 4	54
4 & 5	53
5 & 6	79
6 & 7	88
7 & 8	70
8 & 9	75
9 & 10	94
10 & 11	33
11 & 12	40



APPENDIX B

Salt Marsh, Non-Indicator, and Upland Plant Species of California, Oregon, and Washington

Plant species contained in this appendix are categorized as follows: intertidal--plants which are adapted to growth in saturated soils and have a high fidelity with intertidal marsh habitat; non-indicator--plants with broad habitat affinities, which can be found in intertidal marshes but are not restricted to them; upland--plants rarely found in intertidal marshes. It should be noted that the upland plant list contains only the most commonly occurring species adjacent to wetlands.

California

Intertidal Marsh Plants

Plant Species ¹	Plant Species
<u>Atriplex patula</u>	<u>Orthocarpus castillejoides</u> v. <u>humboldtiensis</u>
<u>Batis maritima</u>	<u>Plantago maritima</u>
<u>Carex obnupta</u> *	<u>Potentilla egedei</u> *
<u>Cordylanthus maritimus</u> ***	<u>Salicornia virginica</u>
<u>Cuscuta salina</u>	<u>Scirpus americanus</u> *
<u>Distichlis spicata</u> **	<u>Scirpus californica</u> *
<u>Epilobium watsonii</u> *	<u>Scirpus koilolepis</u> *
<u>Frankenia grandifolia</u>	<u>Scirpus robustus</u> *
<u>Grindelia maritima</u>	<u>Spartina foliosa</u>
<u>Grindelia stricta</u>	<u>Spartina spartinae</u> ²
<u>Jaumea carnosa</u>	<u>Spergularia canadensis</u>
<u>Juncus acutus</u> *	<u>Spergularia macrotheca</u>
<u>Juncus balticus</u> *	<u>Suaeda californica</u>
<u>Limonium californicum</u>	<u>Triglochin concinnum</u>
<u>Monanthochloe littoralis</u>	<u>Triglochin maritima</u>

¹ Nomenclature follows Munz and Keck (1963 with supplement 1968).

² Hitchcock (1950).

* Also found in areas influenced by brackish and fresh water.

** Intertidal Marsh Plants North of San Francisco Bay, non-indicator plant San Francisco Bay and South.

*** Variety palustris is a candidate for federal endangered status, spp. maritimus is a listed federal endangered species.

Non-Indicator Plants

Plant Species ¹	Plant Species
<u>Atriplex watsonii</u>	<u>Festuca rubra</u>
<u>Carex barbarae</u>	<u>Juncus leseurii</u>
<u>Carex pansa</u>	<u>Parapholis incurva</u>
<u>Cressa truxillensis</u>	<u>Salicornia subterminalis</u>
<u>Distichlis spicata</u> **	<u>Vicia sativa</u>
<u>Elymus triticoides</u>	

California

Upland Plants, Page 1

Plant Species	Plant Species
<u>Abronia latifolia</u>	<u>Convolvulus cyclostegius</u>
<u>Abronia umbellata</u>	<u>Convolvulus soldanella</u>
<u>Achillea millefolium</u>	<u>Coreopsis gigantea</u>
<u>Agropyron repens</u>	<u>Descurainia pinnata</u>
<u>Ammophila arenaria</u>	<u>Elymus mollis</u>
<u>Artemisia californica</u>	<u>Elymus vancouverensis</u>
<u>Artemisia douglasiana</u>	<u>Erechites prenanthoides</u>
<u>Atriplex lentiformis</u>	<u>Eriogonum cinereum</u>
<u>Atriplex semibaccata</u>	<u>Eriogonum latifolium</u>
<u>Avena fatua</u>	<u>Eriophyllum staechadifolium</u>
<u>Baccharis pilularis</u>	<u>Erodium cicutarium</u>
<u>Beta vulgaris</u>	<u>Foeniculum vulgare</u>
<u>Brassica campestris</u>	<u>Franseria chamissonis</u>
<u>Bromus madrenitensis</u>	<u>Geranium dissectum</u>
<u>Bromus maritimus</u>	<u>Glehnia leiocarpa</u>
<u>Bromus mollis</u>	<u>Gnaphalium chilense</u>
<u>Bromus rigidis</u>	<u>Heterotheca grandiflora</u>
<u>Cakile edentula</u>	<u>Holcus lanatus</u>
<u>Cakile maritima</u>	<u>Hordeum stebbinsii</u>
<u>Cardionema ramosissimum</u>	<u>Isomeris arborea v. angustata</u>
<u>Centaurea melitensis</u>	<u>Lolium multiflorum</u>
<u>Cirsium arvense</u>	<u>Lolium perenne</u>
<u>Conium maculatum</u>	<u>Lotus purshianus</u>

California

Upland Plants, Page 2

Plant Species	Plant Species
<u>Lotus scoparius</u>	<u>Rhus diversiloba</u>
<u>Lupinus rivularis</u>	<u>Rhus integrifolia</u>
<u>Lycium californicum</u>	<u>Rubus ursinus</u>
<u>Madia subspicata</u>	<u>Rumex acetosella</u>
<u>Malva parviflora</u>	<u>Silybum marianum</u>
<u>Melilotus albus</u>	<u>Solanum xantii</u>
<u>Melilotus indicus</u>	<u>Solidago spathulata</u>
<u>Mesembryanthemum edule</u>	<u>Sonchus asper</u>
<u>Montia perfoliata</u>	<u>Sonchus oleraceus</u>
<u>Nicotiana glauca</u>	<u>Stellaria media</u>
<u>Oenothera cheiranthifolia</u>	<u>Tanacetum douglasii</u>
<u>Picris echioides</u>	<u>Trifolium wormskioldii</u>
<u>Plantago lanceolata</u>	<u>Urtica holosericea</u>
<u>Poa douglasii</u>	<u>Vicia tetrasperma</u>
<u>Poa scabrella</u>	<u>Yucca whipplei</u>
<u>Polygonum paronychia</u>	

Oregon, Washington

Intertidal Marsh Plants

Plant Species ¹	Plant Species
<u>Aster subspicatus</u> *	<u>Oenathe sarmentosa</u>
<u>Atriplex patula</u>	<u>Orthocarpus castillejoides</u>
<u>Calamagrostis nutkaensis</u> *	<u>Physocarpus capitatus</u> *
<u>Carex obnupta</u> *	<u>Plantago maritima</u>
<u>Carex lyngbyei</u>	<u>Potentilla pacifica</u> *
<u>Cordylanthus maritimus</u> **	<u>Puccinella pumila</u>
<u>Cuscuta salina</u>	<u>Rumex occidentalis</u> *
<u>Deschampsia cespitosa</u> *	<u>Salicornia virginica</u>
<u>Distichlis spicata</u>	<u>Scirpus americanus</u> *
<u>Eleocharis palustris</u> *	<u>Scirpus cernuus</u> *
<u>Epilobium watsonii</u> *	<u>Scirpus maritimus</u> *
<u>Galium triflorum</u> *	<u>Scirpus microcarpus</u> *
<u>Glaux maritima</u>	<u>Scirpus validus</u> *
<u>Grindelia integrifolia</u> var. <u>macrophylla</u>	<u>Sidalcea hendersonii</u>
<u>Hordeum brachyantherum</u> *	<u>Spartina alterniflora</u>
<u>Jaumea carnosa</u>	<u>Stellaria humifusa</u>
<u>Juncus balticus</u> *	<u>Spergularia canadensis</u>
<u>Juncus effusus</u> *	<u>Triglochin concinnum</u>
<u>Juncus gerardii</u> *	<u>Triglochin maritimum</u>
<u>Lilaeopsis occidentalis</u> *	<u>Zostera nana</u>

¹ Nomenclature after Hitchcock and Cronquist (1973).

* Also occurs in areas influenced by fresh and brackish water.

** Variety palustris is a candidate for federal endangered status.

Oregon, Washington

Upland Species

Plant Species	Plant Species
<u>Achillea millefolium</u>	<u>Holcus lanatus</u>
<u>Agropyron repens</u>	<u>Hypochaeris radicata</u>
<u>Angelica lucida</u>	<u>Lathyrus japonicus</u>
<u>Carex pansa</u>	<u>Lonicera involucrata</u>
<u>Elymus mollis</u>	<u>Maianthemum dilatatum</u>
<u>Erechtites arguta</u>	<u>Picea sitchensis</u>
<u>Festuca rubra</u>	<u>Plantago lanceolata</u>
<u>Galium aparine</u>	<u>Poa pratensis</u>
<u>Galium triflorum</u>	<u>Rubus ursinus</u>
<u>Gaultheria shallon</u>	<u>Spergularia macrotheca</u>
<u>Heracleum lanatum</u>	<u>Vicia gigantea</u>

Oregon, Washington

Non-Indicator Plants

Plant Species	Plant Species
<u>Agrostis alba</u>	<u>Spergularia macrotheca</u>
<u>Juncus leseurii</u>	<u>Stellaria calycantha</u>
<u>Lotus corniculatus</u>	<u>Trifolium wormskjoldii</u>

APPENDIX C

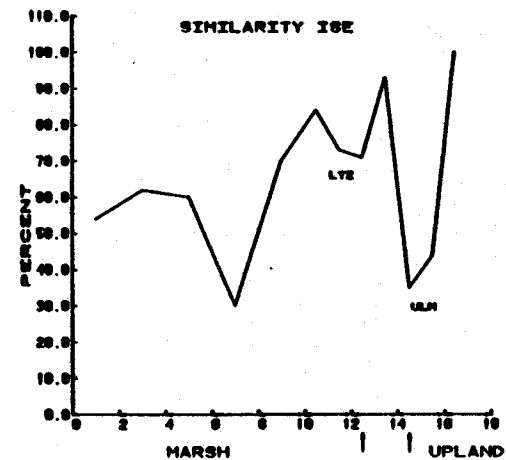
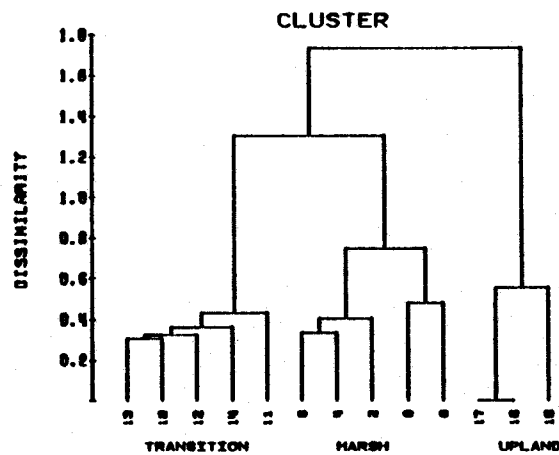
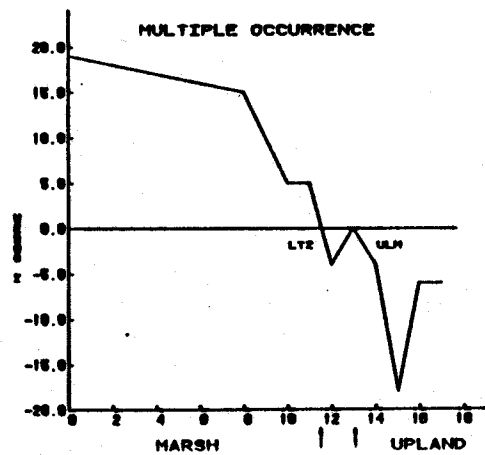
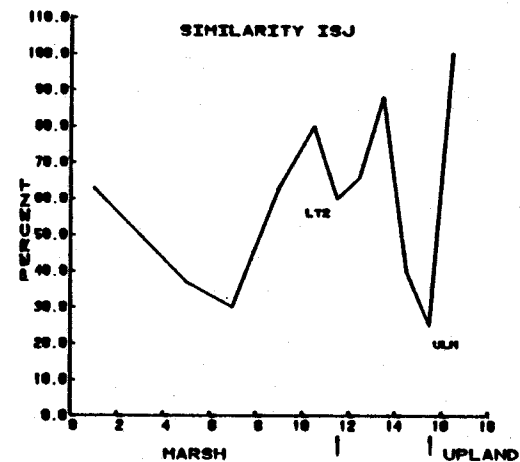
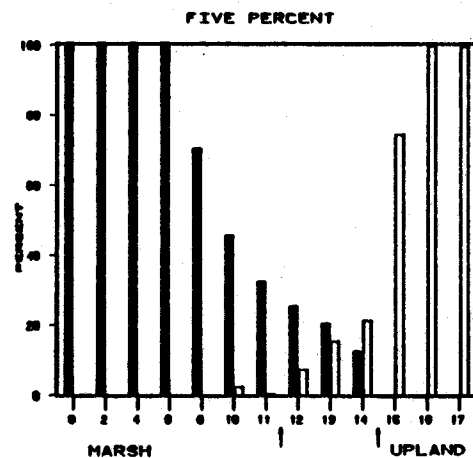
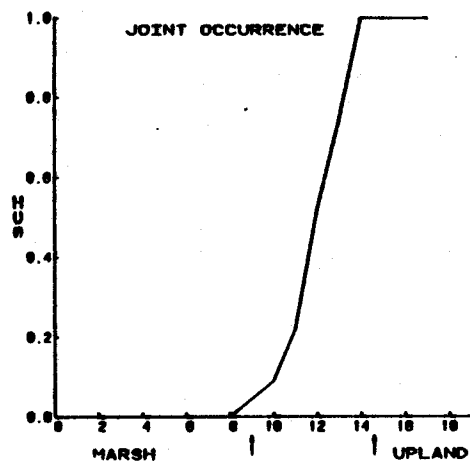
Upper Limit of Marsh (ULM) and Lower Limit of Transition

Zone (LTZ) Determined by 6 Methods Applied to 22

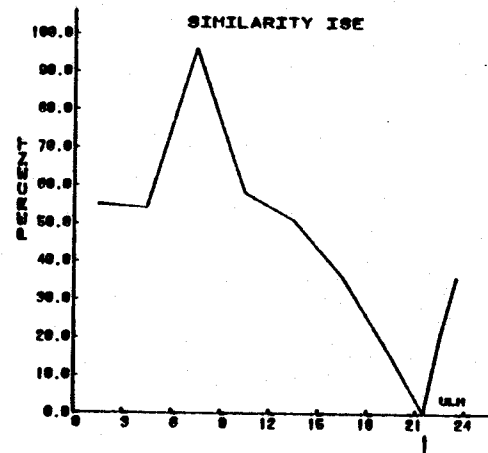
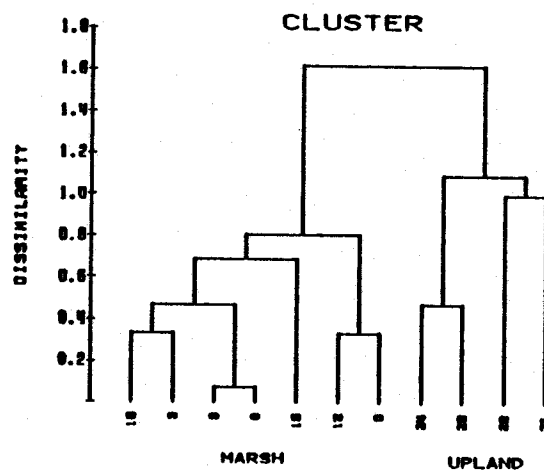
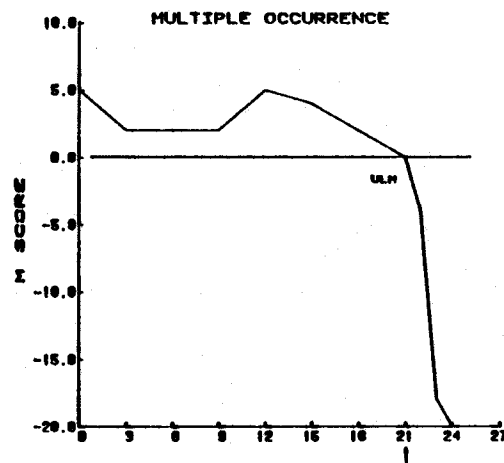
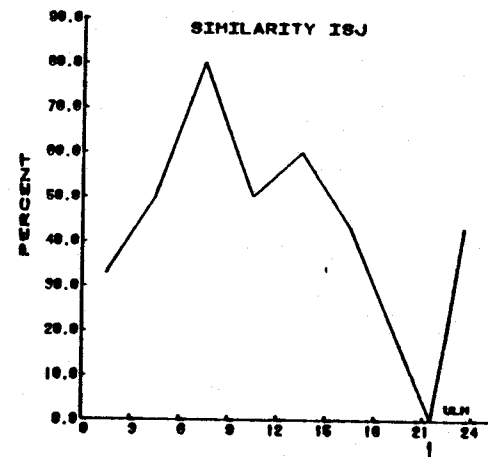
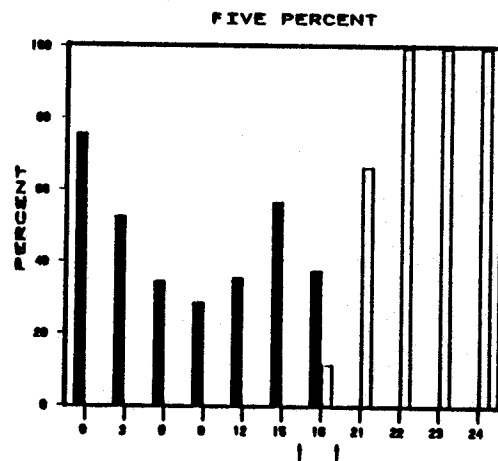
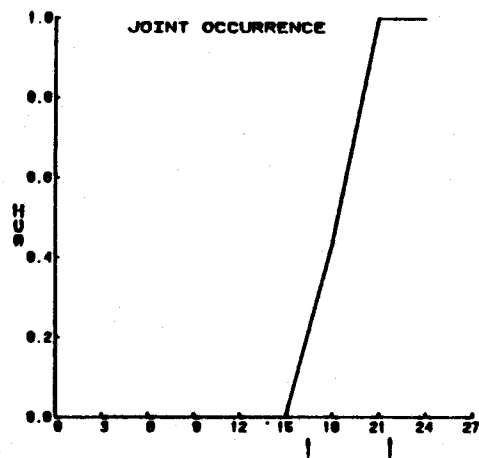
Transects from Frenkel et al. (1978)

Numbers on the ordinate denote distance (m) along sample transect from wetland to upland. Arrows indicate LTZ and ULM positions listed in Table 1.

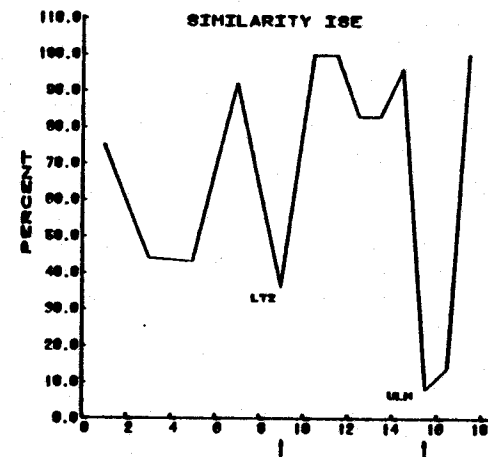
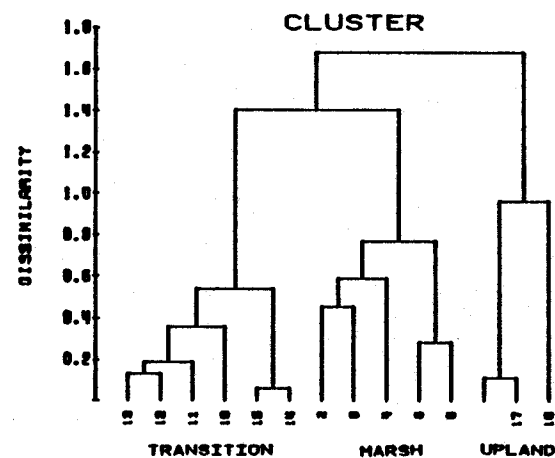
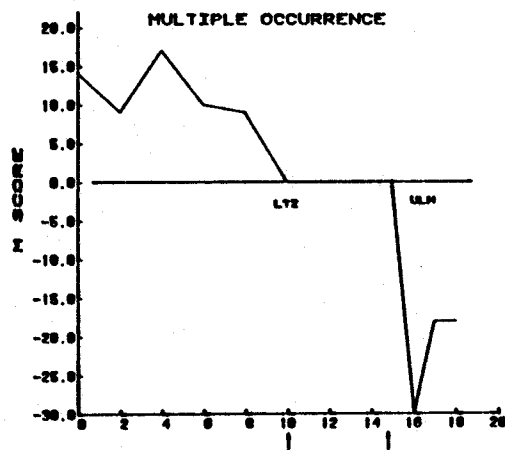
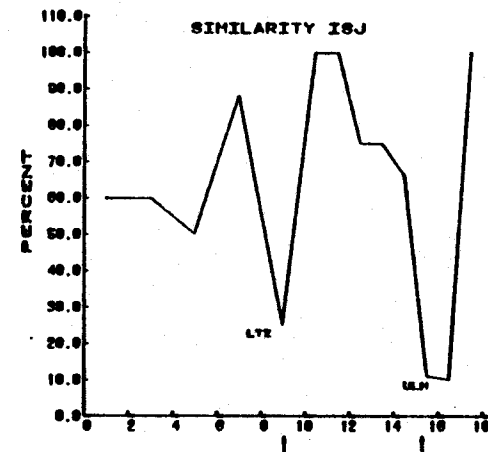
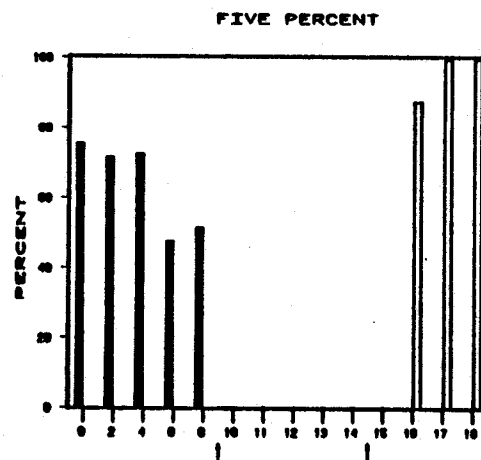
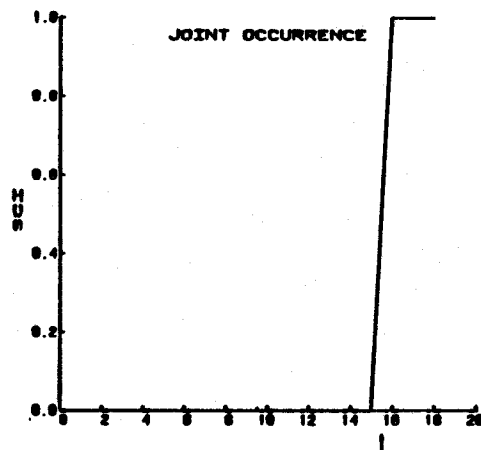
TRANSECT 0105



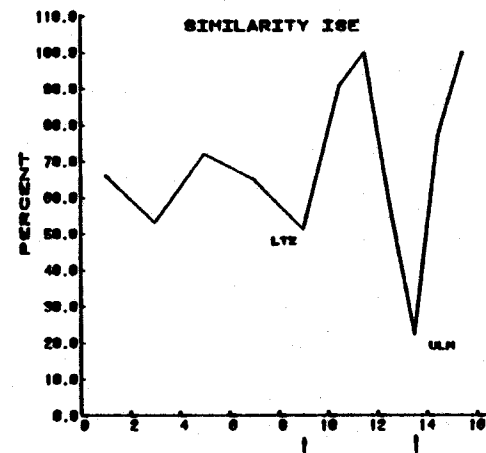
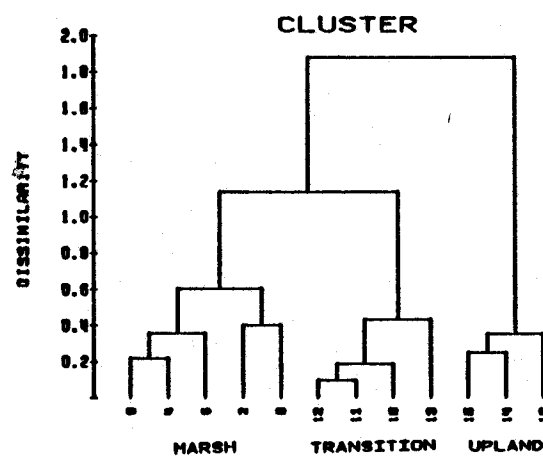
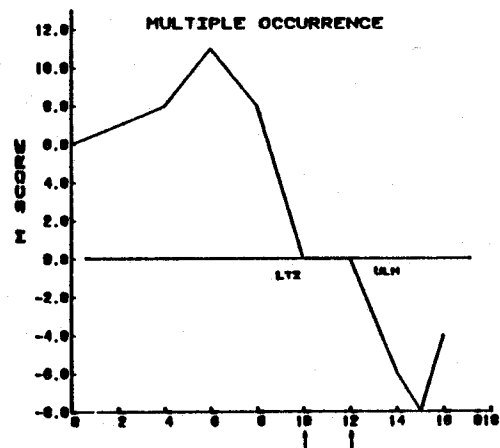
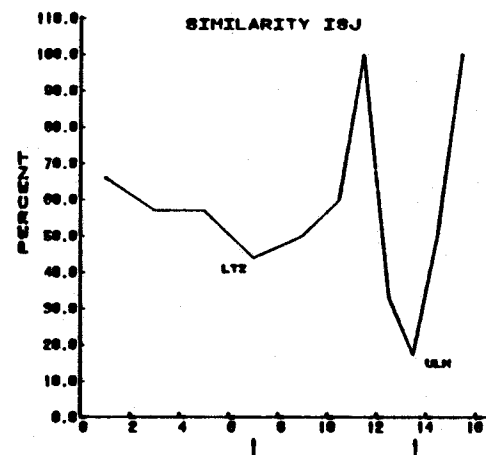
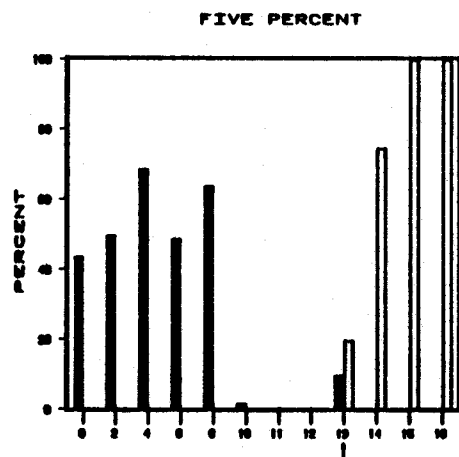
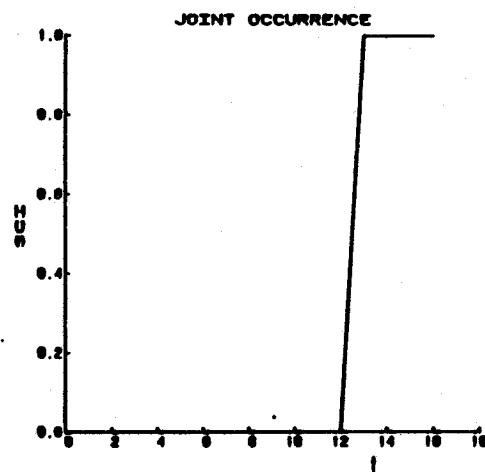
TRANSECT 0208



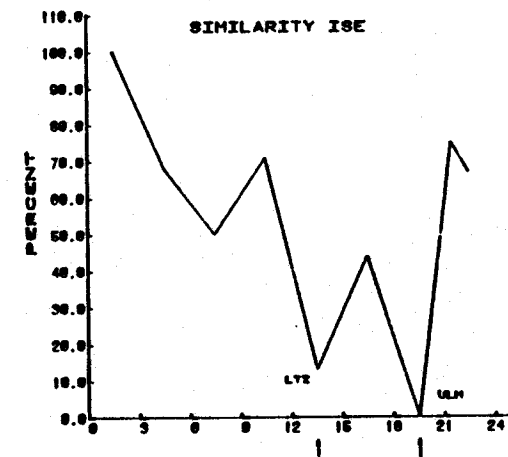
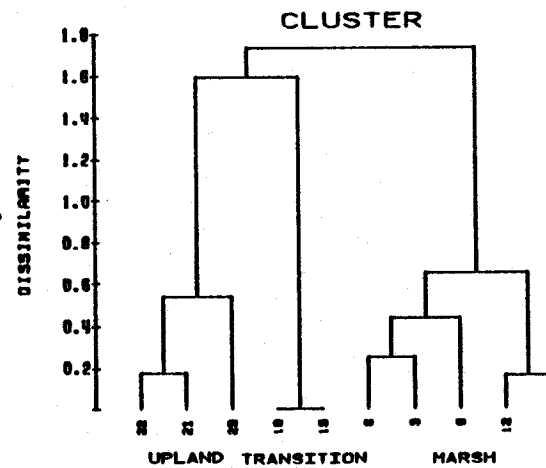
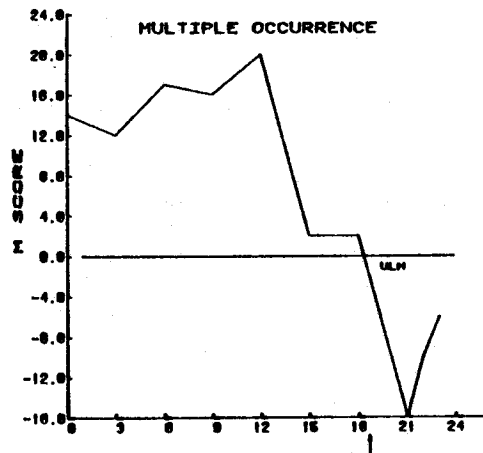
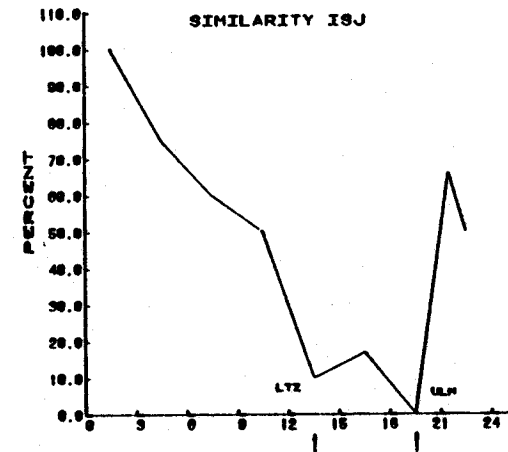
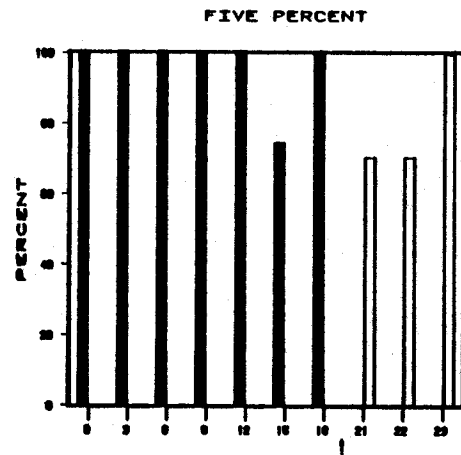
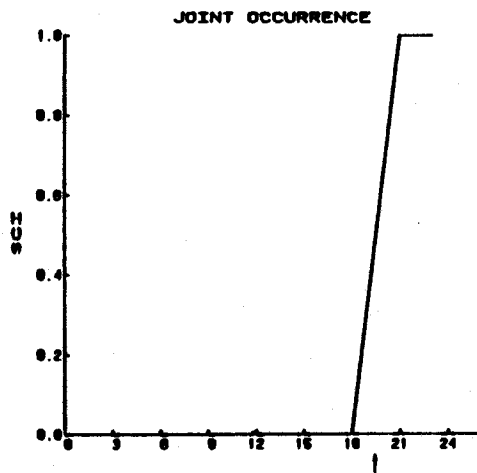
TRANSECT 0301



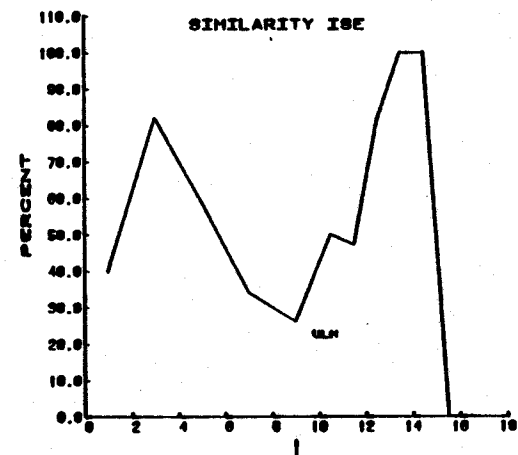
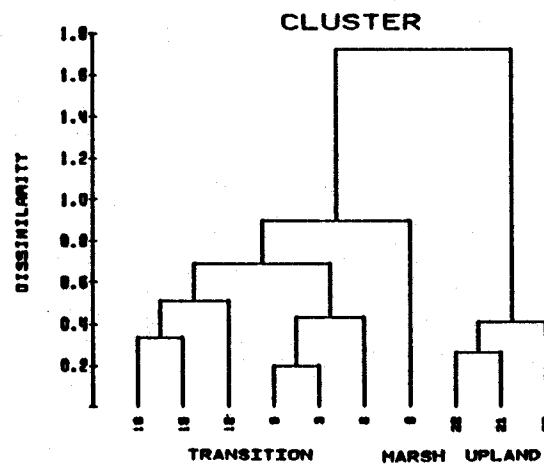
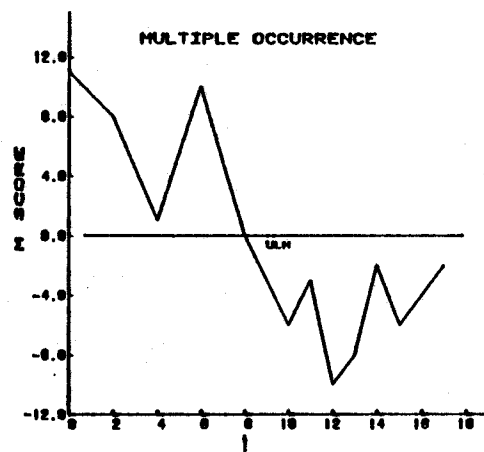
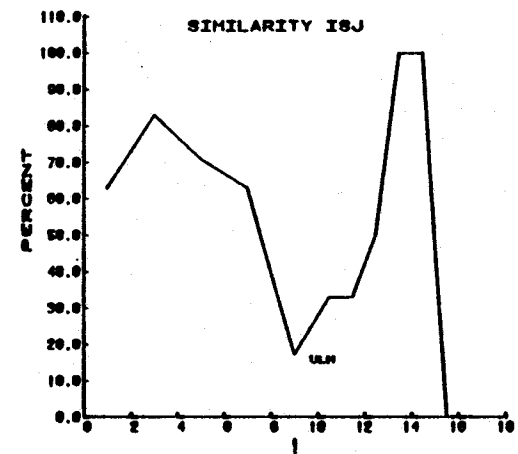
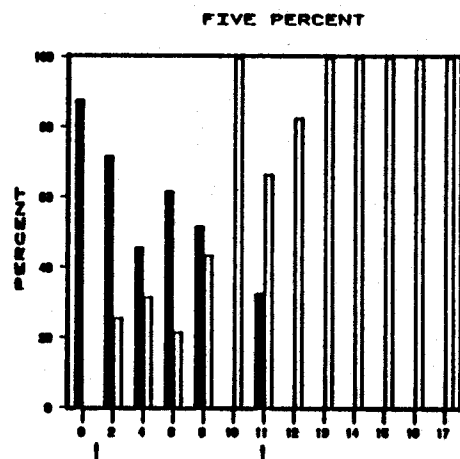
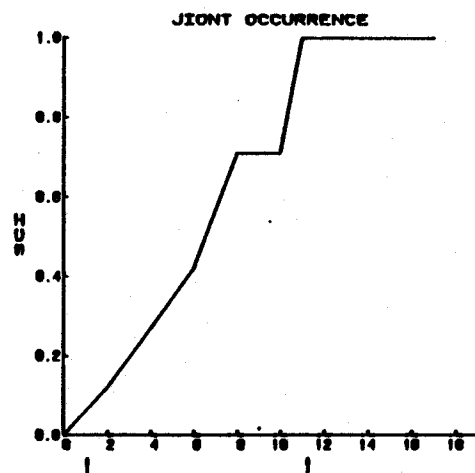
TRANSECT 0310



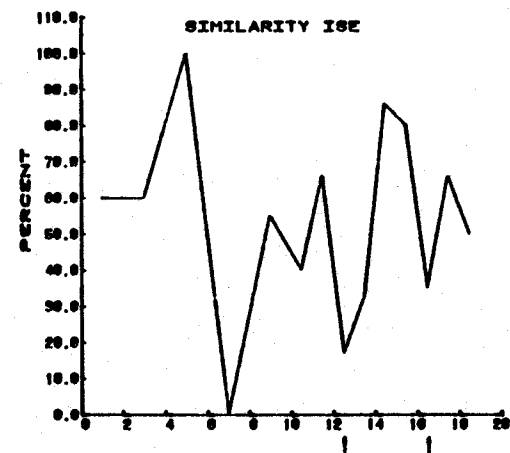
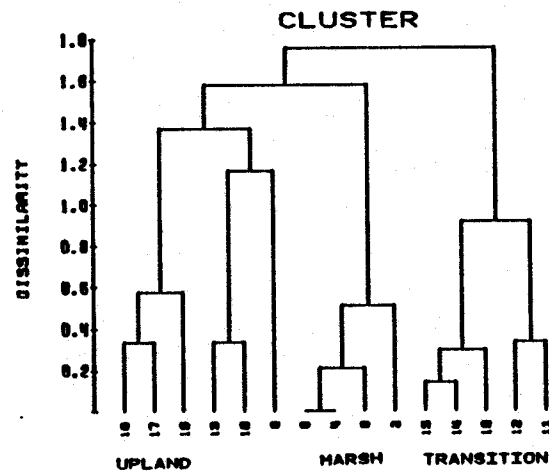
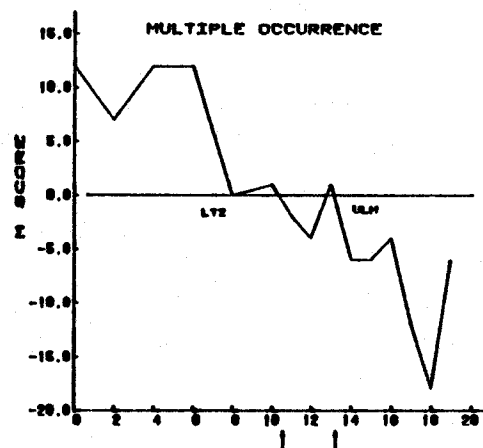
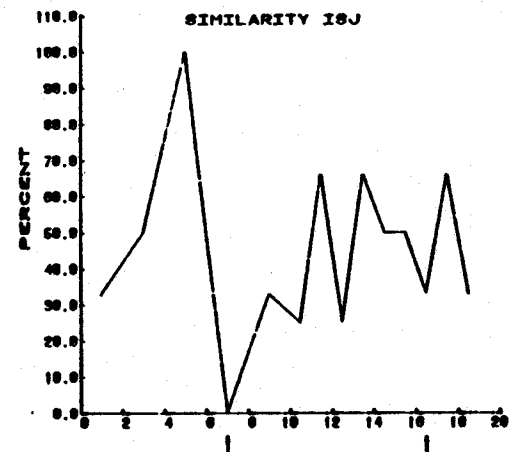
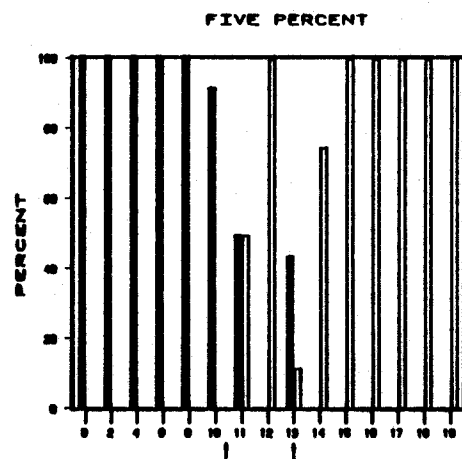
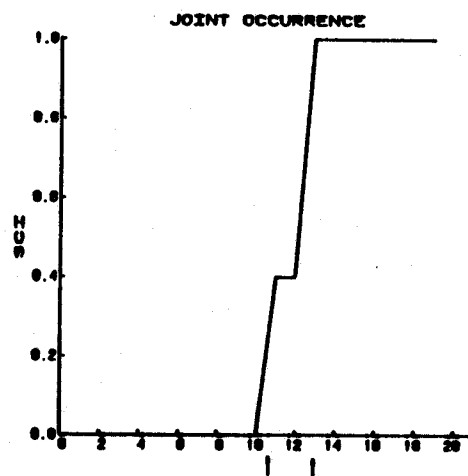
TRANSECT 0402



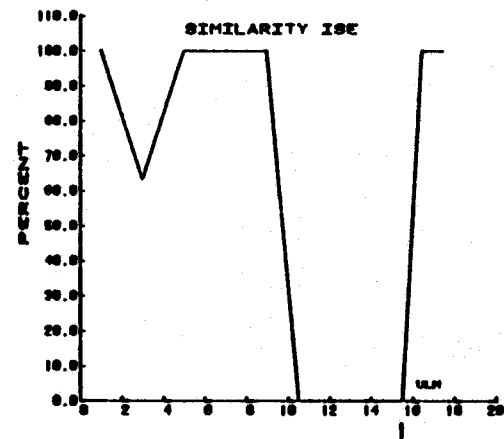
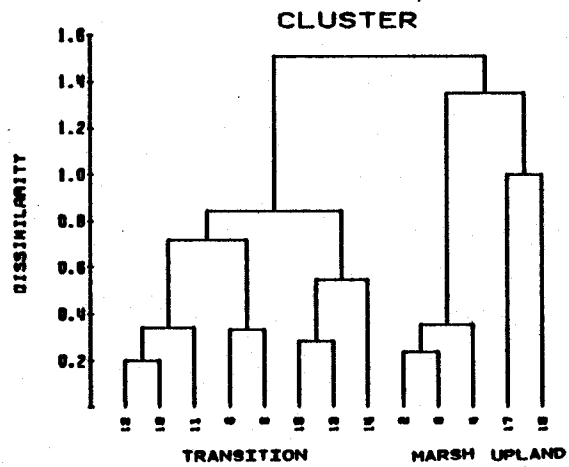
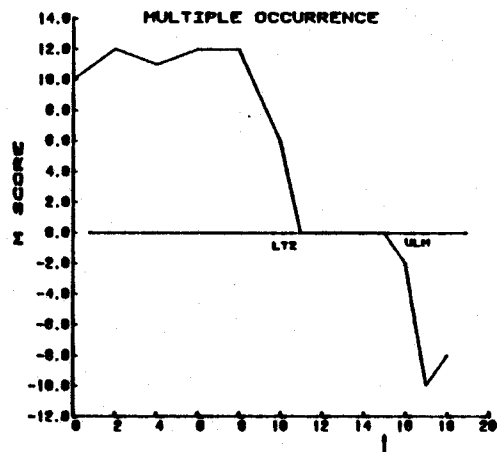
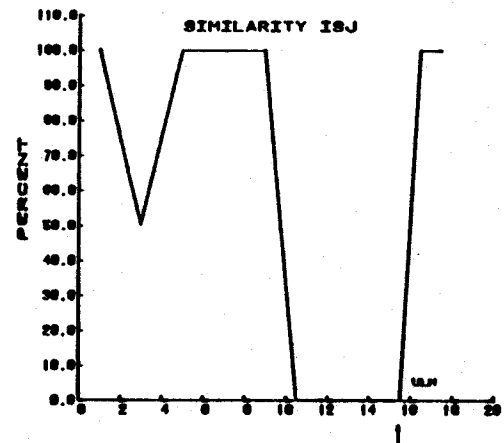
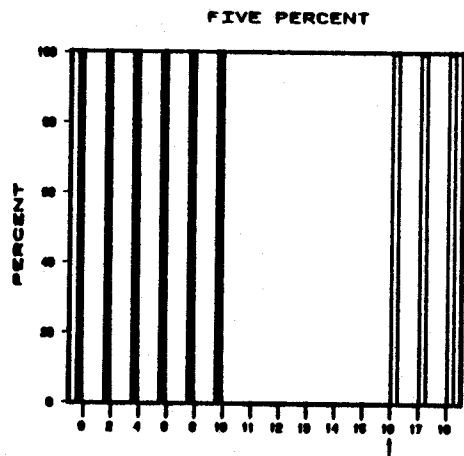
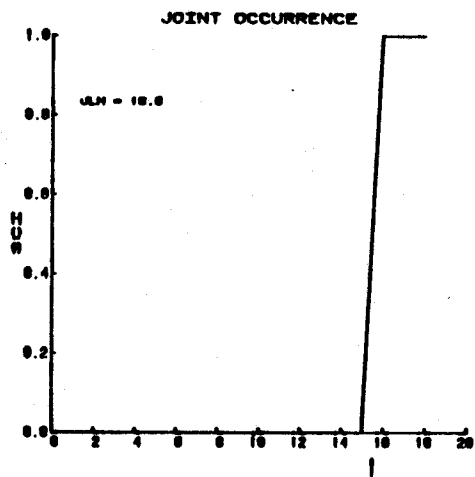
TRANSECT 0704



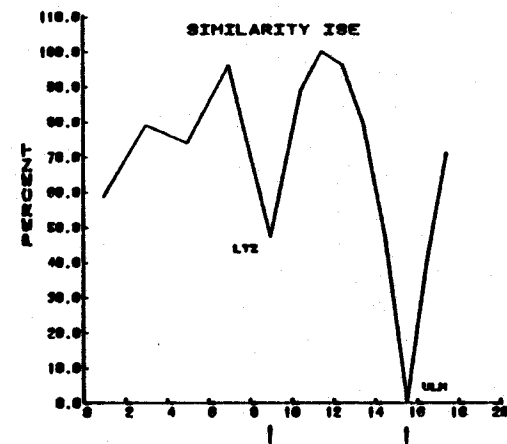
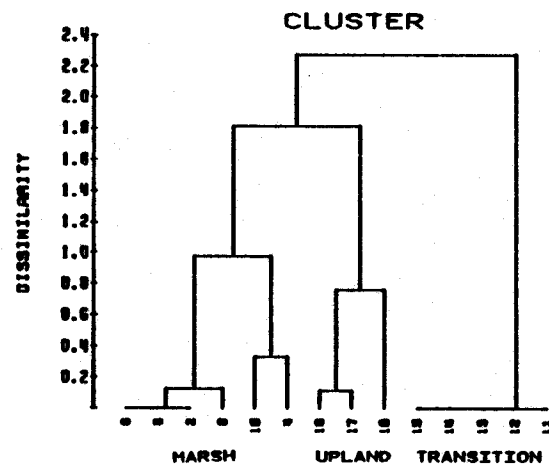
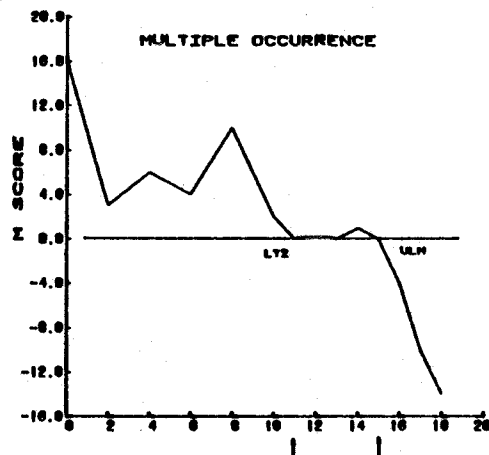
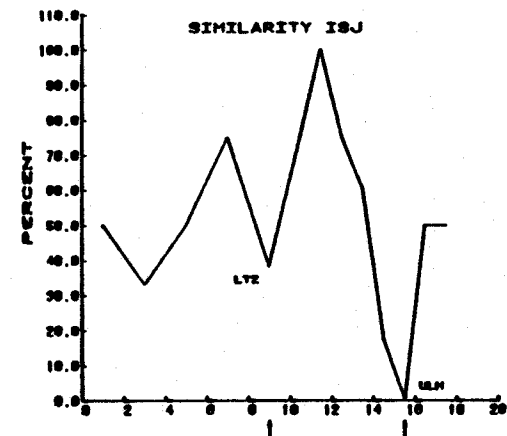
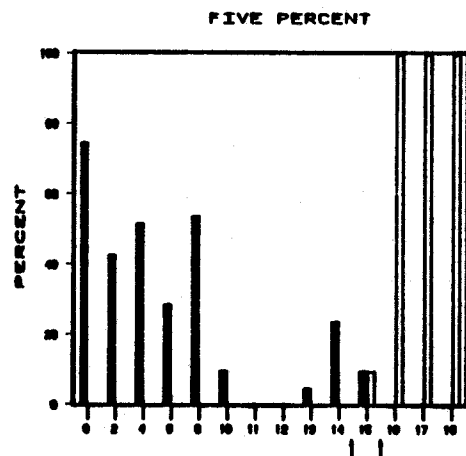
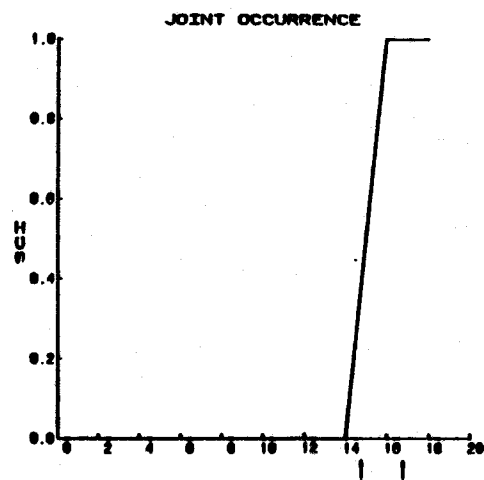
TRANSECT 0706



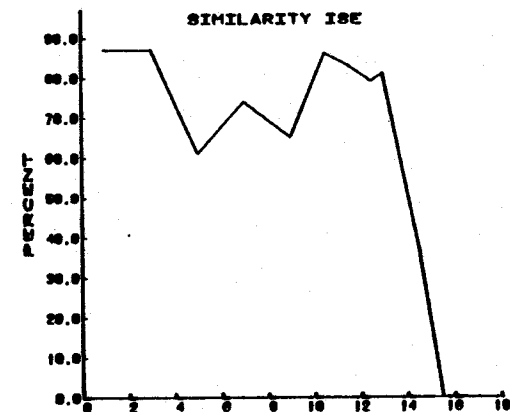
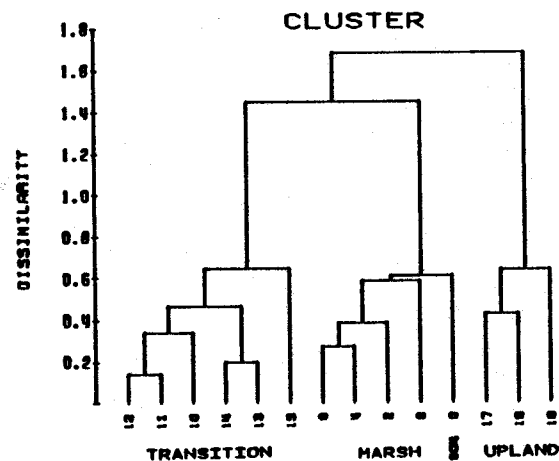
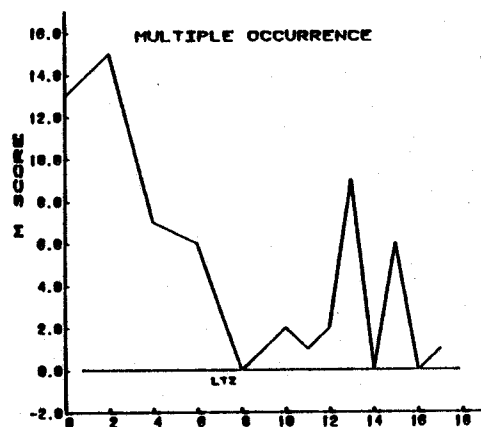
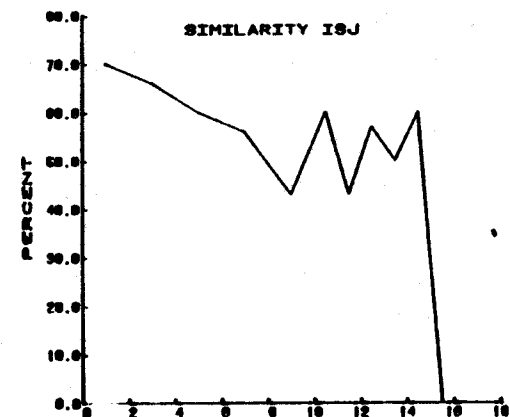
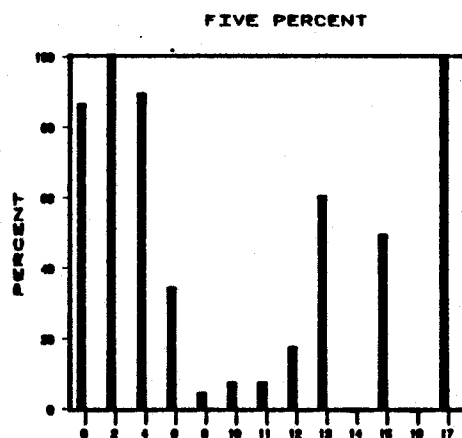
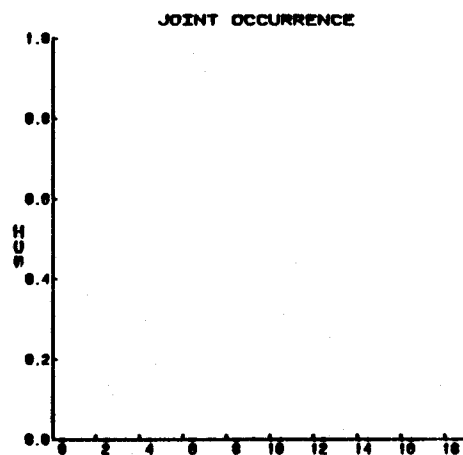
TRANSECT 0710



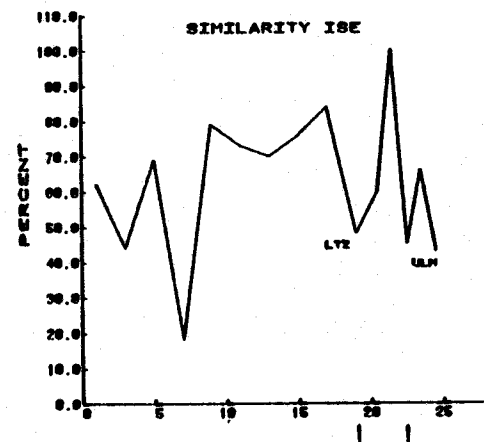
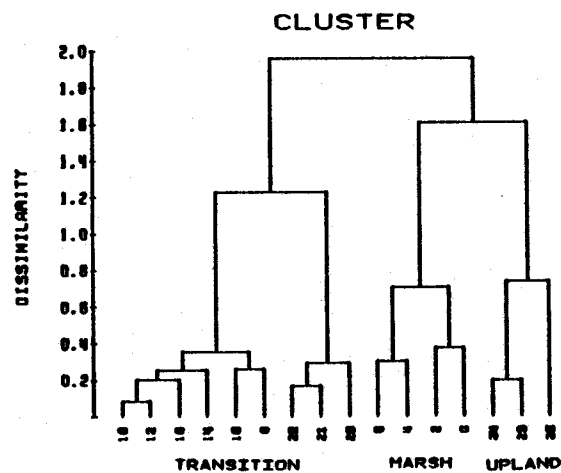
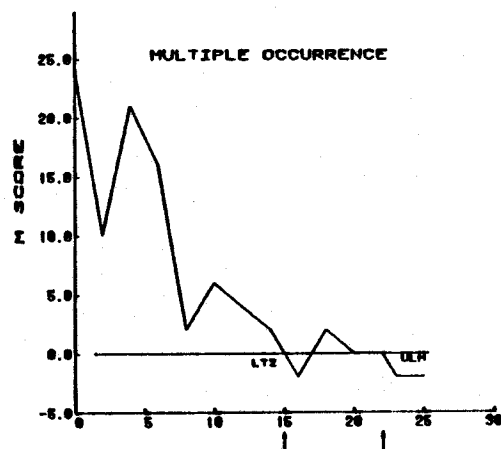
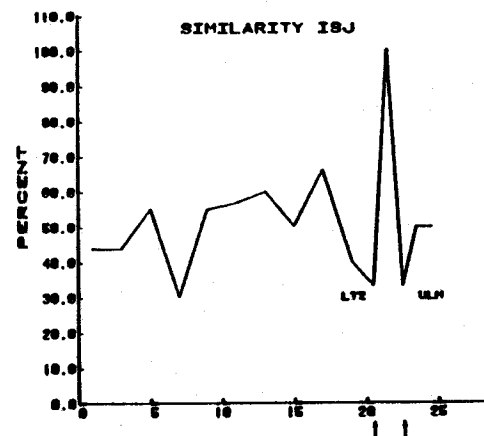
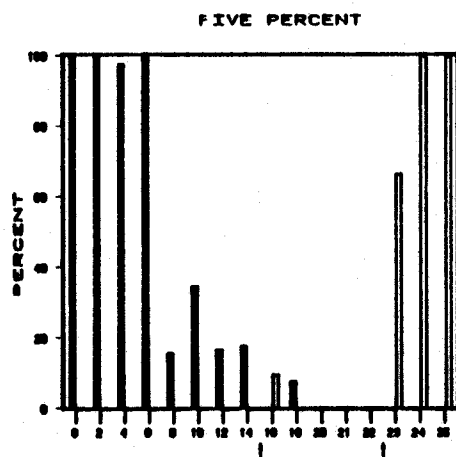
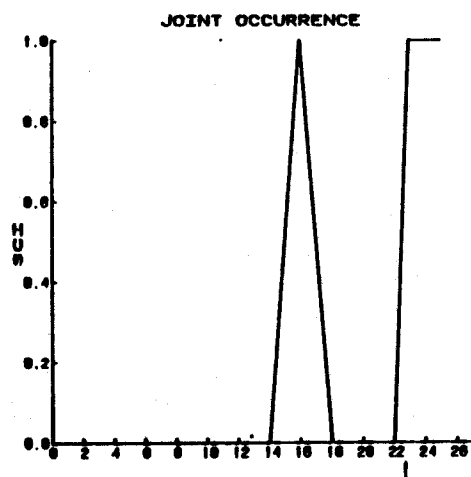
TRANSECT 0804



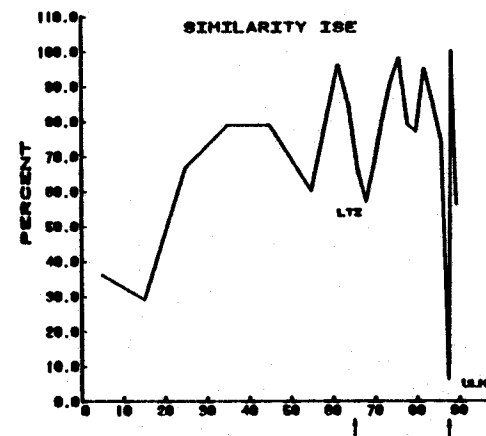
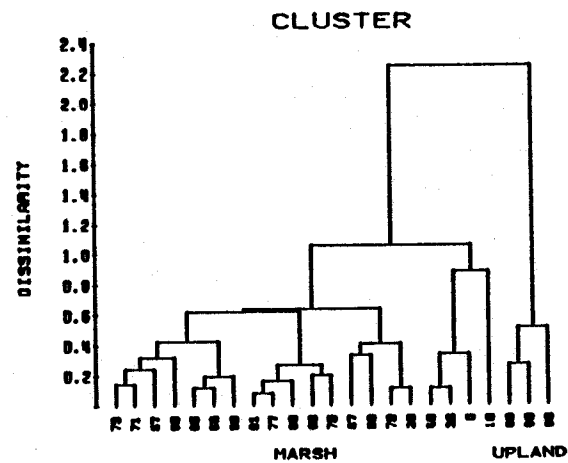
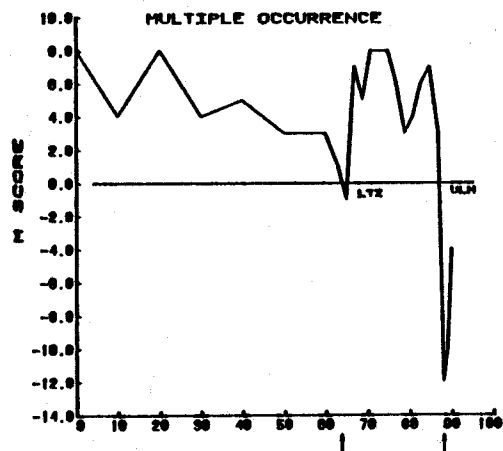
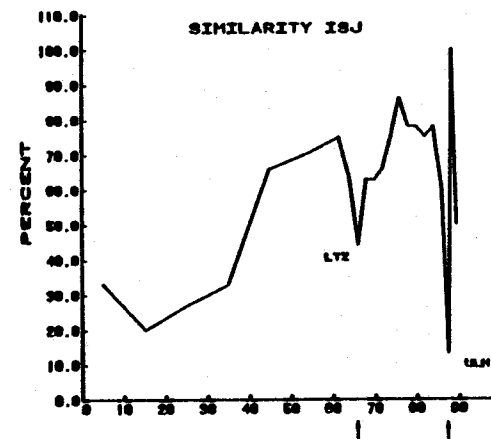
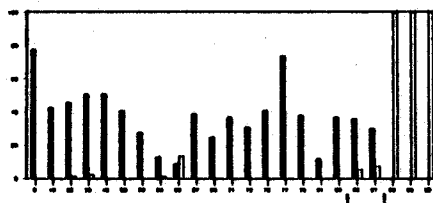
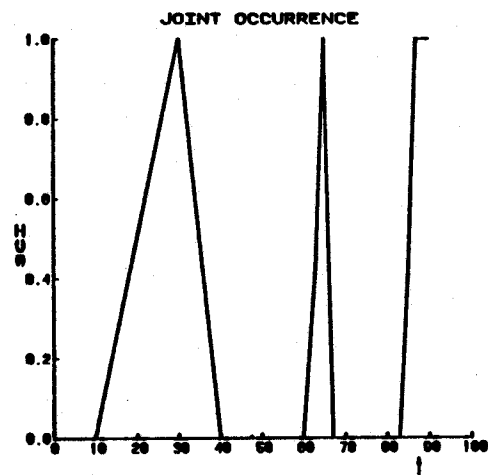
TRANSECT 0808



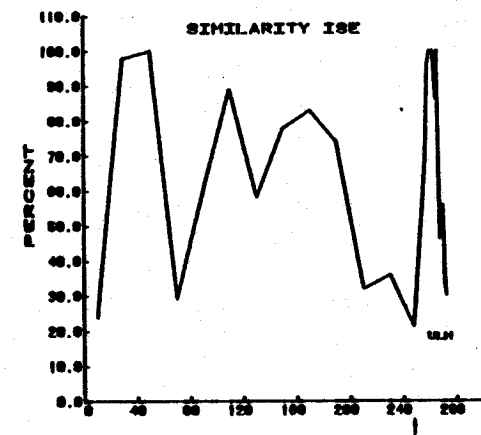
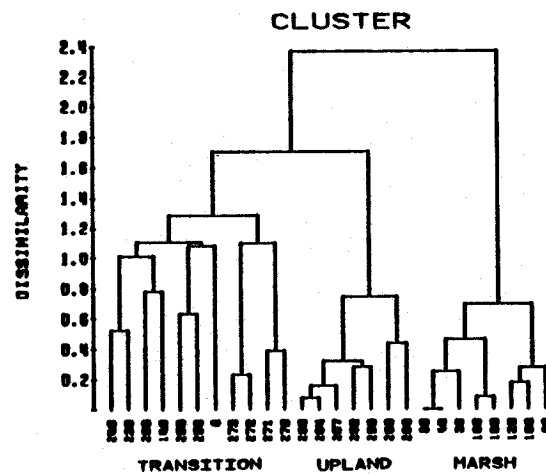
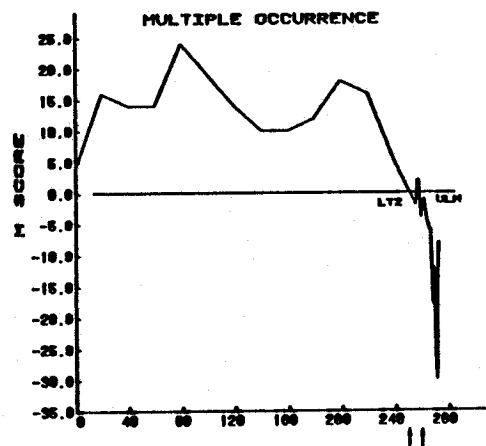
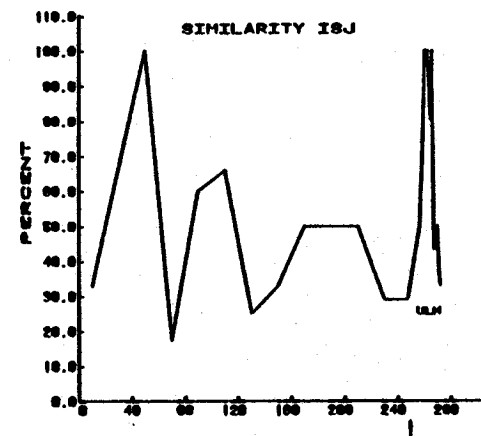
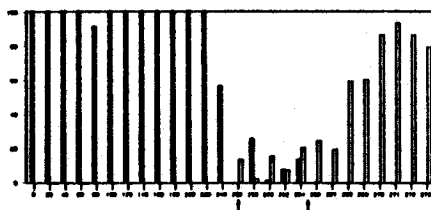
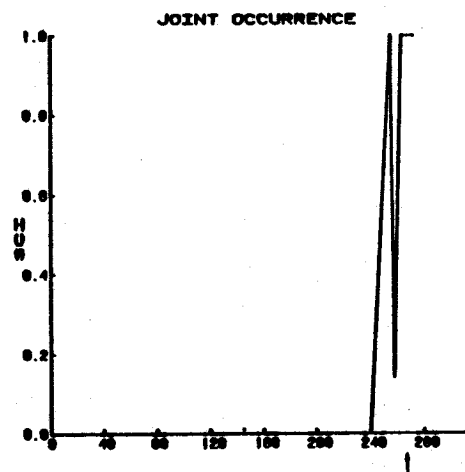
TRANSECT 0809



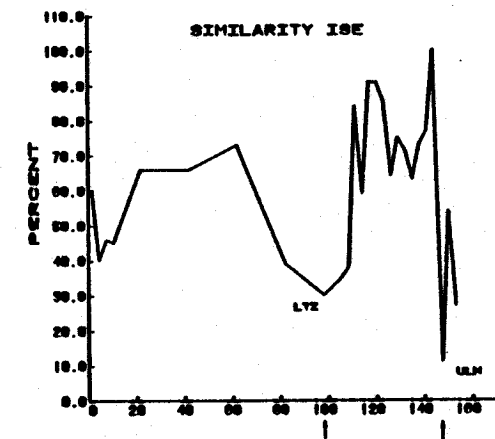
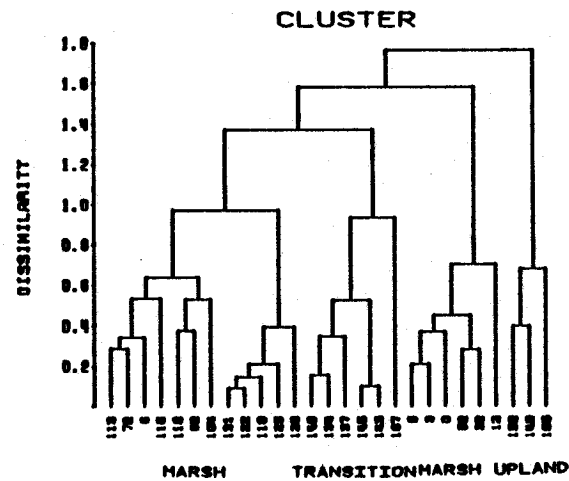
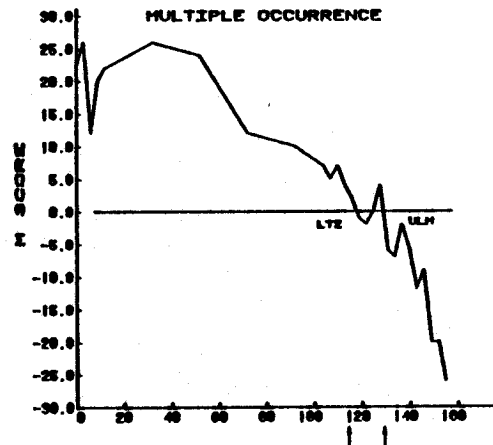
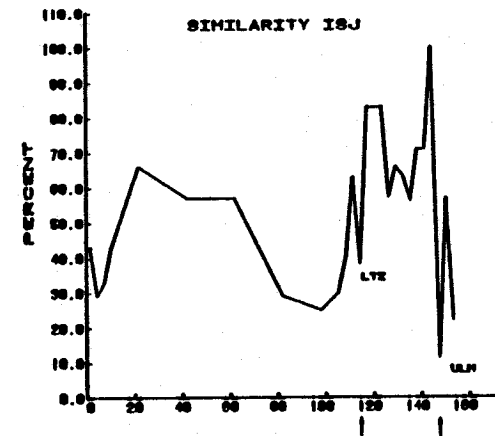
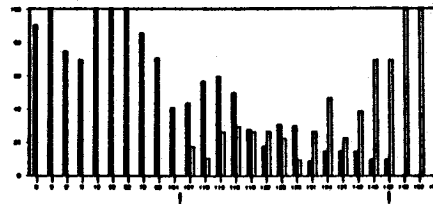
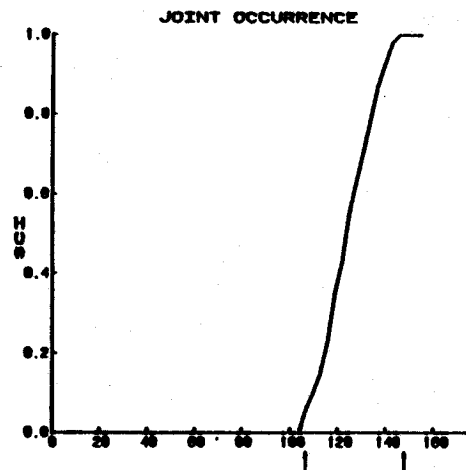
TRANSECT 0910



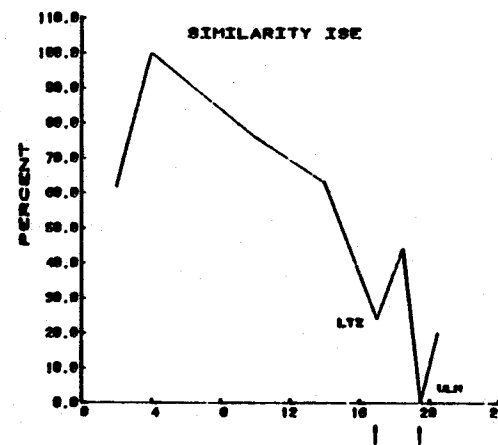
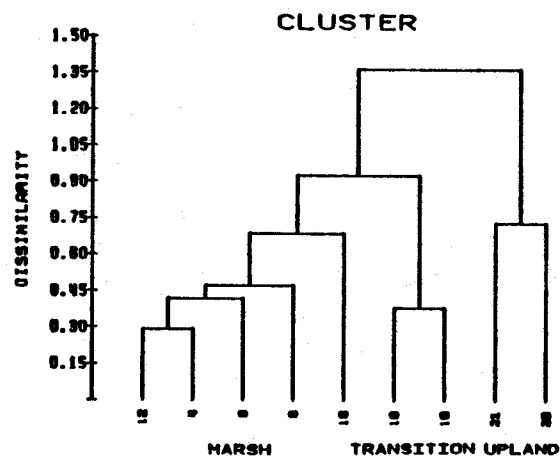
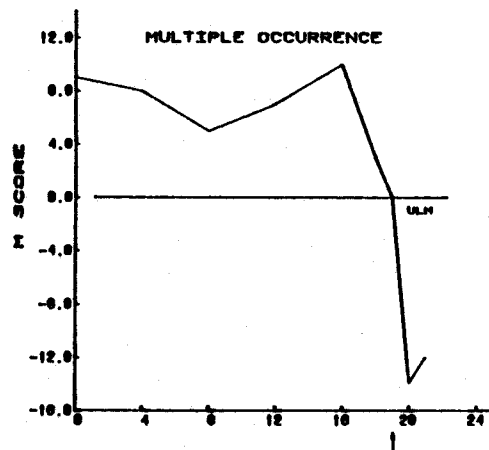
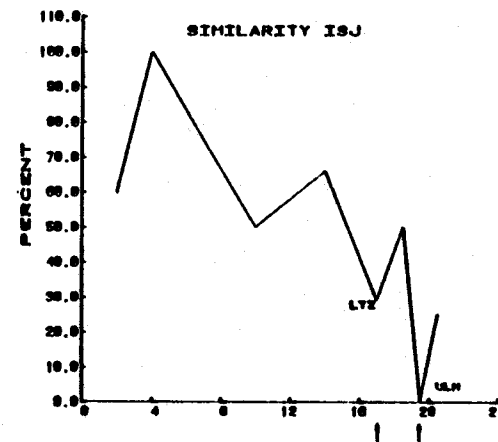
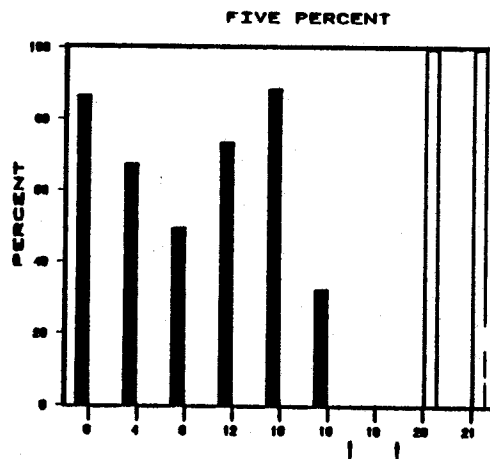
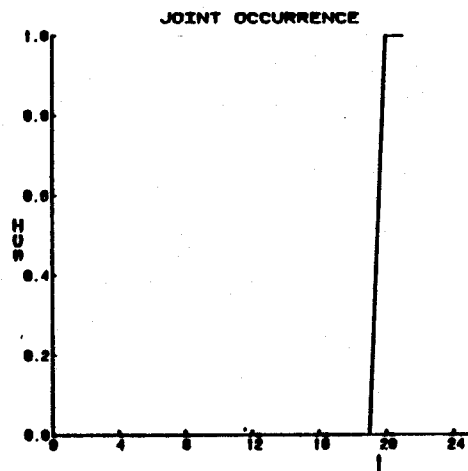
TRANSECT 1001



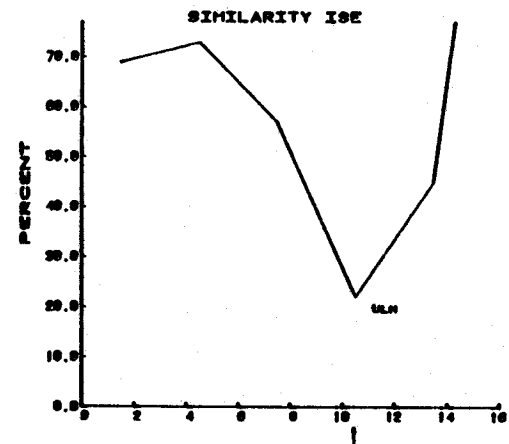
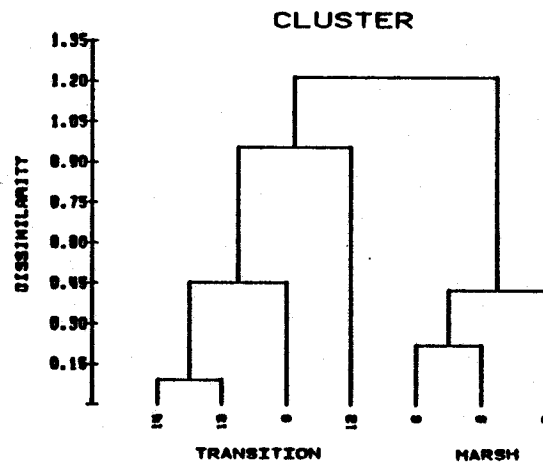
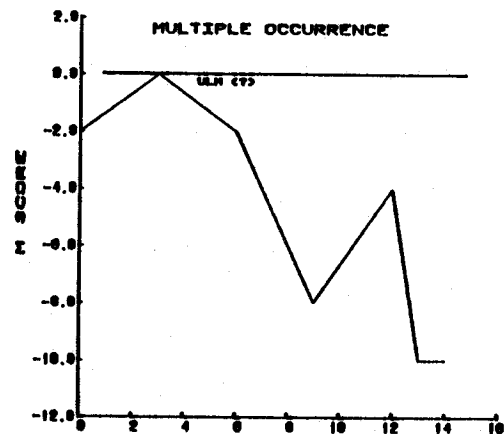
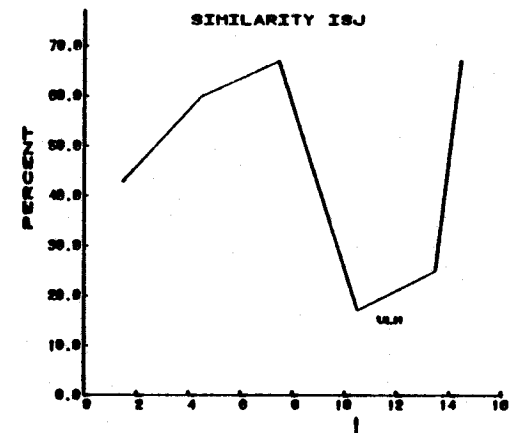
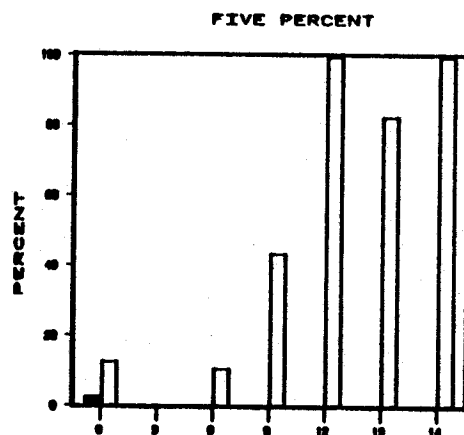
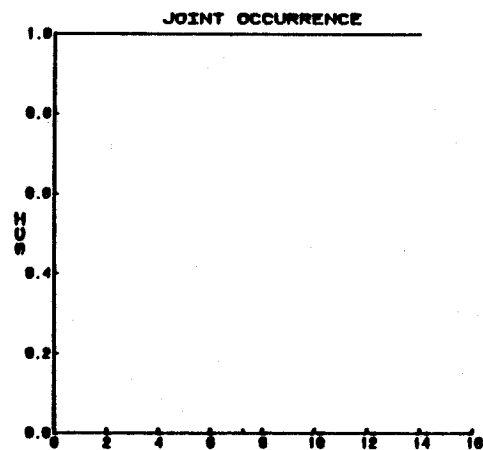
TRANSECT 1103



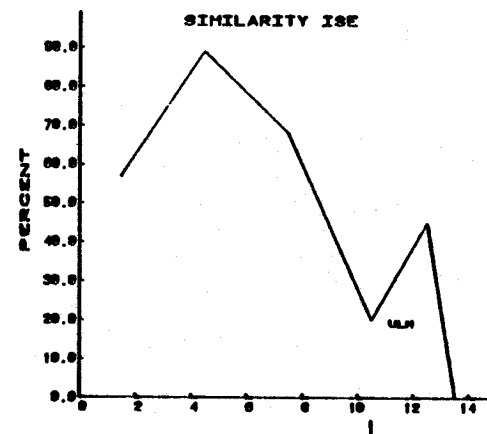
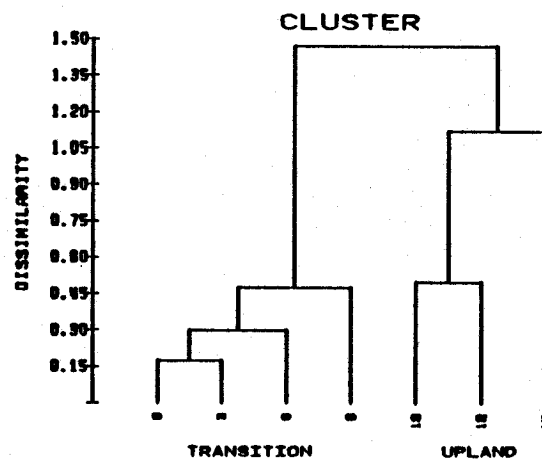
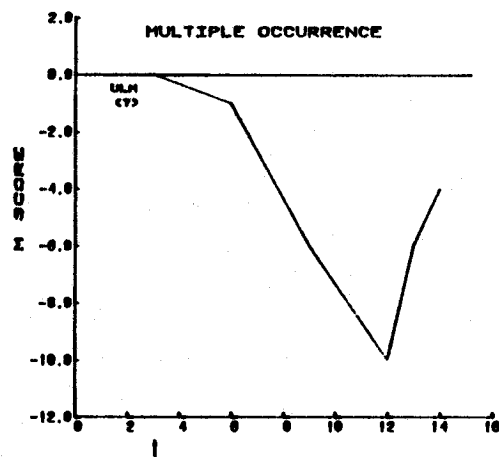
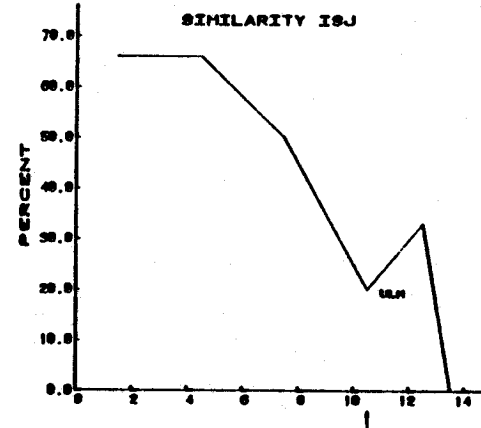
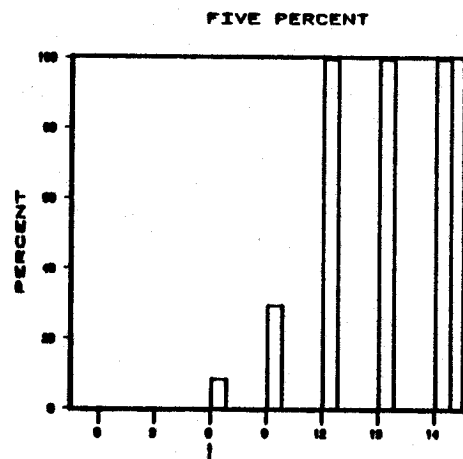
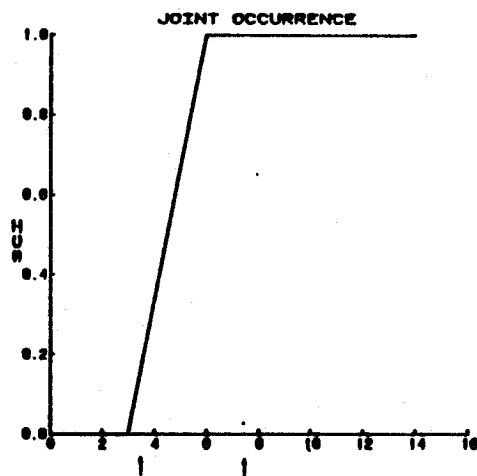
TRANSECT 1201



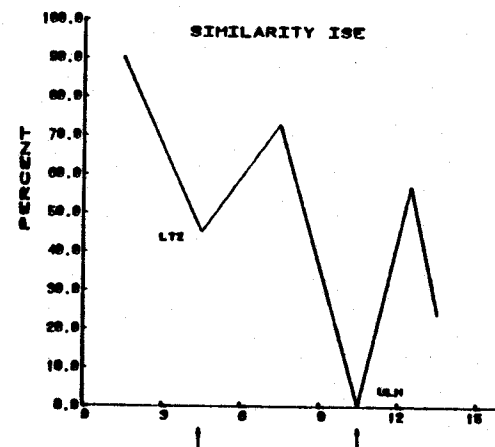
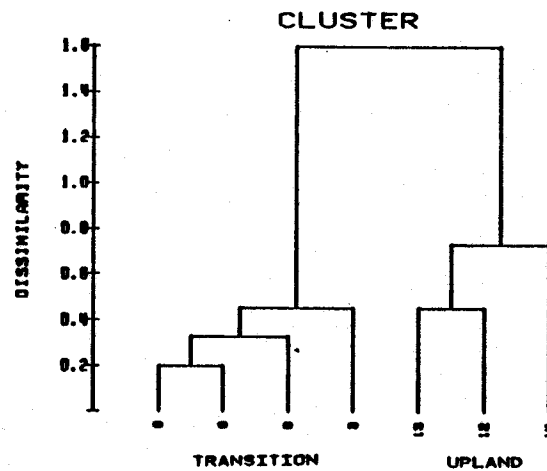
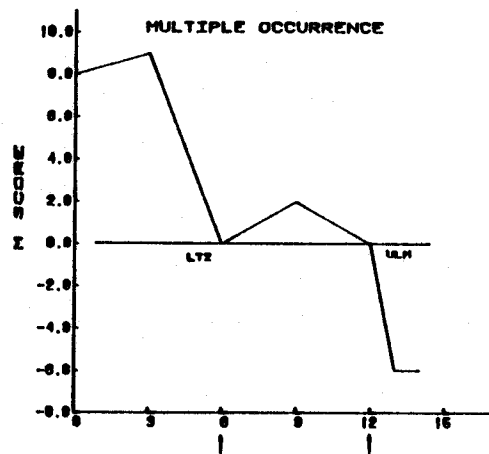
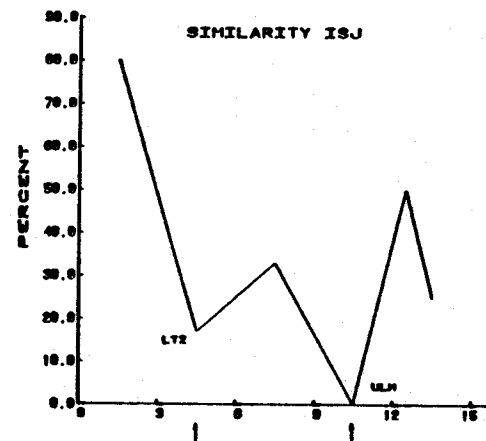
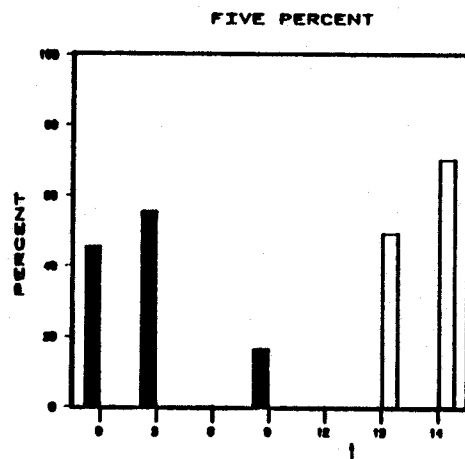
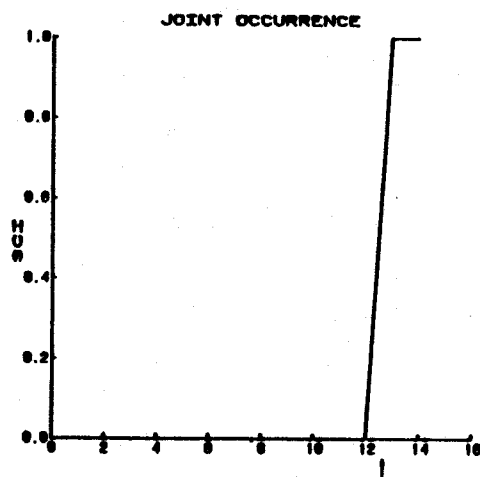
TRANSECT 1606



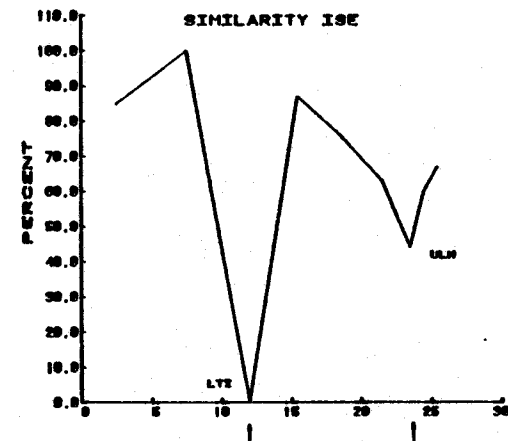
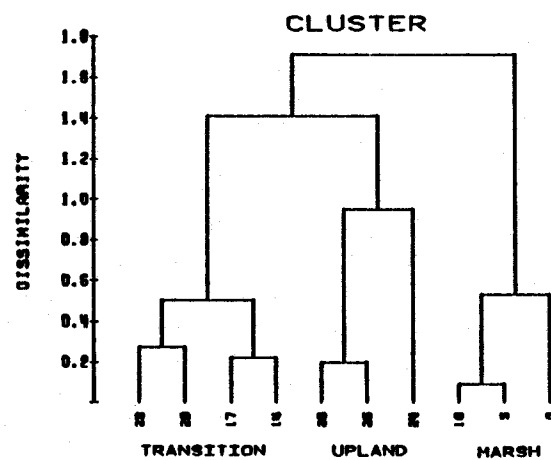
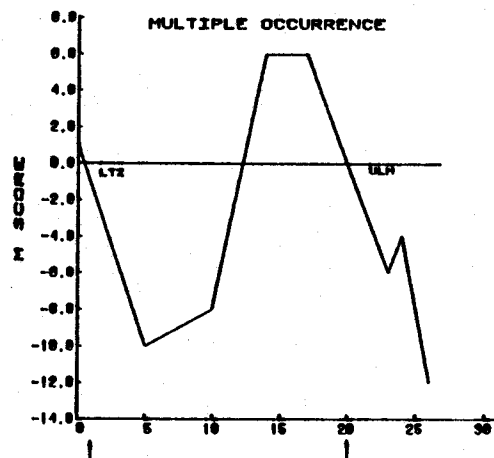
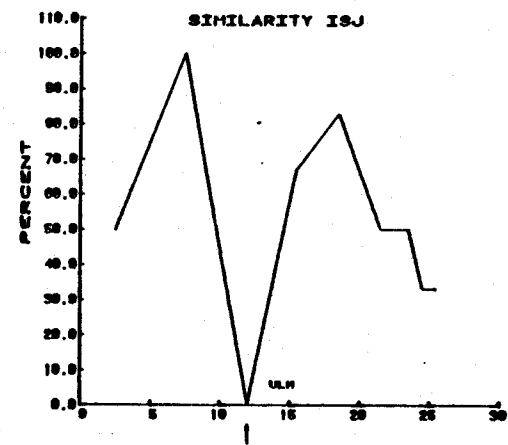
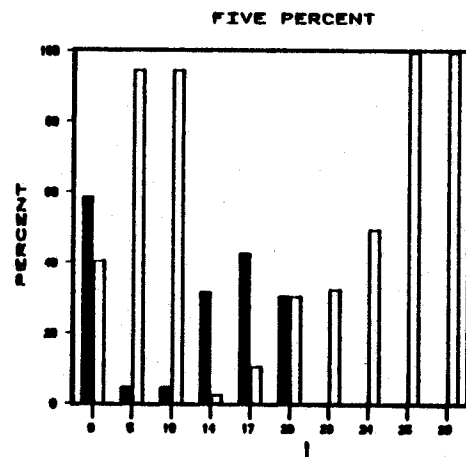
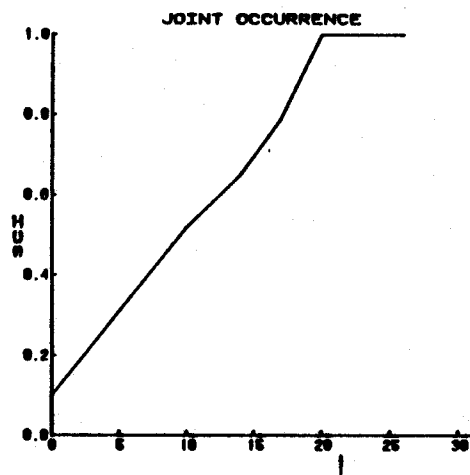
TRANSECT 1610



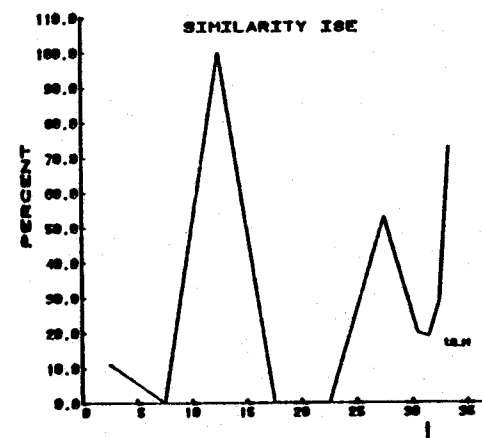
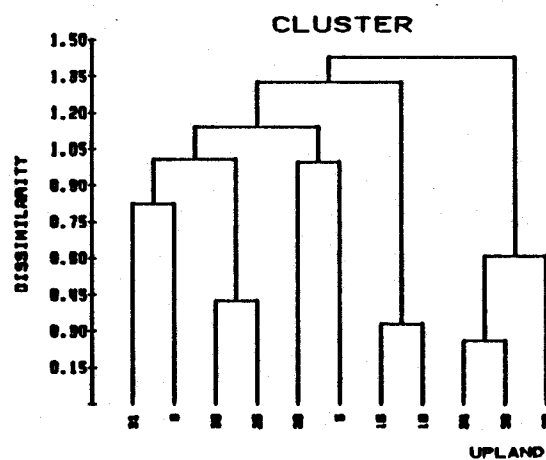
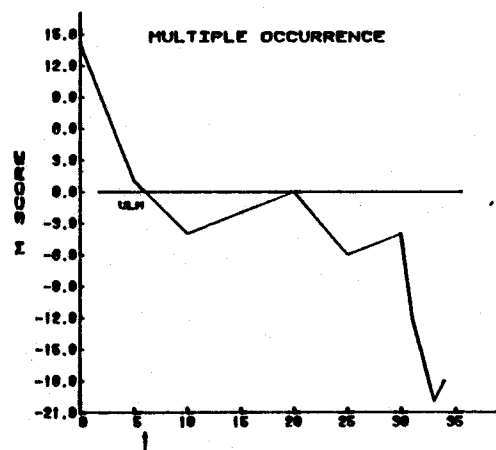
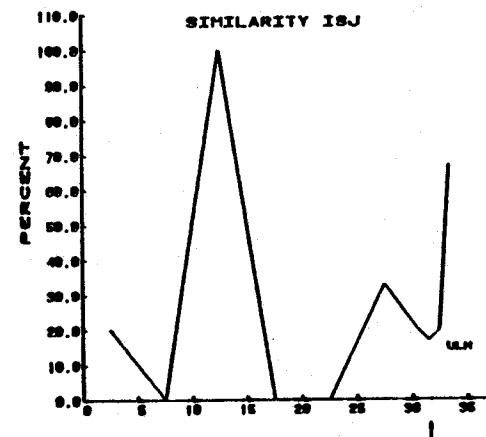
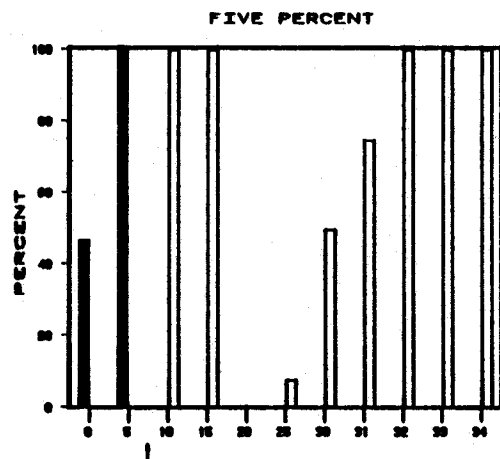
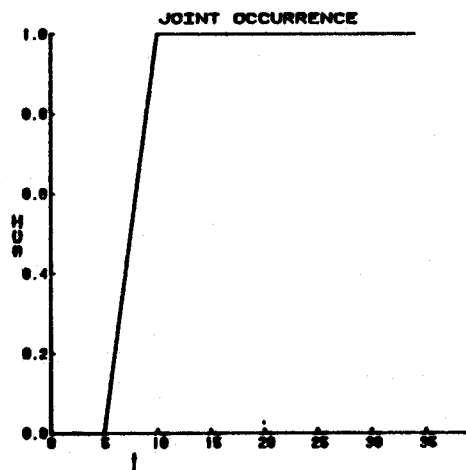
TRANSECT 1611



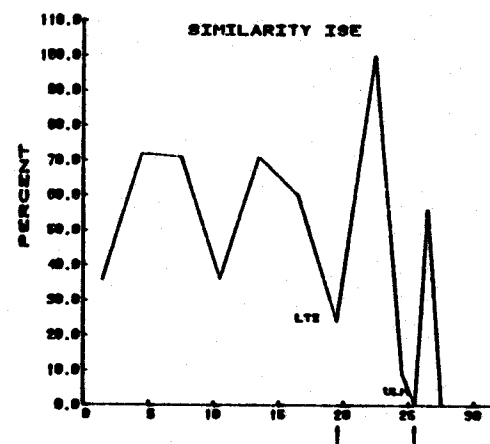
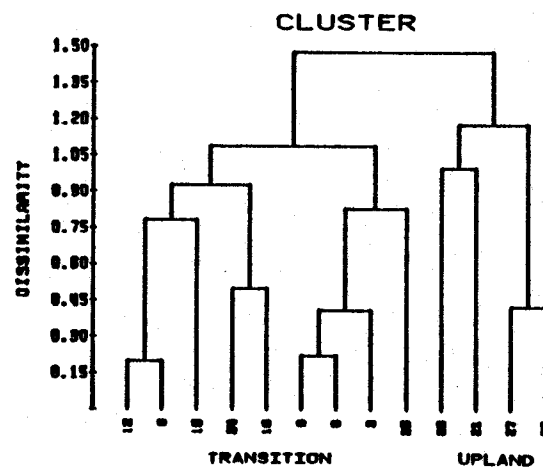
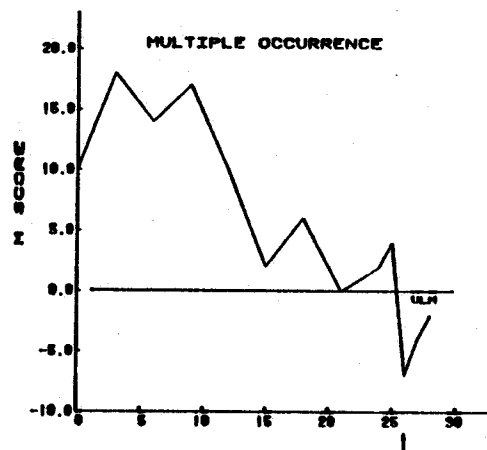
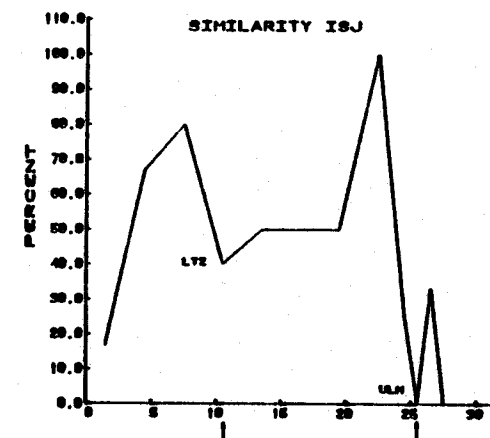
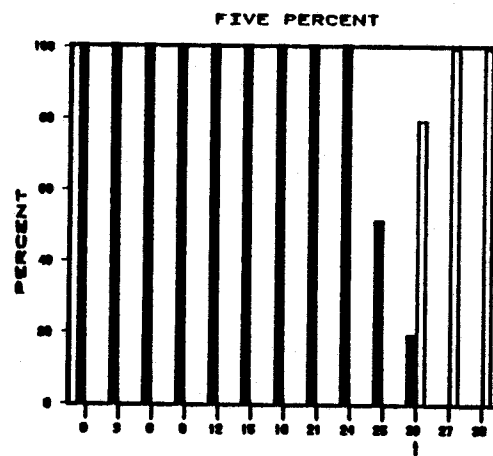
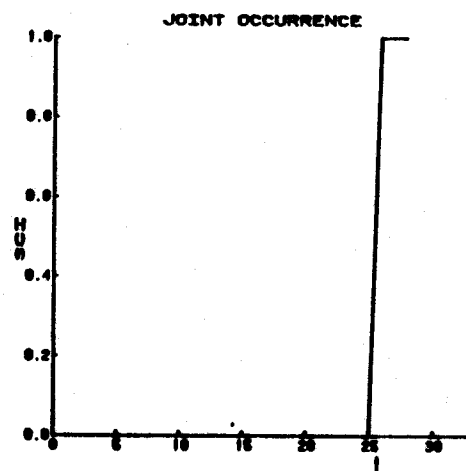
TRANSECT 1612



TRANSECT 1703



TRANSECT 1802



APPENDIX D

Sample Field Data Sheet

Date _____

[illegible]

APPENDIX E

Computer Software Available at U.S. Environmental Protection Agency, Corvallis, Oregon

Computer programs are available at the Corvallis Environmental Research Laboratory, Corvallis, Oregon for the cluster, similarity ISJ and ISE, and joint occurrence methods. We are currently developing an additional program to process data by the multiple occurrence method. Contact Jo Oshiro, U.S. EPA/CERL, Corvallis, Oregon 97330 for further information.