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James A. Moore
CUNY Queens College

Dolores Root
University of Massachusetts - Amherst

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ANADROMOUS FISH, STREAM RANKING AND SETTLEMENT

James A. Moore
Queens College/CUNY
Flushing, New York 11367

Dolores Root
University of Massachusetts
Amherst, Massachusetts 01003

Abstract

The attractiveness of anadromous fish as abundant, predictable and clustered resources is explored in terms of optimal subsistence strategies, the structural properties of drainage basins, and locational choice. Stream ranking is used to describe and to compare the ecological and structural properties of drainage basins. The structural relations of a river system were abstracted and a model system was generated. The statistical properties of this model structure have implications for the hierarchical ordering of drainage basins according to the resource attractiveness of anadromous fish. This, in turn, affects the patterns of settlement location. The predicted settlement structure, as well as several competing structures, are evaluated against the distribution of archaeological sites in the Middle Connecticut River Valley.
...settlement patterns throughout the Northeast between 8,000 and 5,000 B.C. are similar for ecological reasons. A functional analysis of the artifacts demonstrates that atlatl hunting, and meat and hide processing tools are not common, nor is fishing equipment. All told, deer hunting supplemented by some seasonal plant collecting and hunting of smaller mammals and birds resulted in hunting territories of varying size depending on local floristics (Ford 1974:356).

This statement, made by Richard Ford in a 1974 review of Eastern North American prehistory, provides a fitting summary of the assumptions and results of a site-centered approach to archaeology. The conclusions about subsistence and settlement patterns drawn from investigations of single sites have been generalized to the whole of the Eastern Woodlands. This research strategy, however, has been challenged by one with a greater concern for the variability of human behavior within its regional ecological and social context.

Anadromous fish and other riverine resources have been slighted by this site-centered approach. This is not to say that the abundance and temporal predictability of anadromous fish have gone unnoticed, but when noted these attractive qualities have not been applied to the explanation of regional subsistence and settlement behavior (cf. Sanger and others 1977; Ritchie and Funk 1973:356; Funk 1977; Ritchie 1969:375; Rippeteau 1977; and many others). A regional approach invites a reconsideration of subsistence resources which are patterned at a scale which is not easily recognized by site-centered or site catchment centered archaeology. There is more to a regional approach than the recognition of model characteristics.

Drainage basin models of river systems provide an elegant way to focus on the regional impact of anadromous fish and riverine resources on settlement-subsistence adaptations. A theoretical framework for interpreting the ecology of anadromous fish and qualifying their attractiveness as a food resource is provided by optimal foraging models. The model river system, with its consideration of the interaction of salmon and shad ecology with the structural properties of stream networks, reveals a patterned distribution of riverine resources. These patterns are used to generate hypotheses relating settlement densities to the characteristics of drainage basins. These hypotheses, and several alternatives, are tested with settlement location data from the Middle Connecticut River Valley. Finally, we discuss the implications of these models for the interpretation of New England prehistory, and archaeological approaches to settlement pattern analysis in general.

Anadromous Fish

The temporal and spatial distribution of anadromous fish created by their ecological requirements accounts for their attractiveness as a food
resource. The American Shad (Alosa sapidissima) and the Atlantic salmon (Salmo salar) provide a very good fit to the general portrait of anadromous fish with which we are all familiar. Natal homing seems to be the rule for both these species as they make their annual migrations up fresh water streams to spawn. The movements of these fish, particularly their upstream migrations, are governed by temperature. It is their preference for a certain range of temperatures which leads to an orderly and precisely timed movement between the marine and riverine environments. The timing of upstream migration is consistent; from year to year, the appearance of the run at any given location usually varies by less than five days (Leggett 1973). On the Connecticut River, shad migrate from April to June with a peak in early June (Leggett and Richard 1972), while the April to May salmon run peaks in early May (Netboy 1974; Mills 1971).

To appreciate the abundance and availability of anadromous fish, we must consider how environmental factors influence their distribution. Anadromy is an evolutionary adaptation found in highly seasonal environments. Fresh water environments are utilized to maximize reproduction, while individual growth is favored in marine environments. Streams in temperate and northern latitudes have a low primary productivity in contrast to marine environments (Schalk 1977), thus the populations of fresh water fish in these regions tend to be food and space limited. Anadromous fish do not compete for space with fresh water species, since spawning grounds with their fast-moving water and high oxygen concentration have a low productivity (Allen 1969). Nor do they compete for food, since they do not eat during migration or spawning. It is these characteristics of anadromy which account for the localized abundance of anadromous fish every spring and summer. This seasonal, clustered abundance of riverine resources stands in contrast with both the dispersed distribution of most terrestrial animal populations generated by density dependent factors and the limited availability of usable plant biomass during the spring.

The absolute peak abundance of anadromous fish does vary locally from year to year. The riverine environment is affected by the temperature and precipitation of the surrounding terrestrial environments (Hynes 1970). Fluctuations in these terrestrial factors are likely to cause a greater relative variation in small streams than in larger rivers where the effects of local variations are averaged out as the small streams flow together (Saunders 1967; Lotrich 1973). Thus smaller streams tend to be less stable environments; and it is this stability of the river environment, in particular water temperature and stream discharge of the rapidly moving, oxygen rich, and silt free waters of the smaller streams' spawning beds which controls the mortality of eggs and alevins. This, and the mortality incurred on the downstream migration create the variability in the size of returning upstream runs. Due to natal homing, the fluctuations in productivity in any one stream tend to remain independent of the variation in other streams (Talbot and Sykes 1958). It is the interaction of this variability with the dendritic structure of river systems which creates predictable distinctions within the stream habitat.
Optimal Foraging

Ecological models of optimal foraging provide a framework for predicting hunter-gatherer subsistence strategies and settlement organization. Optimization is said to occur when the rate of energy and time expenditure is minimal in relation to the rate of energy capture. This input/output index is strongly affected by the distribution of resources in time and space. Thus the strategy expected for the optimal utilization of a homogeneous environment differs greatly from the strategy applied to environments with decidedly discontinuous distributions of resources; that is, a patchy environment (MacArthur and Pianka 1966; Wiens 1976). When there is a patchy distribution of resources, the optimal foraging strategy would attempt to decrease the time and effort spent travelling between patches in order to maximize the time spent within high-density patches (MacArthur and Pianka 1966; Schoener 1971; Pianka 1974).

In mosaic environments, hunting-gathering subsistence activities will be dependent on the structure of patches through space and time. The magnitude and predictability of resource fluctuations influences locational decisions. According to this strategy, a predictable, abundant and clustered resource such as anadromous fish should structure the subsistence and settlement decisions of hunter-gatherer populations.

The Model River System

Given optimal foraging strategy and the nature of riverine ecology, it is possible to model the distribution of anadromous fish as an abundant, predictable and clustered resource, and, in turn, evaluate how it is reflected in the distribution of settlements. To proceed toward this goal we need to abstract the regional structure of a riverine system, and to examine the statistical properties of this structure which reflect the patterned distribution of resources.

One can describe and evaluate the ecological and structural properties of any drainage basin using the methods of stream ranking developed by geomorphologists (Haggett 1967:624-632; Strahler 1952, 1957, 1958). The Strahler method of ranking used in this analysis starts with the smallest streams at a given scale of analysis. These small streams, the rivulets, are labelled rank one streams (Figure 1). The merging of two rank one streams creates a rank two stream. Two rank two streams merge to form one rank three, and so on. With indices derived from this organizational technique, it is possible to compare drainage basins, and to examine the evolution of landforms, as is done by geomorphologists, or to examine the relationship of these landforms to the distribution of archaeological sites (Dincauze, Moore, and Root 1977; Dincauze 1978).

Our studies of the Connecticut River drainage have established that, on the average, three to five lower order stream segments flow into each higher order segment (Dincauze, Moore, and Root 1977). Once this bifurcation ratio is assumed, an abstracted model river system can be generated. In Figure 1 we have established the structure of our model river system with
Figure 1. The model river system.
a bifurcation ratio of three to one. This model structure has statistical properties which have strong implications for the selection of optimal foraging strategies and the hierarchical ordering of resource utilization areas. The statistical properties and their implications are understood by first quantitatively defining the features of resource attractiveness and then using these quantitative expressions to predict the distribution of anadromous fish attractiveness in our model river system, and, in turn, the distribution of settlements.

The Mathematical Model

The optimal foraging strategy model highlighted abundance, predictability, and patchiness as characteristics which should structure the hierarchy of resource attractiveness. In order to place these concepts into an integrative model it is necessary to carefully develop definitions which will allow us to mathematically manipulate the concepts. Resource abundance at any location can be measured as the estimate of the population mean. The predictability of resources can be discussed in terms of the standard error of the estimate of the population mean (Fig. 2). This is an indicator of the variability in the estimates of the mean made from the same statistical population. Conceptually less straightforward, but more mathematically tractable is the variance of the estimate of the population mean; that is, the square of the standard error. We will assume that for riverine resources the degree of spatial clustering is constant. Combining these measures, we have the variance to mean (VM) ratio which quantitatively expresses the variance, or unpredictability, per unit of abundance (Fig. 2). This measure allows us to compare the variability of anadromous fish populations in streams which have differing abundances. We will refer to this VM ratio as pattern strength. High variance to mean ratios indicate that the distribution is more irregular than random, that is, resource predictability is less; while smaller variance to mean ratios indicate that the distribution is more uniform or regular, and the relative abundance of resource is predictable (Pielou 1969; Odum 1971:205-207; Paynter, Green and Wobst 1977). Lower variance to mean ratios mean a greater degree of pattern strength, and a greater attractiveness of the location for subsistence activities.

To develop the statistical relationships of the pattern strength of anadromous fish and the model river system, to the choice of settlement locations, it is necessary to make a simplifying assumption concerning the nature of anadromous fish migration and spawning. The complexity of the interactions among the multiple factors affecting the success of the spawning and migration for any bed is assumed to create a normal distribution in the numbers of fish returning to that bed from year to year (Bradley 1976:383-433). If more complex modeling of anadromous fish attractiveness was desired, the mathematical model could manipulate means, variances, and covariances for the productivity of each spawning bed to create a more complex hierarchical ordering of stream attractiveness. Presently, such complexity will not improve our understanding of settlement process and so we will assume that the means and variances of all spawning beds are equivalent.

We can now illustrate the hierarchy of pattern strength for anadromous fish in the different rank streams. It is a statistical fact of life that the poorest estimate of the population mean is likely to be made if a
**Figure 2.** Model parameters. $\bar{X}$ is the mean abundance of a rank I stream. $N$ equals the number of rank I segments subsumed by a given rank stream segment.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Pattern Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank 1</td>
<td>$\frac{\sigma^2}{\bar{X}}$</td>
</tr>
<tr>
<td>Rank 2</td>
<td>$\frac{\sigma^2}{3\bar{X}}$</td>
</tr>
<tr>
<td>Rank 3</td>
<td>$\frac{\sigma^2}{9\bar{X}}$</td>
</tr>
<tr>
<td>Rank 4</td>
<td>$\frac{\sigma^2}{27\bar{X}}$</td>
</tr>
<tr>
<td>Rank 5</td>
<td>$\frac{\sigma^2}{81\bar{X}}$</td>
</tr>
<tr>
<td>Rank 6</td>
<td>$\frac{\sigma^2}{243\bar{X}}$</td>
</tr>
<tr>
<td>Rank 7</td>
<td>$\frac{\sigma^2}{729\bar{X}}$</td>
</tr>
</tbody>
</table>

**Figure 3.** Pattern strength for the model river system.
single sample unit is drawn. Repeated draws of single samples from the same statistical distribution will likely show large differences. In terms of the distribution of shad and salmon, this means that the number of adults returning to a rank one stream may vary considerably from year to year and place to place. However, the accuracy of a sampling procedure, as measured by the standard error, is affected by the number of sample units drawn. The probable accuracy of the estimate of the population mean can be enhanced by increasing the number of sampling units drawn before calculating the estimate of the mean. Therefore, if we increase the number of sample units of spawning beds, the estimate of the mean number of salmon or shad returning to the spawning bed is more probably accurate, and the variance of the estimate is reduced relative to the abundance. It is this effect of the increase in sample size on the variance of the estimate which creates a pattern strength hierarchy of the different stream ranks. In effect, each higher ranked stream segment samples a greater number of spawning beds. This means, in turn, that there is a lower degree of variability per unit of abundance of the fish running upstream as the stream rank increases (Fig. 3).

The index of pattern strength, a combined measure of abundance, predictability and clustering, can be applied to all segments of our model drainage basin to develop a ranking of the attractiveness of each river segment for exploitation. In our model drainage system, stream segments of each rank order will have three times the attractiveness of the next lower ranked segment (Figure 1). In this framework, the pattern strength generated by a salmon run in a rank seven stream is 729 times greater than the pattern strength of a run in a rank one stream. The implication for the real world is that higher ranked streams have less variable fish runs, are more predictable, and therefore, are more attractive to humans. And, finally, the relationship of locational attractiveness to stream rank is not a simple linear relation.

Following the logic to its conclusion, it is possible to say that the best location for salmon fishing is the estuary. Brennan (1977), however, has pointed out that although both shad and salmon run up the Hudson, excavation of over twenty Archaic and Woodland period sites has failed to reveal any indication of heavy reliance on anadromous fish. What then are the factors which limit the attraction of the high ranking streams - technology and social organization. As the size of the stream increases, so do the technological problems of exploitation. In the lower Hudson Valley, the estuary is well over a mile wide. This presents a severe technological challenge. Large boats and large fishing nets, and the social organization they imply are costly solutions (Schalk 1977). There are, however, low technology-low cost solutions to this problem. Falls and rapids provide locations which can be effectively exploited with small nets, gill nets, fishweirs, or by hand.

The temporal unpredictability of anadromous fish has been put forth as another a priori objection. Brennan (1977) has suggested that even a week's delay in the appearance of the salmon and shad could have had disastrous effects for the groups living on the Lower Hudson River. It should
be recognized that in specific cases scheduling conflicts might exist which would lower the attractiveness of anadromous fish. But in the general case, the spring bloom of plants in the valley bottoms occurs weeks before the surrounding hills. Game as well as waterfowl are attracted to the valley bottom during the spring fluorescence. It can be concluded that generally there is neither spatial nor temporal conflict among the vernal resources. The timing of the fish run in the context of these subsidiary resources is not critical.

Using the pattern strength hierarchy, we can now predict the frequency of spring fishing sites on the high ranking waterways in terms of the resource attractiveness of the anadromous fish runs. The physical properties of river systems structure anadromous fish runs to form a hierarchical arrangement of pattern strengths. The technological problems of exploiting the higher rank streams and the vagaries of the subsidiary resource distributions can limit the realization of the potential suggested by the pattern strength; however, the presence of falls and rapids with the existence of a reasonably broad and diverse valley bottom should permit the suggested pattern strength hierarchy to structure prehistoric subsistence/settlement behavior.

The Connecticut Valley: A Trial Evaluation of the Model

Shad and salmon were present in the lower and middle reaches of the Connecticut River until the dams, pollution, and erosion of the 19th century sharply reduced their range and numbers. In the historic period salmon migrated to within 27 miles of the headwaters of the Connecticut River to Beecher Falls (374 miles inland), while shad ran as far upstream as Bellows Falls, Vermont (195 miles inland) (Banks 1969:105, Walburg and Nichols 1967:79-81). Their presence offers the opportunity to evaluate our regional model of the effects of anadromous fish on prehistoric settlement patterns against the distribution of known archaeological sites in Franklin County, Massachusetts.

Sixty-six known archaeological sites were placed into the sixteen Franklin County drainage basins (Massachusetts Water Resources Council Map). The number of sites in each drainage basin was then tabulated. Of the sixteen drainages, only seven contained known archaeological sites. It is our belief that the drainage basins which are without known sites have not been adequately surveyed, or have sites which have not been properly reported (Gero and Root 1978). Only the seven basins with reported sites were included in the hypothesis testing.

The hypotheses to be tested are offered as implication of possible explanations of the distribution of sites among the drainage basins. Alternate hypotheses are considered to evaluate the degree to which different locational rules could lead to similar distributional patterns (Table 1).

It could be suggested that the distribution of archaeological sites in Franklin County is independent of the analytic drainage basins units we
<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>PREDICTED DISTRIBUTION</th>
<th>( X^2 )</th>
<th>D.F.</th>
<th>( P &lt; .005 )</th>
<th>FAILURE TO REJECT H AT .05 LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H_0 )</td>
<td>RANDOM</td>
<td>46.0</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_1 )</td>
<td>PROPORTIONAL TO AREA</td>
<td>51.8</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_2 )</td>
<td>PROPORTIONAL TO STREAM LENGTH</td>
<td>45.5</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_3 )</td>
<td>PROPORTIONAL TO NO. RANK 1 STREAMS</td>
<td>52.2</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_4 )</td>
<td>PROPORTIONAL TO NO. RANK 2 STREAMS</td>
<td>37.5</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_5 )</td>
<td>PROPORTIONAL TO NO. RANK 3 STREAMS</td>
<td>50.9</td>
<td>6</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_6 )</td>
<td>PROPORTIONAL TO NO. RANK 4 STREAMS</td>
<td>27.0</td>
<td>3</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_7 )</td>
<td>PROPORTIONAL TO NO. STREAMS ( \geq ) RANK 5</td>
<td>32.2</td>
<td>3</td>
<td>( P &lt; .005 )</td>
<td>X</td>
</tr>
<tr>
<td>( H_8 )</td>
<td>PROPORTIONAL TO BASIN WEIGHTING FACTORS</td>
<td>12.1</td>
<td>6</td>
<td>(.05 &lt; P &lt; .10)</td>
<td>X</td>
</tr>
</tbody>
</table>

Table I. Summary of hypotheses and test results.
have proposed. This leads to our null hypothesis:

\[ H_0: \text{The known sites are randomly distributed among the drainage basins.} \]

Alternately, it could be proposed that terrestrial resources do strongly affect the distribution of sites. If this were the case, the surface area of each of the drainage basins would be a factor controlling the distribution of sites:

\[ H_1: \text{The known sites are distributed in proportion to the area of each of the drainage basins.} \]

The distribution of resources may not be affected by stream rank. Instead, it would be the total length of streams in each of the basins which would influence the distribution of sites:

\[ H_2: \text{The known sites are distributed in proportion to the total stream length of each of the drainage basins.} \]

It is possible that our estimate of the variability of spawning bed productivity is unrealistic. All spawning beds would then be very attractive for exploitation. One could also question our placing of the spawning grounds in rank one streams. Given these considerations several alternate hypotheses are possible:

\[ H_3: \text{The known sites are distributed in proportion to the number of rank one streams in each of the drainage basins.} \]

\[ H_4: \text{The known sites are distributed in proportion to the number of rank two streams in each of the drainage basins.} \]

\[ H_5: \text{The known sites are distributed in proportion to the number of rank three streams in each of the drainage basins.} \]

\[ H_6: \text{The known sites are distributed in proportion to the number of rank four streams in each of the drainage basins.} \]

The distribution of sites could be influenced by higher ranked streams. This settlement distribution might reflect an association of resources with higher ranked streams. A similar distribution of settlement location could be generated by the access to trade routes along major waterways.

\[ H_7: \text{The known sites are distributed in proportion to the number of streams with a rank of five or greater in each of the drainage basins.} \]

Finally, the pattern strength model developed in accordance with optimal foraging strategy and the model river system predicts a hierarchy of resource attractiveness among the different ranked streams. The attractiveness of each of the drainage basins can be calculated as the sum of the pattern strengths of all of the streams in each drainage basin.
H8: The known sites are distributed in proportion to the summed attractiveness of all of the streams in each of the drainage basins.

A chi-square test was performed to evaluate the goodness of fit of the predicted distributions to the observed distribution of known sites. Table 1 summarizes the hypotheses and the outcomes of the tests. All hypotheses were rejected with the exception of H8—the distribution generated by the pattern strength-optimal foraging strategy model. At the .05 confidence level, we cannot reject the proposed regional relationship of the pattern strength of anadromous fish abundance to the distribution of settlements.

The coefficient of linear correlation (Pearson's r) can be used to further examine the strength of the relationship between the drainage basin pattern strengths and the distribution of known sites. The correlation coefficient can vary from a positive one, a perfect positive correlation, to a negative one, a perfect inverse relationship. A zero would indicate that the variables are independent. The correlation of the basin pattern strengths to the distribution of known sites was moderately strong at .595. This can be interpreted to mean that variation in the pattern strength among the basins accounts for 35.4% of the variation in site distribution. Our model has generated a structuring principle which accounts for a not insubstantial part of the subsistence and settlement behavior of the Middle Connecticut Valley.

Discussion

Our interest in regional processes has led to a model of the regional impact of anadromous fish runs on subsistence and settlement patterns. The model consists of three components—optimal foraging strategy, generalized patterns of anadromous fish behavior, and a mathematical model of river systems which links the model subsistence strategy to the regional spatial framework. The hypothesis generated by the model was not falsified when evaluated against sixty-six known Archaic and Woodland period sites in Franklin County.

We can conclude that the tools used in the analysis have demonstrated their potential. Furthermore, optimal foraging strategy provided a framework more sensitive to the spatial and temporal variability of resource abundance and consumption than the annual productivity estimation methods commonly used. The stream ranking model imposed a regional approach to subsistence/settlement problems. It also provided us with drainage basin units for comparative analysis of settlement decisions. This use of drainage basins prevents the terrestrial bias which is inherent in the use of comparative units based solely on soil types, or geomorphology. Finally, mathematical modeling of the characteristics of stream networks invited new hypotheses which were not obvious prior to formal modeling.

The relative success of a model based solely and simplistically on anadromous fish in accounting for site location suggests problems with some dominant assumptions of Northeastern prehistory. First, the
prehistoric resource base has consistently been reconstructed from soil and pollen data, or from mapping of present day vegetation patterns. This has resulted in a bias toward terrestrial resources. Second, the descriptive generalization of "primary forest efficiency" has then been applied to this biased reconstruction to support a catch-as-catch-can local subsistence model (Caldwell 1958). While Caldwell's model, and Ford's later restatement of it, do recognize the importance of differences in local conditions, the site-oriented approach failed to deal with regional or inter-regional patterns of variation. These two points now deserve a challenge.

The optimum foraging model implies that one must consider fish when generating models of subsistence patterns. Yet this cannot be done blindly. Shad jump only five to six feet; salmon twelve. Falls can easily block the upstream movement of these fish. The migration of fish up the Hoosatonic River is blocked at Falls Village, Connecticut. The lower rank of the Hoosatonic also affects the pattern strength of the other riverine resources. Clearly, the subsistence/settlement model we have developed for the Connecticut River cannot be transferred directly to the Berkshires. The balance of terrestrial to riverine resources will vary according to regional characteristics. (As an aside we might note that it would be an evaluation of the model's usefulness, if it were demonstrated that the basin weighting model accounted for less of the variance of settlement location on the Hoosatonic River.)

These differences in the late spring/early summer subsistence base between the Connecticut River Valley and the surrounding highlands affects the operation of the subsistence system in the following seasons. Archaeologists have often started modeling seasonal rounds with the implicit assumption that subsistence activities of any one season are independent of the subsistence activities of other seasons. This is not the case. The information about resources collected and shared at any aggregation affects the future locational decisions made by the group. In this manner, information sharing networks effectively lower search costs, and provide for a fuller utilization of resources (Hamilton and Watt 1970).

Along the Connecticut River, population clusters at the spring fishing sites would allow greater exchange of information among the aggregated groups. This, in turn, leads to a more intensive utilization of summer and fall resources owing to more effective planning, more efficient use of space, and lower search costs during the dispersal from the spring fishing aggregations (Moore 1977). The Massachusetts section of the Hoosatonic drainage, and most likely the Worcester Plateau as well, appear to lack resources with sufficient pattern strength to encourage spring or summer aggregation. Given the lack of aggregation in these areas, information should have flowed less rapidly and less uniformly; and as a result, these highland areas had a lower resource utilization intensity—spring, summer, and fall—than the areas around the fishing falls of the Connecticut River Valley.
More generally, our study suggests that population is not distributed in a simple, immediate relation to the distribution of the biomass. Rather, locational choice is made with regard to the limited available information of the resource distribution. Aggregation amount of information available about resources, and the ease of planning the use of these resources. We would do well to remember that it is the pattern of information exchange, as well as the pattern of resource distribution, which creates regional settlement systems.

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