The influence of time averaging and space averaging on the application of foraging theory in zooarchaeology

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Abstract

Use of models derived from foraging theory to explain variation in prey-abundance indices over time and space, evidenced in the zooarchaeological record, is common in western North America. Such use presumes that models derived from ecologically scaled observations are applicable to archaeologically scaled observations. The influence of time averaging and space averaging, whether inherent in the zooarchaeological record or resulting from analytical lumping, on interpretations of changes in relative availability of prey is demonstrated with real data to mask fine-scale variation. The critical issue that must be addressed at the beginning of any application of foraging-theory models is the specification of the spatio-temporal scale of the research question.

Keywords: Foraging theory; Prey-choice model; Space averaging; Time averaging; Zooarchaeology

1. Introduction

For more than 20 years, Americanist zooarchaeologists have called on foraging theory [58] to provide models of human-resource use [3,68]. Even biologists have occasionally applied such models to zooarchaeological materials [35,55]. During the 1990s, use of these models in western North America resulted in the development of a set of methods for monitoring the history of human resource use as evidenced by the zooarchaeological record [8–11,15,19,32–34,50,51,63]. Some of the more interesting implications of these models concern the fact that pre-industrial humans had significant influences on prehistoric faunas the world over; these implications have now been abundantly confirmed by the zooarchaeological record (summarized in Ref. [29]). In particular, as a result of their selective exploitation of prey taxa that provided either or both low costs and high returns, humans with primitive technologies often caused changes in faunal diversity (taxonomic richness and evenness), independent of changes in climate. Therefore, humans sometimes had to alter what they were exploiting as a response to a change in the availability of animal prey that they themselves had caused.

Many significant new insights into the past have been provided by applying foraging theory to zooarchaeological problems. Yet such application is not always straightforward and thus the voice of caution has occasionally been heard. For example, many studies conclude that changes in the list of exploited prey to include more small, low-value prey taxa were the result of human exploitation depressing the availability of large, high-value prey taxa. The voice of caution requires that this explanation be substantiated by disconfirmation of alternative causes of depressed prey availability, such as changes in technology, changes in how technology was used, and environmentally or climatically driven changes in taxonomic abundances [30]. Further, it has been pointed out from an Old-World context that zooarchaeological abundances of Linnaean taxa do not always reveal changes in prey availability with respect to particular spatio-temporal coordinates [59]. Finally, it has been noted that the traditional means of quantifying prey abundances—the number of identified (faunal) specimens (NISP) per taxon—entails various epistemological and interpretive difficulties [66]. Importantly, analytical techniques have
been and are being developed for addressing a number of these issues [18,31,60,61,67].

One potential difficulty for which there presently is no obvious analytical solution is that, as Grayson and Delpech [31, p. 1119] put it, if one is to apply explanatory models derived from foraging theory to the zooarchaeological record, “concepts that are meant to apply in ecological time must be translated to archaeological time.” In particular, they underscore the fact that with respect to prey-choice or diet-breadth models, where either is measured as the number of taxa exploited or taxonomic richness (NTAXA), the time period represented by a zooarchaeological assemblage results in taxonomic richness (NTAXA), the time period represented by a zooarchaeological assemblage results in taxonomic richness (NTAXA), the time period represented by a zooarchaeological assemblage resulting from that 100 years will be 10—the maximum number of taxa exploited (see also Ref. [12]). The significant point of this example is that variation between the first 99 years and the 100th year will be masked by the fact that multiple annual assemblages have been lumped by the formational history of the assemblage. Paraphrasing their example, if five taxa are exploited over 99 years, but those five taxa plus five additional taxa are procured in the 100th year, then diet breadth rendered as NTAXA for the assemblage resulting from that 100 years will be 10—the maximum number of taxa exploited (see also Ref. [12]). The significant point of this example is that variation between the first 99 years and the 100th year will be masked by the fact that multiple annual assemblages have been lumped by the formational history of the zooarchaeological assemblage. It is the effect of such lumping, whether along the temporal dimension, the spatial dimension, or both, that is one concern here.

A second concern is that there is another potential difficulty not previously mentioned in the pertinent literature. It resides in the variable typically referred to as sample size. The influences of sample size rendered as NISP are often acknowledged, and most zooarchaeologists who apply models derived from foraging theory to their data take steps to account for sample size when taxonomic richness or taxonomic abundance is measured with NISP (see Ref. [20] for a particularly important method in this respect). No zooarchaeologist I am aware of, however, has considered the potential influence of sample size rendered as the number of analyzed spatio-temporally distinct assemblages—what I will term NASM—of faunal remains, which arguably comprises a measure of sample size at a different scale than NISP.

The third and final concern resides in the fact that zooarchaeological assemblages comprise samples of different portions of the spatial and temporal continuums. For discussion purposes I refer to these portions as contexts, irrespective of size or duration. Each assemblage of faunal remains occupies a unique context in terms of its spatial and temporal coordinates. The influence of the number of unique spatio-temporal contexts included in an analysis on interpretations of changes in prehistoric foraging is only now beginning to be examined (see subsequently). I refer to the frequency of these contexts generally as NCTX, the number of spatial contexts as NCTXspace, and the number of temporal contexts as NCTXtime. Note that sometimes NASM = NCTX, but the more typical relation will be NASM > NCTX as a result of analytical lumping. In this article, I explore some of the effects that NASM and NCTX have on analytical results produced by application of methods derived from foraging-theory models and used by zooarchaeologists working in western North America.

2. The usual method

I will not review the reasoning behind the application of foraging-theory models to zooarchaeological data here, as there are numerous such discussions now available [8,9,30]. It suffices to note that as used in western North America, the typical basic model—the prey-choice model—is that human foragers will preferentially exploit the largest prey first because these taxa are the most valuable. The model further holds that if valuable prey decrease in availability and thus the frequency at which they are encountered decreases, then foragers will turn to progressively more kinds of less valuable, generally smaller, prey—each individual considered less valuable than a single larger individual—to maintain a constant level of nutrition. Thus, the ratio of large to small + large prey will fluctuate over time, decreasing (becoming progressively smaller than 1.0) as large prey become less available relative to small prey and increasing (becoming progressively closer to 1.0) as large prey become more available relative to small prey. Typically, prey abundances measured as NISP are rendered as an index value between 0.0 and 1.0 that expresses the ratio of large to small + large prey. Ugan and Bright [66, p. 1309] refer to these index values as “relative abundance indices (AIs),” and I use their acronym in the remainder of my discussion. Plotting each AI against the temporal midpoint of the time span during which the faunal remains on which it is based were deposited—whether stratigraphically, radiometrically, or culturally determined—in a bivariate scatterplot, visually reveals what are interpreted to be changes in prey return rates that are in turn interpreted to reflect changes in prey availability or abundance. Interpretation of the scatterplot is sometimes aided by calculating a simple best fit regression line through the point scatter in order to reveal temporal trends [8,9,33].

Many applications of foraging-theory models to zooarchaeological data concern temporally distinct (usually stratigraphically delimited) faunal assemblages recovered from a single site, or faunal assemblages from several geographically propinquitous sites distributed across several temporal periods. In a bivariate scatterplot of data points, with the x-axis usually representing time and the y-axis usually representing the AIs, there are few data points. This makes both the visual and the
statistical detection of trends in changing faunal abundances relatively easy and the interpretation of the covariation between the two variables rather straightforward. The critical issue to recognize is that if NASM is small, then few points comprising AIs will be plotted. For example, Butler [16] plotted AIs for eight temporally distinct assemblages from a single site against their ages; Broughton [9] plotted AIs for nine assemblages from nine sites against their ages; Potter [50] plotted AIs for six assemblages from two sites against four time periods; Janetski [33] plotted AIs for 20 assemblages from 19 sites against their ages; Broughton [8] plotted AIs for 18 assemblages from 14 sites against their ages; and Broughton [11] plotted 14–16 AIs against 10 temporally distinct strata in a single site. In each of these applications, NASM ≤ 20.

Not only does NASM tend to be small, but in each of the examples just listed, spatial and/or temporal variation was variously muted over multiple assemblages. There are several ways in which spatio-temporal variation can be analytically muted. These can be illustrated by considering two fictional assemblages (NASM = 2), each from a different site. Assume that the sites are geographically close, but vary in microhabitat (NCTXspace = 2), that the assemblages were deposited over similar durations of time (say, 400 years), that the assemblages are temporally sequential in age (NCTXtime = 2), and that the assemblages belong to the same archaeological culture based on their associated artifacts. What are the analytical alternatives? Because the assemblages differ in spatial and temporal coordinates, each AI might be plotted against its age in a separate graph or plotted in the same graph with a different symbol denoting a different geographic position, thereby maintaining the distinctive geographic (and temporal) coordinates of the two. Or, the two AIs might be plotted in the same graph using the same symbol, thereby muting their geographic distinctiveness (NCTXspace = 1), but maintaining their temporal distinctiveness (NCTXtime = 2). Alternatively, the AIs might be plotted with different symbols in the same graph to maintain their geographic contexts, but according to the cultural period to which they belong, thereby muting their temporal distinctiveness (NCTXtime = 1). Finally, the NISP per taxon of the two assemblages might be summed, an AI calculated, and that value plotted against either the absolute (average) age of the two assemblages or the cultural period represented by the two. This last possibility would mute the spatial and temporal distinctiveness of the two assemblages (NCTX = 1) as well as mute their distinctive taxonomic richnesses, evennesses, and heterogeneities in favor of what we can call a general or universal (with respect to the two assemblages) spatio-temporal-taxonomic measure (NASM = 1). In the first three alternatives, variation in geographic space and/or time between the two assemblages is muted; NCTX is reduced analytically. In the fourth alternative, not only are both spatial and temporal variations muted, but so are variables of taxonomic structure and composition; NASM is reduced.

Examples of the potential ways that one might analytically lump contexts or assemblages are found in the extant literature. For example, Janetski [33] plotted (NASM = 16) AIs from a single physiographic area and representing a single cultural period against the midpoint of their absolute ages. The 16 assemblages were derived from an area approximately 400 × 150 km, but NCTXspace was analytically reduced from 16 to 1 by lumping. Szuter and Bayham [64] summed NISP data from 70 sites (NASM = 70, NCTX = 70) into 11 temporally distinct sets (NASM = 11, NCTXtime = 11) in a single area (NCTXspace = 1) and plotted the AIs against the midpoint of the temporal period represented, thereby muting both temporal and spatial variations. Butler [15] summed NISP data from eight sites (NASM = 9, NCTXspace = 8, NCTXtime<9) by cultural period (NCTXtime = 4) for an area (NCTXspace = 1) and plotted AIs against the appropriate temporal midpoint of a cultural period, thereby potentially muting both temporal variation and spatial variation.

With no explicit warrant for analytically reducing NCTX or NASM by lumping temporally and/or spatially propiniquous assemblages, the question of what effect that lumping might have on results is begged. The source of such a question resides in a fundamental dictum of archaeology that the subject of study comprises three dimensions of archaeology which AIs are derived; and time comprises variation in the temporal positions of the assemblages from which AIs are derived.

In many cases, the lumping of otherwise spatially and/or temporally distinct assemblages is not explicitly justified in the literature. Some possible reasons for such lumping can, however, be suggested. It could be argued that lumping removes the effects of seasonal, geographic, and individual variation in resource exploitation in the interest of determining an annual, regional, or overall pattern; such a warrant has been characterized as the “‘noise-filtering’ of time averaging” [47, p. 226]. In zooarchaeology, such noise filtering would provide what Uerpmann [65] referred to 30 years ago as the “average diet” of prehistoric peoples across a geographic area (rather than a single site locality) and/or across a greater or lesser span of time (rather than a single meal or day’s worth of meals). Paleoecologists have long been concerned about the influence of what they refer to as “time averaging” on ecological interpretations of faunal assemblages [4,48,52], and they have developed various
methods for analytically detecting and contending with time averaging (Refs. [14,37], and references therein). Paleobiologists have also long been aware that some accumulations of faunal remains represent multiple biotic communities [53,54], or what are readily termed ‘space-averaged’ assemblages, and methods have been developed for recognizing these [28]. Archaeologists, too, have long been cognizant of such assemblages, referring to them as resulting from ‘blending and smearing’ [2] that produces “coarse-grained assemblages” [6]. Such spatio-temporal palimpsests are the bane of those seeking fine-scale resolution, but this is not meant to suggest that spatially or temporally lumped or blended assemblages are to always be avoided. Palimpsest assemblages may be useful and appropriate for some questions [47], and I return to this point later. “Palimpsest,” “blended,” and “averaged” are reasonable terms for those spatio-temporally unique materials that were lumped during formation of the zooarchaeological record or that have been analytically produced. The important point in the context of how foraging theory has been applied to zooarchaeological data is that such averaging comprises the conversion of ecological time and space into archaeological time and space. Choosing to plot an assemblage against the temporal midpoint of the period during which it was deposited, or lumping data of various ages into a single temporal or cultural period to derive a measure of diet—a more or less ‘space-averaged’ assemblage—per period results in some unknown degree of time averaging. Similarly, lumping zooarchaeological data from multiple sites that are variously geographically distant from one another and that date to the same period (if not precisely contemporaneous) in order to derive a measure of diet results in some unknown degree of spatial averaging. Cannon [19] has recently addressed the possible effects of the spatial averaging and suggested ways to analytically contend with such effects. In the following sections, I use real data sets to explore the potential effects of temporal averaging, spatial averaging, and simultaneous averaging of both time and space on interpretations. In doing so, I am less interested in the interpretations that one might derive from a data set than on the effects on those interpretations that result from temporal and spatial averaging.

3. Materials and methods

For purposes of detecting the influences of spatio-temporal lumping on analyses and interpretations, the ideal situation would be to have assemblages meeting three criteria. First, the assemblages would be from various geographic locations in one physiographic area. Such cases are commonplace in western North America where many archaeological projects have been undertaken under the auspices of cultural-resource management. Second, each assemblage would be of sufficient size in terms of NISP to allow analytical lumping of more-or-less contemporaneous and geographically propinquitous assemblages. This is sometimes found in western North America, but many assemblages there are also small, given the contingencies of the particular project. Third, the assemblages would be of relatively short duration—say, deposited in a single season in temperate latitudes—in order to allow analytical lumping dictated by research questions rather than by the realities of the variously time-averaged zooarchaeological record. No such zooarchaeological record in terms of this third criterion is known to me. Several regional archaeological projects can, however, be analytically made to come close to meeting these criteria.

In the 1970s and 1980s, a number of archaeological sites located adjacent to a stretch of the Columbia River of north-central Washington state were excavated as part of two reservoir projects [17,21]. These sites contained evidence of human occupation spanning the last 7000 years and representing multiple local cultural periods. Many, but not all, of the sites produced numerous faunal remains. I compiled data on NISP per taxon per assemblage, assemblage age, and assemblage location from reports resulting from the excavations. The data comprise 31 assemblages (NASM = 31) recovered from 18 sites (NCTXspace = 18) distributed along approximately 420 km of the Columbia River (Table 1). Five individual site assemblages from the westernmost portion of the area (Wells Reservoir) were spatio-temporally lumped for purposes of this analysis to avoid possible effects of sample size rendered as NISP, so NCTXspace has already been reduced to 12. Assemblages used in my analyses are of various ages (NCTXtime = 30) and span the last 5000 radiocarbon years; some of them are relatively synchronous and represent brief time intervals (ca. 200 years) whereas others represent longer periods of duration (e.g. 2200 years). For analytical and graphing purposes, I follow previous researchers and use the chronological midpoint (to the nearest 100 years) of each assemblage. This means that varying degrees of time averaging have already been built into the analysis.

In light of a recent study of the early historic faunal situation in eastern Washington that suggested that prehistoric human foragers there had depressed large game populations [44,45], I designed three indices to monitor changes in prey abundances over time. One index is based on the fact that as large mammalian prey decrease in abundance, one response of human foragers might be to broaden the diet to include more small-mammalian prey and more individuals of small-mammal taxa. Because few small-mammal taxa seem to have served as human prey throughout the Holocene (last 10,000 years) of eastern Washington [41], and because NISP sample sizes for these taxa tend to be
small, I lumped all small-mammal prey taxa into a single category—small mammals. Similarly, because virtually all large-mammal prey are artiodactyls, and because deer (*Odocoileus hemionus* (mule deer) and *O. virginianus* (white-tailed deer)) tend to dominate most collections, I lumped the five taxa of artiodactyls (*Odocoileus* spp., *Ovis canadensis* (bighorn sheep), *Antilocapra americana* (pronghorn antelope), *Cervus elaphus* (wapiti, or elk), *Bison bison* (bison)) into one category—artiodactyls.

The first AI is termed the small-mammal index and is calculated as

$$\text{small mammal AI} = \frac{\sum \text{ small mammal NISP}}{\sum \text{ artiodactyl NISP}}$$

To calculate this index, I included only taxa the remains of which displayed evidence of human exploitation. That evidence typically was in the form of butchering marks, burning, bone breakage, and skeletal disarticulation [42]. Small-mammal taxa include marmot (*Marmota flaviventris*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), red fox (*Vulpes vulpes*), canids (*Canis latrans, C. lupus*), mustelids (Mustelidae), and bobcat (*Lynx rufus*). Bears (*Ursus americanus, U. arctos*) and cougars (*Felis concolor*) were omitted from the analysis because they are very rarely represented. Note that the greater the abundance of artiodactyl remains relative to small-mammal remains, the closer the small-mammal AI will be to 1.0.

The specific response of human foragers in eastern Washington to depressed large-game populations hypothesized by Martin and Szuter [44,45] involved the intensification of fishing. To determine if this in fact happened, a measure of the abundance of artiodactyls relative to that of fish is necessary. The second AI, then, is termed the fish index and is calculated as

$$\text{fish AI} = \frac{\sum \text{ fish NISP}}{\sum \text{ artiodactyl NISP}}$$

Fish exploited by prehistoric foragers included several species of salmonids and steelhead trout

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Table 1

Zooarchaeological data from north-central Washington state by site and age

<table>
<thead>
<tr>
<th>Site/location</th>
<th>Age midpoint</th>
<th>Artiodactyl NISP</th>
<th>Small mammal NISP</th>
<th>Fish NISP</th>
<th>Small mammal AI</th>
<th>Fish AI</th>
<th>Nonartiodactyl AI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wells Reservoir*</td>
<td>4350–3800</td>
<td>247</td>
<td>151</td>
<td>303</td>
<td>0.62</td>
<td>0.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Wells Reservoir*</td>
<td>3300–2200</td>
<td>88</td>
<td>82</td>
<td>4812</td>
<td>0.52</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Wells Reservoir*</td>
<td>900–100</td>
<td>2</td>
<td>13</td>
<td>7235</td>
<td>0.13</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>45DO-326</td>
<td>300–100</td>
<td>81</td>
<td>21</td>
<td>8</td>
<td>0.79</td>
<td>0.91</td>
<td>0.74</td>
</tr>
<tr>
<td>45DO-326</td>
<td>1500–800</td>
<td>64</td>
<td>52</td>
<td>3</td>
<td>0.55</td>
<td>0.96</td>
<td>0.54</td>
</tr>
<tr>
<td>45DO-326</td>
<td>4500–3000</td>
<td>12</td>
<td>51</td>
<td>10</td>
<td>0.19</td>
<td>0.55</td>
<td>0.16</td>
</tr>
<tr>
<td>45DO-326</td>
<td>5000–4500</td>
<td>45</td>
<td>166</td>
<td>67</td>
<td>0.21</td>
<td>0.40</td>
<td>0.16</td>
</tr>
<tr>
<td>Eastern</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>45OK287/288</td>
<td>1500–850</td>
<td>167</td>
<td>1</td>
<td>5</td>
<td>0.99</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>45OK287/288</td>
<td>4400–1500</td>
<td>426</td>
<td>11</td>
<td>4</td>
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<td>0.99</td>
<td>0.97</td>
</tr>
<tr>
<td>45OK287/288</td>
<td>4800–4400</td>
<td>103</td>
<td>22</td>
<td>0</td>
<td>0.82</td>
<td>1.00</td>
<td>0.82</td>
</tr>
<tr>
<td>45OK-2</td>
<td>300–100</td>
<td>581</td>
<td>22</td>
<td>61</td>
<td>0.96</td>
<td>0.90</td>
<td>0.88</td>
</tr>
<tr>
<td>45OK-2</td>
<td>1300–300</td>
<td>662</td>
<td>22</td>
<td>84</td>
<td>0.97</td>
<td>0.89</td>
<td>0.86</td>
</tr>
<tr>
<td>45OK-2</td>
<td>3000</td>
<td>346</td>
<td>6</td>
<td>95</td>
<td>0.98</td>
<td>0.78</td>
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</tr>
<tr>
<td>45OK-2</td>
<td>4000–3000</td>
<td>506</td>
<td>8</td>
<td>117</td>
<td>0.98</td>
<td>0.81</td>
<td>0.80</td>
</tr>
<tr>
<td>45OK-240</td>
<td>2300–1000</td>
<td>158</td>
<td>4</td>
<td>16</td>
<td>0.98</td>
<td>0.91</td>
<td>0.89</td>
</tr>
<tr>
<td>45OK-250</td>
<td>3300–2300</td>
<td>492</td>
<td>37</td>
<td>340</td>
<td>0.93</td>
<td>0.59</td>
<td>0.57</td>
</tr>
<tr>
<td>45OK-250</td>
<td>5000–3800</td>
<td>136</td>
<td>5</td>
<td>20</td>
<td>0.96</td>
<td>0.87</td>
<td>0.84</td>
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<tr>
<td>45OK-4</td>
<td>2000–200</td>
<td>91</td>
<td>6</td>
<td>48</td>
<td>0.94</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>45OK-4</td>
<td>3200–2000</td>
<td>744</td>
<td>16</td>
<td>1108</td>
<td>0.98</td>
<td>0.40</td>
<td>0.40</td>
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<tr>
<td>45OK-4</td>
<td>5000–3200</td>
<td>72</td>
<td>2</td>
<td>60</td>
<td>0.97</td>
<td>0.55</td>
<td>0.54</td>
</tr>
<tr>
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<td>800–100</td>
<td>1872</td>
<td>41</td>
<td>27</td>
<td>0.98</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>45OK-258</td>
<td>3600–2400</td>
<td>2030</td>
<td>170</td>
<td>88</td>
<td>0.92</td>
<td>0.96</td>
<td>0.89</td>
</tr>
<tr>
<td>45DO-242</td>
<td>4000–2000</td>
<td>537</td>
<td>46</td>
<td>42</td>
<td>0.92</td>
<td>0.93</td>
<td>0.86</td>
</tr>
<tr>
<td>45OK-11</td>
<td>4000–2000</td>
<td>283</td>
<td>94</td>
<td>201</td>
<td>0.75</td>
<td>0.58</td>
<td>0.49</td>
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<tr>
<td>45DO-214</td>
<td>1200–1000</td>
<td>228</td>
<td>27</td>
<td>264</td>
<td>0.89</td>
<td>0.67</td>
<td>0.64</td>
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<tr>
<td>45DO-211</td>
<td>3500–2000</td>
<td>41</td>
<td>25</td>
<td>1026</td>
<td>0.62</td>
<td>0.04</td>
<td>0.04</td>
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<tr>
<td>45OK-197</td>
<td>800–100</td>
<td>201</td>
<td>52</td>
<td>110</td>
<td>0.79</td>
<td>0.65</td>
<td>0.55</td>
</tr>
<tr>
<td>45OK-197</td>
<td>1100–800</td>
<td>157</td>
<td>20</td>
<td>47</td>
<td>0.89</td>
<td>0.77</td>
<td>0.70</td>
</tr>
<tr>
<td>45OK-197</td>
<td>1500–1200</td>
<td>456</td>
<td>19</td>
<td>30</td>
<td>0.96</td>
<td>0.94</td>
<td>0.90</td>
</tr>
<tr>
<td>45OK-197</td>
<td>1950–1600</td>
<td>354</td>
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<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
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<td>273</td>
<td>8</td>
<td>609</td>
<td>0.97</td>
<td>0.31</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*Data from five sites and 13 assemblages.*
(Salmonidae), several species of cyprinid (Cyprinidae), and several species of catastomids (Catastomidae). Most fish bones were identified only to family. Given that the genus and species of fish is not central to the issue of concern here, and that Martin and Szuter’s [44,45] hypothesis did not include expectations with respect to which fish species would have been more intensively exploited, finer taxonomic distinctions are unnecessary. The greater the abundance of fish relative to artiodactyls, the lower the fish AI.

Because the response to depressed abundances of artiodactyls could have involved an intensification of the exploitation of both small mammals and fish, I also determined what I call the nonartiodactyl AI, calculated as

$$\Sigma \text{artiodactyl NISP}/(\Sigma \text{artiodactyl NISP} + \Sigma \text{small mammal NISP} + \Sigma \text{fish NISP})$$

If artiodactyl abundances were progressively more depressed over time—irrespective of why they were depressed—then small mammals, fish, or both should increase in abundance as human foragers attempted to maintain their food intake levels. Again, low values of the nonartiodactyl AI suggest that artiodactyls were of low availability whereas high AI values indicate artiodactyls were of high availability. Technological change, environmental change, change in the human-population level, or some combination of these factors might be the causal variable driving any perceived changes in the AIs, and although I call on these variables in the following, they are of less concern to the discussion than the effects of time averaging and of space averaging.

It is possible in the geographic area and temporal period of concern that intensification of the exploitation of river mussels (Pelecypoda) might have compensated in part for depressed ungulate populations (Refs. [39,40] and references therein), but shellfish remains were not consistently identified among the 31 assemblages. Further, so few bird remains were recovered that it is apparent that exploitation of this taxon would not have made any significant difference in measures of human subsistence. I follow analytical tradition and use the temporal midpoint of an AI’s age for graphing and statistical purposes, and plot a simple best-fit regression line to identify trends in prey abundances graphed in scatterplots. I do not reproduce all scatterplots here, but instead show only representative ones. Similarly, I do not always discuss all possible indices.

4. Results

To examine the influence of spatio-temporal lumping of assemblages, I first calculated the three AIs for all 31 assemblages. Here, NASM = 31, NCTXspace = 1, and NCTXtime = 30; Fig. 1 shows the scatterplot for the nonartiodactyl index. All three indices tend to increase over time—the slopes of the best-fit regression lines are positive—suggesting that the overall trend was for the abundance of artiodactyls to increase relative to small mammals (r=0.15), fish (r=0.17), or small mammals + fish (r=0.21). The slopes are not steep, suggesting that change in the structure of the exploited resource pool was gradual and not very marked. The correlation coefficients are, however, low and insignificant (P>0.25 in all), indicating that the conclusion that there was in fact change in the exploited resource pool is statistically unwarranted. What happens when assemblages are lumped into a limited number of temporal periods?

4.1. Time averaging

To address the preceding question, the temporal midpoint of each assemblage was used as its ‘age’ to assign it to one of five time periods of 1000 radiocarbon years duration each beginning with the period 0–1000 BP. (All included assemblages are in fact ≥100-year old.) This reduces NCTXtime from 30 to 5. Values of the nonartiodactyl AI were plotted against their time period. The resulting scatterplot (Fig. 2) is a bit less noisy than that produced when the midpoint age of each assemblage is used (Fig. 1) because the ages have been ‘averaged’ to fall within a particular 1000-year period. Not surprisingly, given the reduced variation in the independent variable, the correlation coefficient increases slightly, although it is still insignificant (r=0.23, P>0.1). The midpoint age was then used to assign each assemblage to one of three cultural phases recognized in the area [17]. These phases and their temporal durations are Coyote Creek (0–2000 BP), Hudnut (2000–4000 BP), and Kartar (4000–7000 BP). This reduces NCTXtime from 30, or 5, to 3. Once assigned to a phase, the nonartiodactyl AI for each assemblage was plotted against the temporal midpoint of that phase. Because all Kartar samples date between 4000 and 5000 BP, the age midpoint of 4500 BP was retained. The resulting scatterplot (Fig. 3) is again just what might be expected. Because temporal variation has been removed by ‘time averaging’, the scatterplot is cleaner visually and thus perhaps more easily interpreted subjectively. As well, the correlation coefficient increases a bit more, although it remains insignificant (r=0.28, P>0.1).

Although clarity remains imperfect, successively greater time averaging affected by reducing NCTXtime such as that represented by the progression of Figs. 1–3 seems to produce a clearer result. And, the statistical correlation also, not unexpectedly, improves. Of course the price paid is a loss of temporal resolution; that is, there is a loss of the ability to detect variation across time and also within a particular temporal span. This
begs the question of why the analyst might time average in the first place. The answer is simply that time averaging such as that represented in Fig. 3 relative to Fig. 1 might be said to be warranted by the fact that cultural phases are often construed as periods of cultural stability (e.g. Ref. [56]; see also Ref. [43] and references therein), despite the fact that it has long been known that this is seldom the case in reality [49]. Perhaps the most important thing to note with respect to Figs. 1–3 is that all of them involve plotting an AI value against a single age assigned by determination of a temporal midpoint, whether of the assemblage (Fig. 1), of an arbitrary temporal period (Fig. 2), or of a cultural period (Fig. 3). The differences apparent in those three figures should give us pause when we use the temporal midpoint of an assemblage as the plotting algorithm. When we use temporal midpoints, we are using an estimate of the ‘average’ age of the assemblage. Two problems can be identified: the estimate may be to some unknowable degree off the mark, and we have converted a duration or period of time to a single year. The former is an archaeological problem; the latter is a statistical problem. Do similar problems attend the averaging of variation in geographic space?

4.2. Space averaging

As noted earlier, the area from which the 31 assemblages listed in Table 1 were recovered comprises a stretch of the Columbia River valley. All assemblages were collected from sites adjacent to the river. This stretch of river cannot be subdivided into multiple physiographically distinct areas on the basis of significant vegetation differences from one portion of this stretch of river to the next [25,27]. However, one might divide the stretch into two subareas on the basis of the fact that the western half of this stretch of river valley today receives less than 25 cm mean annual precipitation whereas the eastern half receives over 25 cm mean annual precipitation [26]. In addition and corresponding to this climatic difference is the fact that the western half includes the mouth of the Okanogan River; the eastern half includes only the mouth of the much smaller Nespelem River. Salmon could and did make spawning
runs up the Okanogan as well as the Columbia, but could not proceed more than 1 km up the Nespelem due to an impassable falls. Finally, topographic maps indicate that the western third of the stretch of Columbia River valley comprises broad expanses of level terrain only a few meters above the river whereas the eastern two-thirds of the valley are more deeply incised and level terrain is significantly farther above the active floodplain. Thus, topographic differences may have contributed to geographic variation in human predation behaviors (and perhaps prey—particularly salmonid—availability) between the western and eastern portions of the stretch of Columbia River that produced the 31 assemblages under consideration here.

Seven assemblages were collected from sites in the western half of the valley and the remaining 24 assemblages from the eastern half (Table 1). Bivariate scatterplots for each areally designated set of assemblages (NCTXspace = 2) were generated. The tendency is for the western assemblages to have more small mammals and more fish relative to artiodactyls than the eastern assemblages (Fig. 4). Such is not noticeable if NCTXspace = 1, as in Figs. 1–3. With spatial variation included, the correlation coefficients are a bit stronger and the slopes of the simple best-fit regression lines are a bit steeper for the western assemblages (r=0.09 for the small-mammal AI, r=0.11 for the fish AI) than for the eastern assemblages (r=0.30 for the small-mammal AI, r=0.20 for the fish AI), suggesting artiodactyls became more important (relative to small mammals and fish) over time more rapidly in the west than in the east, although none of these differences are statistically significant (P>0.05). The important point here is that by considering all 31 assemblages simultaneously without regard for geographic variation (NCTXspace = 1), as in Figs. 1–3, the differences between the eastern and western assemblages are undetectable because in effect the geographic signal has been muted by spatial averaging.

4.3. Simultaneous time averaging and space averaging

Thus far, index values for individual assemblages have been lumped by plotting them as groups according to their particular temporal or spatial coordinates. That
is, NCTX has been reduced but not NASM. What happens if the NISP values for various assemblages are combined on the basis of spatio-temporal propinquity, and the indices recalculated, such that NASM is reduced? Answer this question requires that the NISP values per assemblage for each taxonomic category be summed if they are not only similar in geographic location, but also similar in age. First, assemblages that fell in the same 1000-year period were lumped together by western or eastern provenience as indicated in Table 1 (NCTXspace = 2, NCTXtime = 5 for each subarea, NASM = 5 for each subarea). The fish index and the nonartiodactyl index were then recalculated for each of the two sets of spatio-temporally lumped data (Table 2) and the index values were plotted against the temporal midpoint of each 1000-year period. The resulting scatterplots (Figs. 5 and 6) are based on 5 points and are cleaner and not as noisy as when all 31 data points are plotted.

The scatterplots suggest that at about 2500 BP, things were different in the two areas. In particular, whether one considers the fish index or the nonartiodactyl index, and whether one considers the west area (Fig. 5) or the east area (Fig. 6), artiodactyls were exploited the least intensively between about 3000 and 2000 BP, and this trend seems to have begun about 4500 BP or earlier. One might be tempted to argue that this decrease was in response to a relatively cool-moist climatic interval between about 4000 and 2200 BP [22,23]. Computer simulations of anadromous fish runs in light of models of climate and river runoff [24,46] suggest fish would have been more abundant in the Columbia River during this cool-moist interval than they were 4500 or 1500 years ago. This, however, leaves unexplained the marked difference between the two areas between 1000 and 0 BP. At that time, there seems to have been decreased exploitation of ungulates in the west area (Fig. 5), but not the east area (Fig. 6). There is no obvious technological
difference between the two areas in terms of artifact inventories, so I am tempted to suggest that the geographic difference is the result of fish being more available (or perhaps more technologically accessible) in the western area where the Okanogan River is found.

Whatever the explanation might be, the influence of spatio-temporal lumping can be shown by comparing the results in Figs. 5 and 6 with the results of lumping all assemblages irrespective of geographic provenience. Now, NCTXspace = 1, NCTXtime = 5, and NASM = 5.
The small-mammal index (Fig. 7) suggests artiodactyls were not very important relative to small mammals at the end of the mid-Holocene climatic interval generally referred to as the Altithermal. The Altithermal period ended about 5000 BP and is locally characterized as comprising warmer, wetter winters than at present; stream flow was reduced as were salmon runs, and grasslands were replaced by shrub–steppe habitats [23]. These environmental differences suggest a possible cause of apparently low artiodactyl abundances at about 4500 BP. The nonartiodactyl index (Fig. 7), which is very similar to the fish index, suggests something quite different. Similar to Figs. 5 and 6, the lumped data suggest much fluctuation in the abundance of artiodactyls over the last 5000 years (Fig. 7). As indicated in the preceding paragraph, explanations might comprise elements of environmental fluctuation. They might also include evidence of fluctuation in the size of the human population [22] and changes in fishing technology such as increased use of nets [1]. Whatever the case, the explanation would be complex.

Explanatory complexity largely disappears if the index values are calculated on the basis of cultural period and irrespective of geographic position. Here, NCTXspace = 1, NCTXtime = 5, and NASM = 3. The plot of the small-mammal index per cultural period indicates that artiodactyls were not frequently exploited relative to small mammals at the end of the Altithermal, but subsequent to that point small mammals were significantly overshadowed by artiodactyls (Fig. 8). This trend aligns nicely with the standard conception of the Altithermal and subsequent climates and habitats and human adaptations [5,38]; small mammals were more economically important during the Altithermal than subsequently. Similarly, the fish index also aligns with standard explanations [13,62] that the exploitation of fish intensified after the Altithermal as a result of increased run sizes and improved technology (Fig. 8). These results align with inferences produced by archaeologists who were working 35 years ago and were interested in region-wide economic trends, a point I will return to subsequently. Of more concern here is the
following simple fact: interpreting a bivariate scatterplot of many points representing relatively precise spatio-temporal data (Fig. 1) is a rather different matter than interpreting a bivariate scatterplot of few points representing the same data in spatio-temporally lumped form (Fig. 8).

5. Discussion

The general significance of the example discussed above for applications of models derived from foraging theory (or any explanatory theory) to zooarchaeological data should be clear. On the one hand, the manner in which zooarchaeological samples are lumped by space or by time—whether taphonomically or analytically—may reveal regionwide trends precisely because that lumping masks spatio-temporal variation within the region. Lumpung data without consideration of the included spatio-temporal variation, on the other hand, could mask what may otherwise comprise significant differences in resource exploitation patterns.

Notice that I said “may comprise significant differences.” Does spatio-temporal lumping in fact mask significant differences? That depends on the spatio-temporal scale of the question being asked, and this is the most critical point of this discussion. Paleobiologists who have examined time averaging argue that it only occurs when the process or property one seeks to measure occurs or was created, respectively, over a shorter time span than is represented by the fossil record under study [28,36,47,57]. Thus, time averaging is a problem when two or more analytically interesting events of distinct ages appear to be contemporaneous. A similar argument is made for spatial averaging. If the property of analytical interest is a biological community’s structure in terms of taxonomic richness, evenness, or diversity, and if the fossil record under study comprises organisms from multiple communities,
then that record is spatially averaged. The critical issue, as paleobiologists note, is one of ascertaining the spatio-temporal scale of the fossil record and asking questions of the same scale.

In terms of applying explanatory models derived from foraging theory to the zooarchaeological record, the critical issue is the same as that in paleobiology. Asking if prehistoric hunters depressed prey populations by exploiting them is so general as to have no spatio-temporal coordinates. Adding the phrase “in area X during cultural periods A, B, and C” to the question provides coordinates. The zooarchaeologist must, however, determine if the assemblages included in the analysis fall within those coordinates and thus not be spatio-temporally averaged. To make this determination demands that explicit spatio-temporal parameters be built into the research questions we ask. If they are not, then zooarchaeologists will be open to criticisms that their analyses mask potentially significant spatio-temporal variation at finer scales.

6. Conclusions

The observation of Grayson and Delpech [31] that the application of models derived from foraging theory requires the translation of ecological time into archaeological time must be expanded to include the notion that those applications must also translate ecological space into archaeological space. Such translations have, to date, not been accomplished by literally converting or rewriting the ecological model in terms of archaeological variables. Rather, the models have simply been applied to archaeological data, and the latter interpreted in terms of the former. The influence on interpretations of the resultant muting of temporal and/or spatial variation should be clear and is the central point of the example.

Fig. 7. Small-mammal-index values (open squares) and nonartiodactyl-index values (x) for 31 summed assemblages plotted against 1000-year period (NASM = 5, NCTXspace = 1, NCTXtime = 5). Upper best-fit regression line is for small-mammal index (r=0.78); lower best-fit regression line is for nonartiodactyl index (r=0.10).
discussed here. However, lumping might be affected—decreasing NASM by summing assemblages, ignoring temporal variation by decreasing NCTXtime, ignoring spatial variation by decreasing NCTXtime—it mutes, smooths, and averages what might otherwise be significant differences. This demands a decision regarding what comprise significant differences. Such a decision can be made at the initiation of analysis, but may have to be modified once the degree of spatio-temporal averaging of the assemblages at hand has been determined.

The lessons here, then, are two. We must first be explicit about the values of the spatio-temporal variables within the questions we ask of the zooarchaeological record. What should be abundantly clear is that spatio-temporal palimpsests are averaged, blended, or coarse-grained relative to some preconceived and generally implicit size of spatio-temporal unit [7]. And second, we must be cognizant of the influences of spatial and temporal averaging on our analytical results in lieu of rewriting the ecological models we apply to the zooarchaeological record in terms of the spatio-temporal scale of that record.

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References


