Chapter 4
Testing Brantingham's Neutral Model: The Effect of Spatial Clustering on Stone Raw Material Procurement

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4.1 Introduction

The archaeological record shows that foragers varied their stone tool raw material preferences, even when several types of stone material were available. The changing use, and co-use of different stone tool raw materials is well known from a wide range of environmental and climatic contexts, time-periods, and 'cultures' (Andrefsky 1994; Bamforth 1990; Bar-Yosef 1991; Clark 1980; Jelinek 1991; Kuhn 2004, 1991). What explains this changing raw material preference is a question of great interest, and it is debated whether changes in stone tool raw material frequencies in an archaeological assemblage could be considered a reliable proxy for human forager adaptive variability (Brantingham 2003; Féblot-Augustins 1993; Kuhn 1995; Mellars 1996). Explanations for change in raw material usage

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frequency include climate/environmental change and its co-variability with mobility and procurement strategies (Ambrose and Lorenz 1990; Binford and Stone 1985; Kuhn 2004), selection of certain raw materials for their physical properties (Braun et al. 2009; Gould and Saggers 1985; Minichillo 2006), changes in demography (Clark 1980), the preference for appearance or color (Akerman et al. 2002; Clendon 1999; Stout 2002), symbolic value (Wurz 1999), and style (Close 2002).

Brantingham (2003) challenges these explanations and provides a neutral model that was argued to explain some of the observed patterns in the record of raw material abundance. Brantingham argues that in order to demonstrate the deliberate selection of raw materials, patterning must be shown to be different from the results of the neutral model, which provides a baseline for comparison where archaeologists can be certain that observed raw material patterns is not the result of strategic selection.

We agree with Brantingham's sentiment. However, Brantingham (2003: 505) points out that a "…appropriate criticism of the present model would suggest that a forager "could" never engage in a random-walk foraging strategy and "could" never ignore the differences between stone raw material types." Here we explore if such a criticism is valid. In addition, we follow Brantingham's suggestion that quantitative development of the observations presented in his study requires calibration of the agent-based model to run in simulated "worlds" built around the known geographic distributions of actual raw material sources. Here we partly address that suggestion by first exploring two major limitations of the neutral model as currently described. First, the raw material sources are distributed randomly without any clustering across the model landscape, which is not the case on most real landscapes where potential raw material source locations are controlled by the underlying geological structure and geophysical processes. An example of such structures and processes, drawn from our research region, are coastal cliffs and embayed beaches that can produce cobble beaches along a stretch of coastline (Thompson and Marean 2008). Source locations thus appear clustered due to the geological structure and geophysical processes of the landscape.

The second limitation addressed here is the unrealistic assumption that each raw material location in the model represents a unique raw material. Five thousand raw material sources are possible over an extended landscape but not 5000 unique raw materials. It is more likely that a smaller amount of different raw materials, say 1–25, are represented by the 5000 source locations. In addition, the 1–25 unique raw materials are not randomly distributed in isolation away from same type raw materials. As discussed above, not only are source locations clustered due to the underlying geological structure and geophysical processes, several sources of the same material can be available in a cluster, depending on the geological formation.

4.2 Test Case and Model Description

4.2.1 Mossel Bay Region

The test case is the landscape around the town of Mossel Bay, Western Cape, South Africa. The Mossel Bay region has several archaeological sites that offers a long sequence of change in raw material selection (Brown et al. 2012; Thompson and Marean 2008; Thompson et al. 2010). The local geology is well understood (Malan and Viljoen 2008; Viljoen and Malan 1993; Roberts et al. 2012; Thamm and Johnson 2006), and thorough surveys for potential raw material sources have been undertaken (Oestmo et al. 2014). In total, 38 potential stone tool raw material sources have been discovered, which is likely an underestimate. These sources range greatly in size (Fig. 4.1), are clustered according to geological structures and geophysical processes, and only 6–7 raw materials are represented among the 38 sources.

4.2.2 Model Description

Original Neutral Model Brantingham (2003) created a simple model of one forager with a mobile toolkit of fixed capacity that is randomly placed on the environment. At each time step, the forager moves to one of the nearest eight neighboring cells or stays in the present cell, with equal probability (=1/9). At each

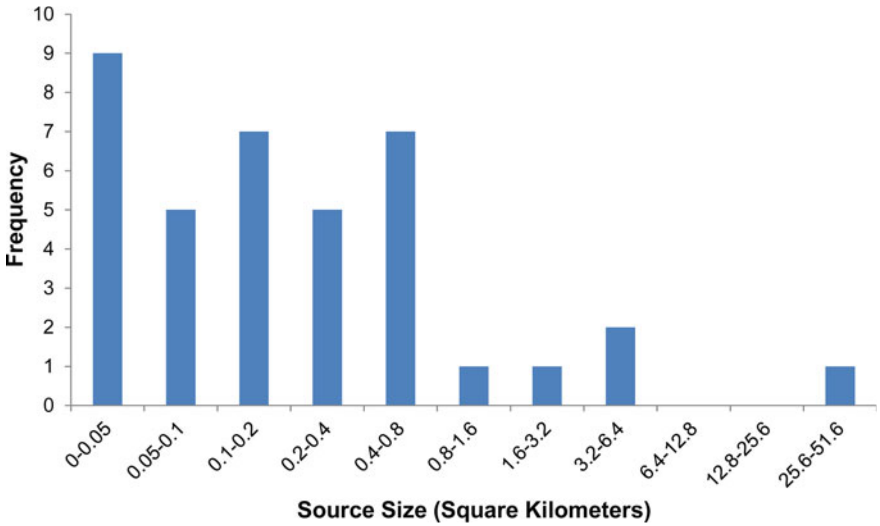

Fig. 4.1 Frequency of stone tool raw material sources by size bin in the Mossel Bay region

time step a fixed amount of raw material is consumed dependent only upon its frequency in the mobile toolkit. If a raw material source is encountered, the toolkit is re-provisioned up to its maximum capacity before moving again at random. If no raw material source is encountered, the forager moves immediately at random. Simulations are run until 200 unique raw material sources are encountered, or the edge of the simulation world is reached. The model is replicated in Netlogo by Janssen and Oestmo (2013).

New Analysis For the initial configuration and analysis in this paper, a maximum capacity of the tool kit equal to 100 was used, the environment was set to 500 × 500 cells and consisted of 5000 unique raw material sources. To include clustering of sources, the probability p_r was included. When the 5000 material sources were placed on the landscape there was a probability p_r determining where the new material source was placed on a randomly chosen empty cell. Five different values of p_r were used (Fig. 4.2) with probability $1 - p_r$, a new material source was placed on a randomly chosen empty cell that had at least one neighbor (one of 8 neighboring cells) that already contained a material source (see Fig. 4.3 for landscape examples for each p_r value used in this paper). Every simulation-run lasted 35,000 time steps, and each type of simulation with different walk behaviors was run 100 times.

Three different model outcomes are addressed here: raw material richness (the number of different raw material types), distance materials move before being discarded, and steps taken without raw material in the toolkit. The two first outcomes are the same as Brantingham (2003) used in his original study to evaluate his neutral model. Here they will be used to evaluate the effect of spatial clustering on the neutral model outcomes. The last model outcome, steps taken without raw

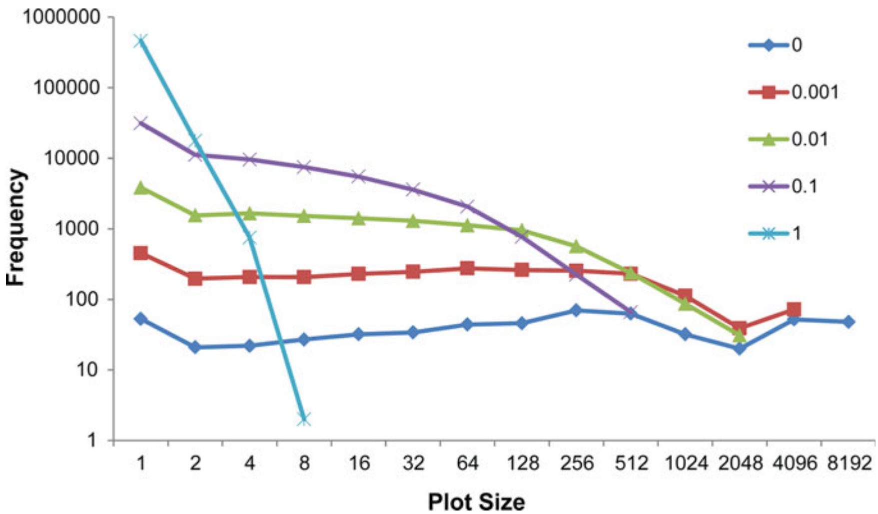

Fig. 4.2 Distribution of source sizes in generated landscapes with different p_r values

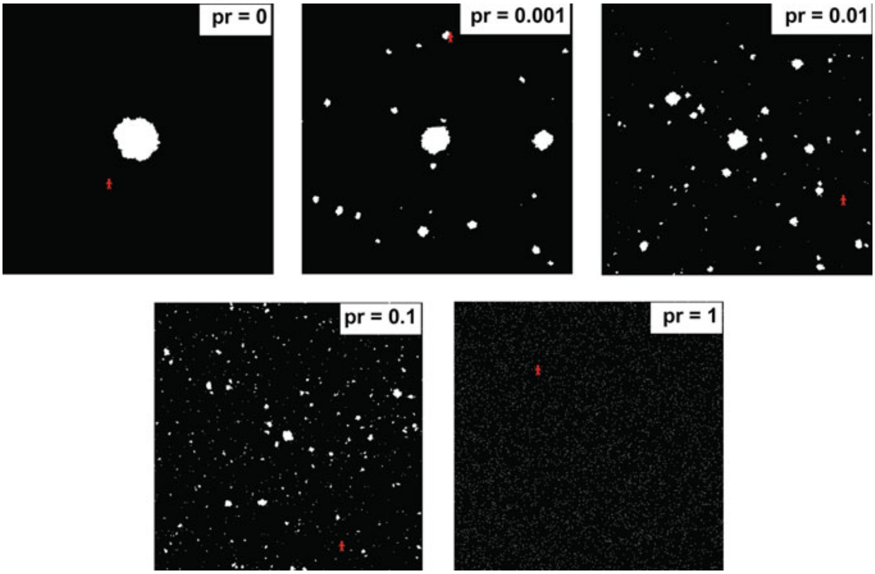

Fig. 4.3 Spatial view of distribution of material sources in generated landscapes with different p_r values

material in the toolkit, is used to evaluate whether the criticism that a forager can never engage in random walk in an environment is a valid criticism.

To address the second limitation that 5000 unique raw materials on an extended landscape is unrealistic, a second model configuration is run where 20 unique raw materials are distributed among the 5000 raw material positions. This can lead to, by chance, a cluster with a majority of one unique raw material distributed next to each other.

In addition to the original random walk behavior, two other walk behaviors will be simulated for both the original configuration with 5000 unique raw materials and with the configuration with 20 unique raw materials. The first one is here called "seeking walk". The seeking walk behavior could be seen as an analogy for returning to a stone cache at a central location. During seeking walk simulations, the forager will move towards the nearest material source if the level of the materials in the toolkit is lower than a certain number. Here the number will be 0. This means that at any moment when a foragers' toolkit is empty it will seek to acquire new material.

The second alternative walk model is termed the "wiggle walk" where it is assumed that a forager has a direction and moves forward one cell each time step. At each time step, the forager changes the direction by taking a left turn with a degree drawn from a uniform distribution between 0 and 90°, and then a right turn with a degree drawn from a uniform distribution between 0 and 90°.

4.3 Model Analysis Results and Discussion

4.3.1 Assuming 5000 Unique Raw Materials

Raw Material Richness in Tool Kit Two different patterns are visible when investigating raw material richness. First, when a forager engages in random or wiggle walk, a more clustered environment leads to lower average raw material richness in the toolkit (Fig. 4.4). However, these relationships are not statistically significant. The random walk data has a non-significant moderate positive relationship with the p_r values (Spearman's $rs = 0.6$; $p = 0.23$), while the wiggle walk data has a non-significant weak positive relationship with the p_r values (Spearman's $rs = 0.3$; $p = 0.52$). Because the forager will consume a unit of raw material at every time step if material is available in the tool kit and will refill the toolkit to the maximum when encountering a source, a high encounter frequency in combination with encountering new sources evenly distributed across the map will increase the richness. This is because no single raw material has a chance to dominate the frequency make-up of the tool kit. As clustering increases, the forager will on average move longer periods without encountering a source. Due to this and the fact that the forager use a material at every step, the forager will then when encountering a source fill up the tool kit to the maximum capacity resulting in one raw material dominating the make-up of the tool kit in terms of frequency. However, as noted above, this relationship is not statistically significant.

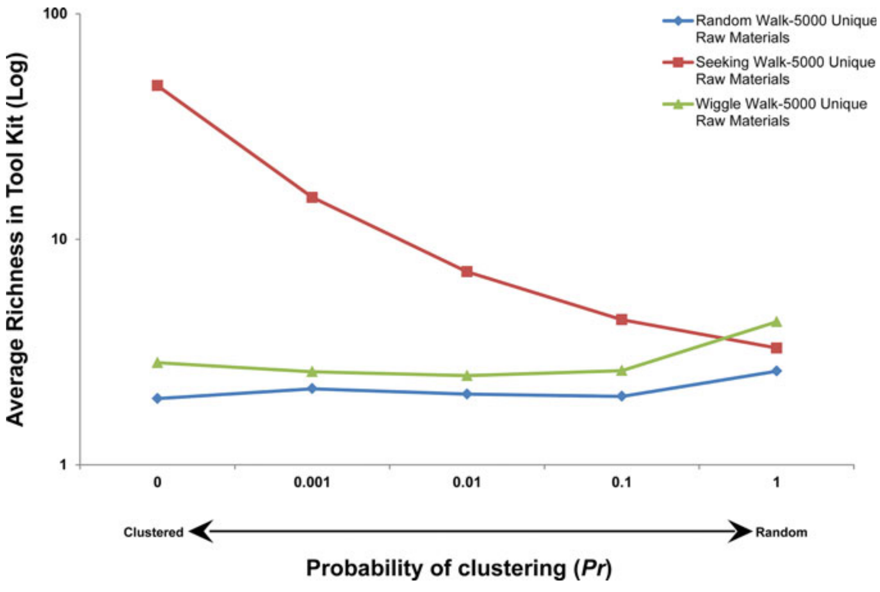

Fig. 4.4 Average richness of toolkit. Y values are shown as log values. Each *curve* is based on the average of 100 simulation runs

In the other pattern, the forager engages in a seeking walk and seeks the closest raw material sources when the tool kit is empty. In this case, the increased clustering of raw material sources leads to increased raw material richness (Fig. 4.4). The seeking walk data has a significant negative strong relationship with the p_r values (Spearman's $rs = -1$; $p = 0.02$). The richness increases because when the forager seeks the nearest raw material source, and this nearest raw material source is clustered with other sources, it increases the chance of encountering other sources in close proximity that in turn could lead to increased richness.

Distance Materials Travel Until Discarded In terms of the distances that raw materials travel until discarded, two patterns can be observed (Fig. 4.5). In the first pattern, when a forager engages in random or wiggle walk, increased clustering leads to decreased travel distance (Fig. 4.5). However, not both of these relationships are statistically significant. The random walk data has a strong but non-significant relationship with the p_r values (Spearman's $rs = 0.7$; $p = 0.2$), while the wiggle walk data has very strong and significant relationship with the p_r values (Spearman's $rs = 1$; $p = 0.02$). Because raw material richness increases with increased random distribution of sources as shown above, the probability that any one raw material is consumed decreases. This decreased probability means that there is increased chance that any one raw material will stay in the tool kit for a longer time, which results in raw materials being carried for longer distances before being consumed.

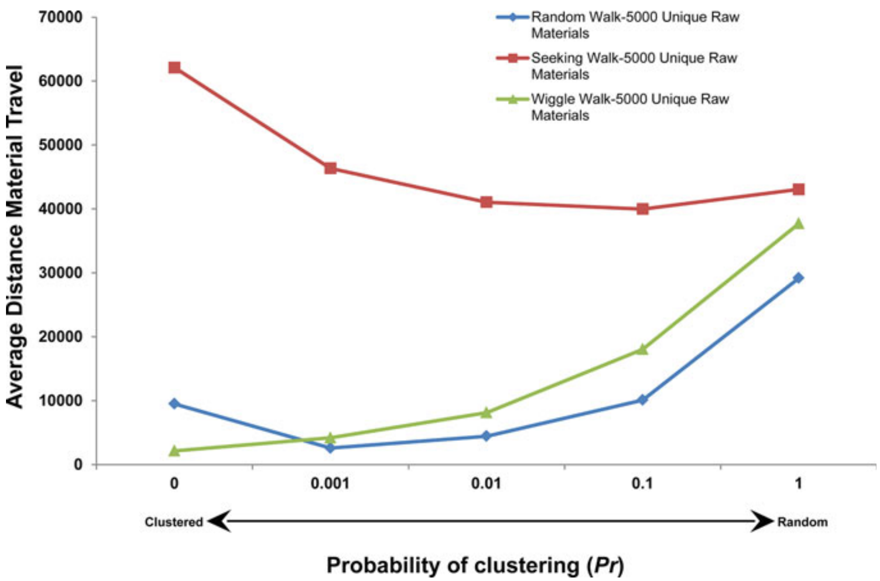

Fig. 4.5 Average distance materials are travelling from the source. Each *curve* is based on the average of 100 simulation runs

On the other hand, when the forager engages in a seeking walk, increased clustering leads to increased travel distance (Fig. 4.5). However, this relationship is not significant although there is a strong negative correlation (Spearman's $rs = -0.7$; $p = 0.2$). As noted above, tool kit richness controls how long a raw material travels before being consumed. Increased richness results in increased distances that any one raw material travels before being consumed because the probability that any one raw material is consumed at each time step is decreased.

Time Steps Without Material in Tool Kit When investigating how much time the forager spends without material in the tool kit one clear pattern can be observed: clustering leads to increased time without materials in the tool kit. Across all three simulated walk behaviors, the analysis shows that when resources are more clustered than simulated in the original neural model, we can expect that foragers run out of materials for longer periods of time (Fig. 4.6). All three walk behaviors have significant and strongly negative relationships with the p_r values (Table 4.1). Table 4.2 shows the estimated time steps without raw materials. If engaging in random or wiggle walk, the forager will on average spend about 55 time steps without materials when the raw materials are randomly placed as simulated in the neutral model. However, as the clustering of the raw material sources increases to mimic a realistic landscape, one can observe that time spent without materials increases 10–30 times. This is because increased clustering leads to more spaces between sources leading to an increased probability that a forager will use up all the raw materials in the tool kit before encountering a new source. Hence, the original neutral model might not be an appropriate model for landscapes with raw material sources clustered like is often typical of most environments. It is unrealistic to expect that foragers go extended periods of time without raw materials in their tool kit to create and repair tools.

Although ethnoarchaeological work and ethnographic description offer some evidence that stone procurement was a daily exercise for some groups (Hayden and Nelson 1981; MacCalman and Grobelaar 1965; Miller 1979; Sillitoe and Hardy 2003; Stout 2002) it has to be noted that this behavior cannot be considered a universal behavior, and that caches of stone to provision daily use can also be maintained at a central location where the foragers operate (Parry and Kelly 1987). An important distinction needs to be made here. If the forager returns to such a central location where a cache is situated, then the forager could go extended periods of time without procuring materials as long as the forager returns to such a central cache and refills the tool kit. However, if random walk takes the forager away from the central location and never or very seldom returns then it is unrealistic to assume that random walk is a realistic behavior because the probability that the foragers runs out of materials is high.

Not surprisingly, when the forager is engaging in seeking walk behavior, the time spent without materials is decreased drastically compared to random and wiggle walk simulations (Fig. 4.6). However, even in seeking walk simulations an

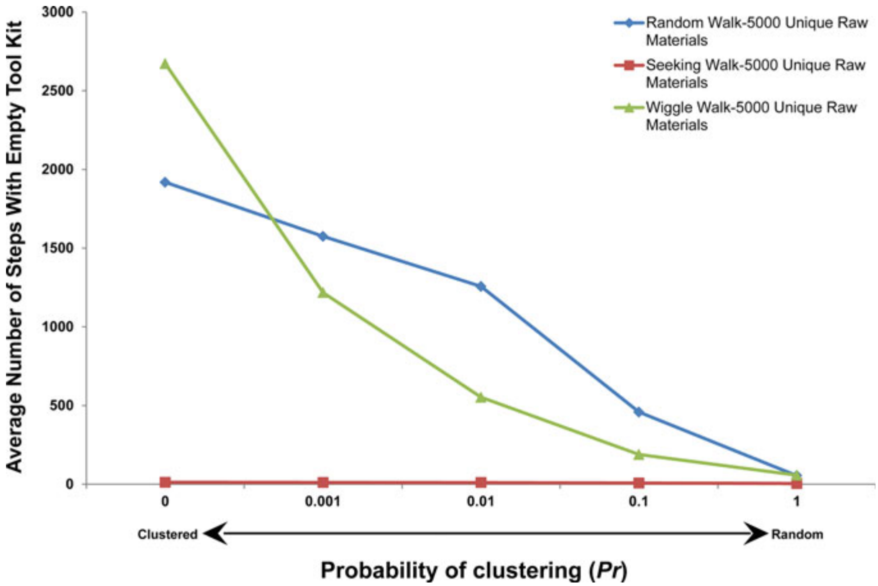

Fig. 4.6 Average number of time steps a tool kit is empty. Each *curve* is based on the average of 100 simulation runs

Table 4.1 Spearman's *rs* test results

	Random walk	Wiggle walk	Seeking walk
p value	0.02	0.02	0.02
rs coefficient	−1	−1	−1

Table 4.2 Time steps spent without material in tool kit

p_r	Random walk	Wiggle walk	Seeking walk
0	1919	2673	12
0.001	1575	1217	11
0.01	1257	552	10
0.1	458	189	8
1	54	57	4

increased clustering of the raw material sources leads to more time without any raw materials in the toolkit. This is because there is an increased probability that a forager can find itself further from a cluster or any single source because of the increased space between any sources. This means that the forager has to travel further to find the nearest material, which leads to increased time without material in the tool kit.

4.3.2 Assuming 20 Unique Raw Materials

Raw Material Richness in Tool Kit When a forager engages in random walk, a more clustered environment leads to lower average raw material richness in the toolkit (Fig. 4.7). The random walk data has a significant strong positive relationship with the p_r values (Spearman's $rs = 0.99$; $p = 0.0002$). Compared to the result of the three different walk modes when assuming 5000 unique raw materials, the random walk while assuming 20 unique raw materials produces, not surprisingly, on average a much lower richness in the tool kit. However, as seen above, when clustering increases, the forager will on average move longer periods without encountering a source. Coupled with the fact that the forager uses a material at every step, the forager will then when encountering a source fill up the tool kit to the maximum capacity, which results in one raw material dominating the make-up of the tool kit in terms of frequency.

Distance Materials Move Until Discarded In terms of the distances that raw materials are moved until discarded, when the forager engages in random walk, greater clustering leads to increased travel distance (Fig. 4.8). However, this relationship is not statistically significant. The random walk data has a non-significant and moderate negative relationship with the p_r values (Spearman's $rs = -0.6$; $p = 0.2$). Similar to random walk simulations with the assumption of 5000 unique raw materials, the raw material richness increases with increased random

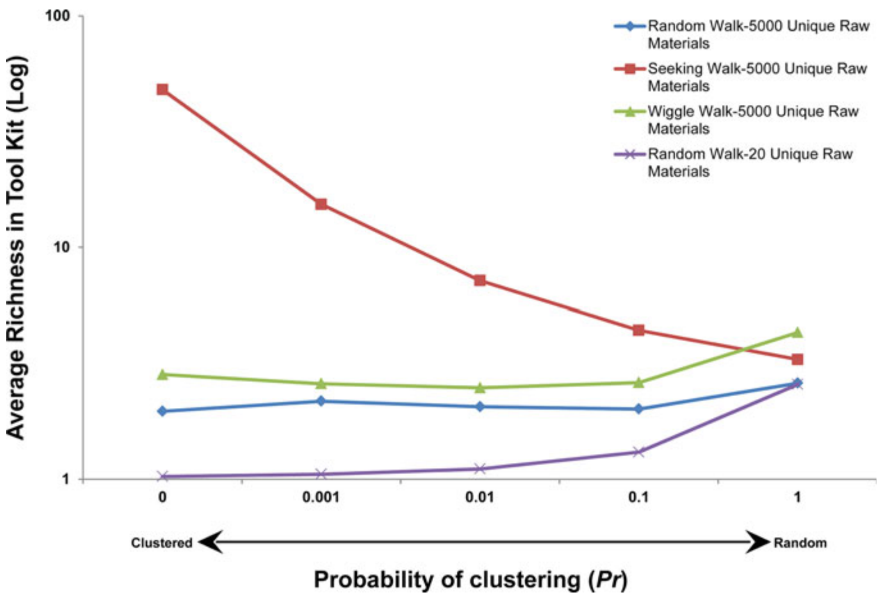

Fig. 4.7 Average richness of toolkit. Y values are shown as log values. Each *curve* is based on the average of 100 simulation runs

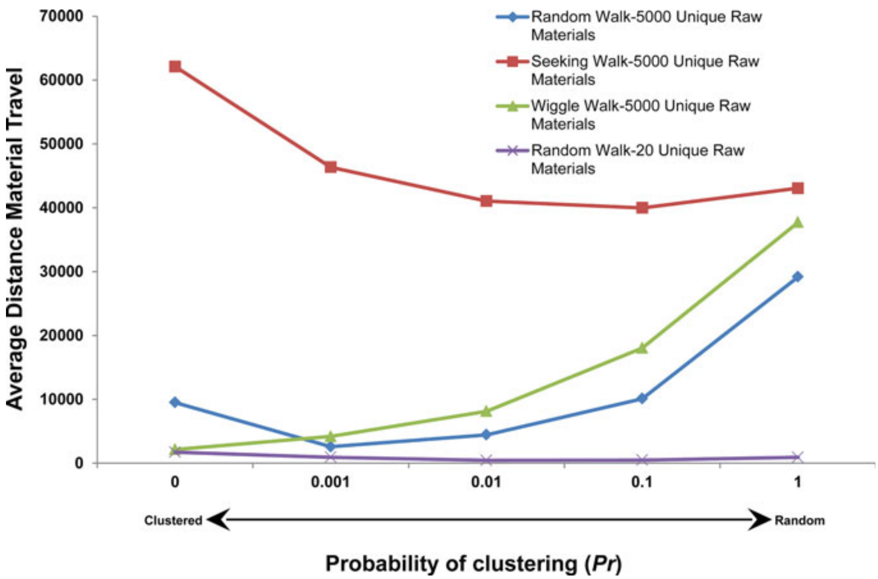

Fig. 4.8 Average distance materials are travelling from the source. Each *curve* is based on the average of 100 simulation runs

distribution of sources in turn leading to a decreased probability that any one raw material is consumed. This decreased probability means that there is increased chance that any one raw material will stay in the tool kit for a longer time. However, compared to the 5000 unique raw materials assumption, here a maximum of 20 raw materials could be available out of the 100 possible in the tool kit. This means that compared to a situation where there are 100 unique raw materials available for consumption, this overall low richness increases the probability that any one raw material is consumed, which results in similar types of raw materials being carried for shorter distances before being consumed.

Time Steps Without Material in Tool Kit The result shows that when resources are more clustered than simulated in the original neutral model, we can expect that foragers run out of materials for longer periods of time (Fig. 4.9). The random walk data has a significant and strong negative relationship with the p_r values (Spearman's $rs = -0.9$; $p = 0.02$). Compared to the analysis with 5000 unique raw materials, the 20 unique materials analysis numbers are very similar. If engaging in random walk, the forager will on average spend about 104 time steps without materials when the raw materials are randomly placed on the landscape as in the original neutral model (Table 4.3). As clustering increases, the time steps without raw materials in the tool kit increases 10–15 times. Decreasing the number of unique raw materials does not affect the finding that increased clustering leads to increased time without raw materials in the tool kit.

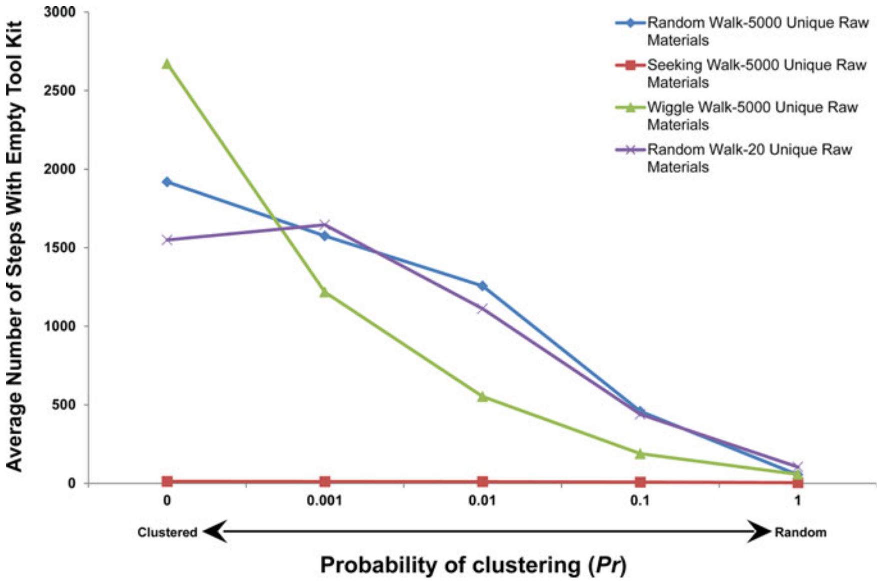

Fig. 4.9 Average number of time steps a tool kit is empty. Each *curve* is based on the average of 100 simulation runs

Table 4.3 Time steps spent without material in tool kit

p_r	Random walk
0	1550
0.001	1646
0.01	1112
0.1	440
1	104

4.4 Archaeological Implications and Predictions

Both the seeking walk, which is a simplified analogy for a forager that returns to a stone cache, and the random walk behavior both show that increased clustering of the raw material sources leads to increased time without raw materials in the tool kit. However, time between procurement instances and time without materials in the tool kit have different implications. If a forager can stockpile a cache at a central location and can return to such a place then the forager can go extended periods without procuring because it could return to the cache to fill up on raw materials. On the other hand, these results suggest that if random walk takes the forager away from the central location and never or very seldom returns directly to a stone cache then random walk is an unrealistic or at least risky strategy because the probability that the foragers runs out of materials is high.

A next step will be to project a map in an ABM of the Mossel Bay region that shows the location of archaeological sites in question, and that has potential raw materials sources and their real extent plotted on it. The forager will then be started at any one archaeological site and will move in a random walk to procure raw materials. Based on the results in this study one can predict several things: first, raw material richness should be low comparatively to the default neutral model as the actual number of unique raw materials on the landscape will be low. Second, as the agent is moving about the landscape the time spent without any raw materials in the tool kit will be high, in the order of days and weeks. This suggests that alternative procurement strategies need to be evaluated that meets the demands of the stone tool economy.

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