# Sensitivity Studies ForeGatherer Model v1.0:

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In order to characterize the features and responsiveness of the ForeGatherer ABM we performed a series of sensitivity experiments by systematically varying one or more factors while monitoring the resulting model performance by selected output factors, e.g. the number of residential moves, the average distance of a logistical trip and the average energetic yield per hour foraging.

## Experimental setup:

For the default levels of the tested factors, we have chosen values corresponding to average values within the expected range of each factor (Tab. 1). The default setting was created using recent hunter-gatherer data derived from R. Kelly's "Hunter-Gatherer Mobility Strategies" to create a potential generic foraging and mobility pattern fitting hunter-gatherers.

Tab. 1: Tested factors and their default level used in the sensitivity studies.

| | Factor | In-Model name | Factor level |
|---|---|---|---|
| Agent | Number of foragers | *number-of-foragers* | 30 |
| Agent | Energy demand per day | *energy-demand-per-day* | 2500 |
| Agent | Maximum load | *maximum-load* | 1500 |
| Environment | Net-primary productivity | *net-primary-productivity* | 1500 |
| Environment | NPP-Multiplicator | *npp-multiplicator* | 15 |
| Environment | Length of dry season | *length-dry-season* | 6 |
| Environment | Productivity reduction in dry season | *productivity-reduction-dry-season* | 50% |
| Environment | Occurrence of seasonal resource | *map-seasonal-resource* | 70% |
| Environment | Occurrence of aseasonal resource | *map-aseasonal-resource* | 30% |

Table 2 lists the experiments for the agent & environmental factors and the bi-factorial experiments related to seasonality. When varying an agent or environmental factor we kept the factor levels of the other factors constant.

| | **Agent Factors:** | | | **Environmental Factors:** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test no. | Number of foragers | Energy demand per day | Maximum load | Net-primary productivity | NPP-Multiplicator | Length of dry season | Productivity reduction in dry season | Occurrence seasonal resource | Occurrence aseasonal resource |
| Default setting | 30 | 2500 | 1500 | 1500 | 15 | 6 | 50% | 70% | 30% |
| Agent-1 | **10** | 2500 | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-2 | **20** | 2500 | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-3 | **40** | 2500 | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-4 | **50** | 2500 | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-5 | 30 | **1500** | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-6 | 30 | **2000** | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-7 | 30 | **3000** | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-8 | 30 | **3500** | 1500 | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-9 | 30 | 2500 | **500** | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-10 | 30 | 2500 | **1000** | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-11 | 30 | 2500 | **2000** | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Agent-12 | 30 | 2500 | **2500** | 1500 | 15 | 6 | 50% | 70% | 0.3 |
| Env-1 | 30 | 2500 | 1500 | **500** | 15 | 6 | 50% | 70% | 30% |
| Env-2 | 30 | 2500 | 1500 | **1000** | 15 | 6 | 50% | 70% | 30% |
| Env-3 | 30 | 2500 | 1500 | **2000** | 15 | 6 | 50% | 70% | 30% |
| Env-4 | 30 | 2500 | 1500 | **2500** | 15 | 6 | 50% | 70% | 30% |
| Env-5 | 30 | 2500 | 1500 | 1500 | **5** | 6 | 50% | 70% | 30% |
| Env-6 | 30 | 2500 | 1500 | 1500 | **10** | 6 | 50% | 70% | 30% |
| Env-7 | 30 | 2500 | 1500 | 1500 | **20** | 6 | 50% | 70% | 30% |
| Env-8 | 30 | 2500 | 1500 | 1500 | **25** | 6 | 50% | 70% | 30% |
| Env-9 | 30 | 2500 | 1500 | 1500 | 15 | **4** | 50% | 70% | 30% |
| Env-10 | 30 | 2500 | 1500 | 1500 | 15 | **5** | 50% | 70% | 30% |
| Env-11 | 30 | 2500 | 1500 | 1500 | 15 | **7** | 50% | 70% | 30% |
| Env-12 | 30 | 2500 | 1500 | 1500 | 15 | **8** | 50% | 70% | 30% |
| Env-13 | 30 | 2500 | 1500 | 1500 | 15 | 6 | **10%** | 70% | 30% |
| Env-14 | 30 | 2500 | 1500 | 1500 | 15 | 6 | **30%** | 70% | 30% |
| Env-15 | 30 | 2500 | 1500 | 1500 | 15 | 6 | **70%** | 70% | 30% |
| Env-16 | 30 | 2500 | 1500 | 1500 | 15 | 6 | **90%** | 70% | 30% |
| Env-17 | 30 | 2500 | 1500 | 1500 | 15 | 6 | 50% | **50%** | **50%** |
| Env-18 | 30 | 2500 | 1500 | 1500 | 15 | 6 | 50% | **60%** | **40%** |
| Env-19 | 30 | 2500 | 1500 | 1500 | 15 | 6 | 50% | **80%** | **20%** |
| Env-20 | 30 | 2500 | 1500 | 1500 | 15 | 6 | 50% | **90%** | **10%** |
| Season-1 | 30 | 2500 | 1500 | 1500 | 15 | **4** | **10%** | 70% | 30% |
| Season-2 | 30 | 2500 | 1500 | 1500 | 15 | **4** | **30%** | 70% | 30% |
| Season-3 | 30 | 2500 | 1500 | 1500 | 15 | **4** | **70%** | 70% | 30% |
| Season-4 | 30 | 2500 | 1500 | 1500 | 15 | **4** | **90%** | 70% | 30% |
| Season-5 | 30 | 2500 | 1500 | 1500 | 15 | **5** | **10%** | 70% | 30% |
| Season-6 | 30 | 2500 | 1500 | 1500 | 15 | **5** | **30%** | 70% | 30% |
| Season-7 | 30 | 2500 | 1500 | 1500 | 15 | **5** | **70%** | 70% | 30% |
| Season-8 | 30 | 2500 | 1500 | 1500 | 15 | **5** | **90%** | 70% | 30% |
| Season-9 | 30 | 2500 | 1500 | 1500 | 15 | **7** | **10%** | 70% | 30% |
| Season-10 | 30 | 2500 | 1500 | 1500 | 15 | **7** | **30%** | 70% | 30% |
| Season-11 | 30 | 2500 | 1500 | 1500 | 15 | **7** | **70%** | 70% | 30% |
| Season-12 | 30 | 2500 | 1500 | 1500 | 15 | **7** | **90%** | 70% | 30% |
| Season-13 | 30 | 2500 | 1500 | 1500 | 15 | **8** | **10%** | 70% | 30% |
| Season-14 | 30 | 2500 | 1500 | 1500 | 15 | **8** | **30%** | 70% | 30% |
| Season-15 | 30 | 2500 | 1500 | 1500 | 15 | **8** | **70%** | 70% | 30% |
| Season-16 | 30 | 2500 | 1500 | 1500 | 15 | **8** | **90%** | 70% | 30% |

# 1. Agent factors:

## 1.1 Number of foragers (Agent1-Agent4)

An increasing group size results in rising numbers of foragers exploiting the same environment. This results in a decrease average yield as they compete for the same environment (Fig. 1). The foragers are not able to exploit distant resources efficiently; therefore the increased competition only results in slightly longer logistical trips (Fig.1). Higher numbers of foragers exploiting the environment results in the group moving more often while also traveling some kilometer further each time they move the camp (Fig. 2). The slight increase in the moved distance (Fig. 2) is the result of the slight increase in the average travelled distance per logistical trip (Fig. 1).

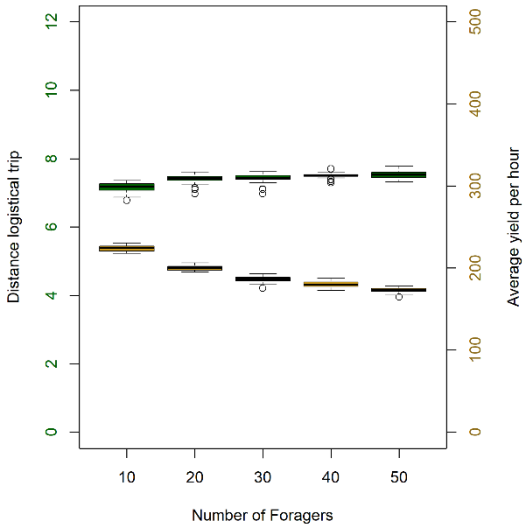


Fig. 1: Average distance moved per logistical trip and the average yield per hour with changing group size.

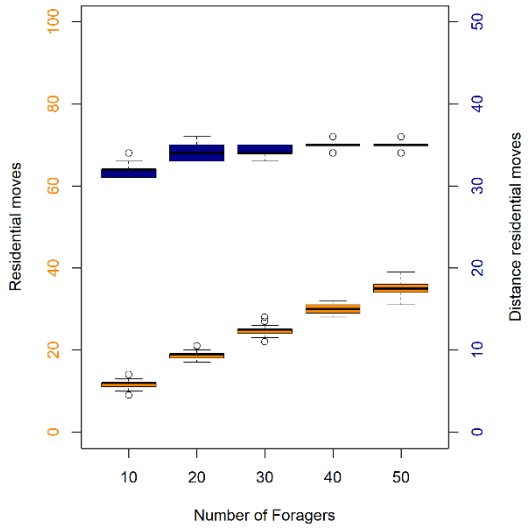


Fig. 2: Residential moves per year and the average distance moved per residential move changing group size.

## 1.2 Energy demand per day (Agent5-Agent8)

The agents react to an increased demand of energy by travelling shorter distances, as longer trips would take too much time and prevent them from covering high demands of energy. As the foragers perform shorter foraging trips the average yield per hour increases (Fig. 4). This decrease in logistical mobility results in more residential moves with decreasing distances between the old and the new base location (Fig.3).

The large increase of residential moves when the energy demand is 3.000 energy units per day or higher (Fig. 4) is most likely the result of the need for further foraging trips per day. With a lower energy demand per day 1-2 foraging trips are sufficient to cover the demand, but from 3.000 engery units onwards 3 trips become necessary per day.

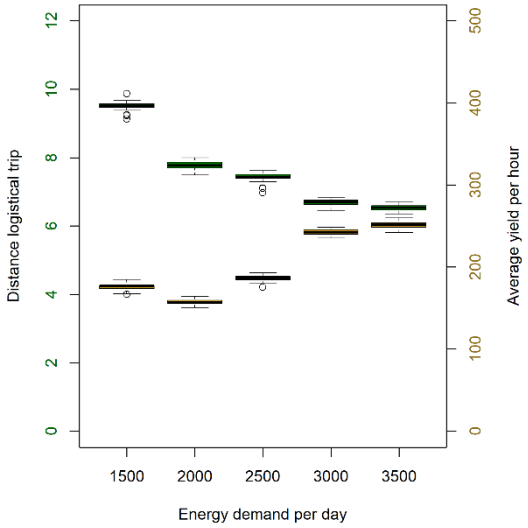


Fig. 3: Average distance moved per logistical trip and the average yield per hour with changing energy demand per day of each forager.

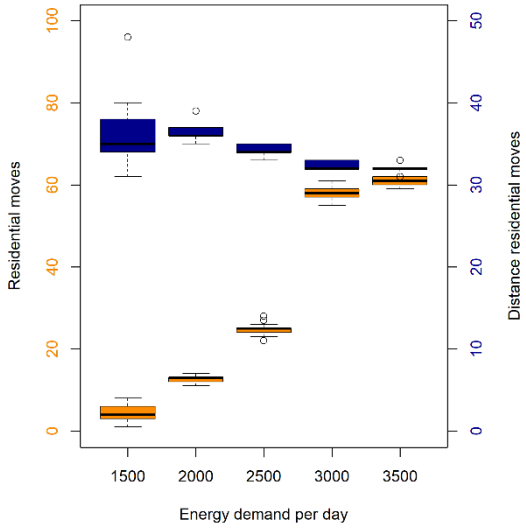


Fig. 4: Residential moves per year and the average distance moved per residential move changing energy demand per day of each forager.

## 1.3 Maximum load (Agent9-Agent12)

An increased maximum load allows the foragers to exploit distant resources more efficiently as they can carry more resources back to the camp resulting in longer logistical trips (Fig. 5). The average yield remains relatively unchanged by the longer logistical trips, only at a maximum load of 1.000 units the average yield is higher, but decreases afterwards (Fig. 5). The number of residential moves greatly decreases with a maximum load of 1.500 or higher, while the distance per residential move increases steadily (Fig. 6).

There seems to be a threshold between the maximum load of 1.000 and 1.500 which heavily influences the ability of the foragers to exploit their surrounding (Fig. 5). This phenomenon is most likely caused by the average number of foraging trips the agents must perform per day. With a maximum load below 1.500 the foragers always have to perform at least 3 foraging trips to cover their daily energy demand. A higher maximum load may allow the foragers to collect all necessary resources after two trips.

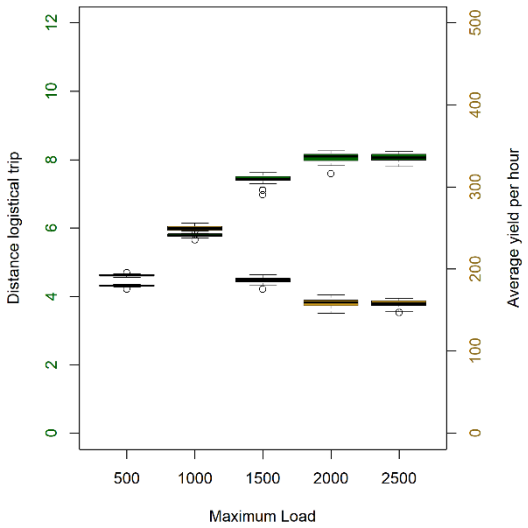


Fig. 5: Average distance moved per logistical trip and the average yield per hour with changing amount of resources the foragers can carry while gathering.

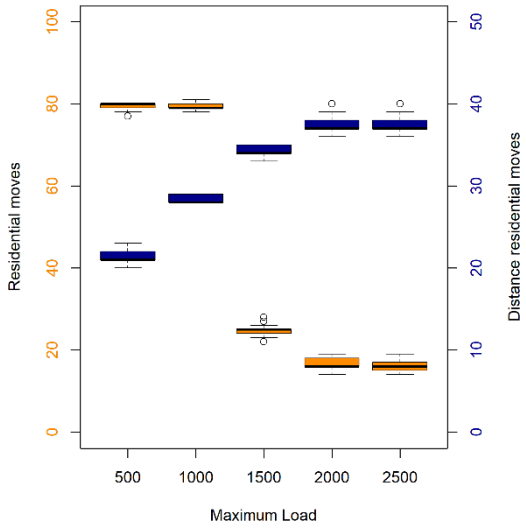


Fig. 6: Residential moves per year and the average distance moved per residential move with changing amount of resources the foragers can carry while gathering.

# 2. Environment factors:

## 2.1 Net-Primary productivity (Env1- Env4)

Net primary productivity is the first factor which determines the average amount of resources available throughout the year. With an increasing amount of resources, the agents travel further during foraging trips while increasing the average yield per hour (Fig. 7). The increased average yield allows the agents to stay longer at each location; with a very high NPP being an exception as the residential mobility increases again (Fig. 8).

This increase in residential mobility most likely is related to a decrease in the distance moved during foraging trips (Fig. 7). Instead of travelling further and increasing the average yield the foragers decrease the distance travelled while increasing the average yield (Fig. 7). The cause of this phenomenon is currently unknown. With an even higher amount of available resources the residential mobility decreases again.

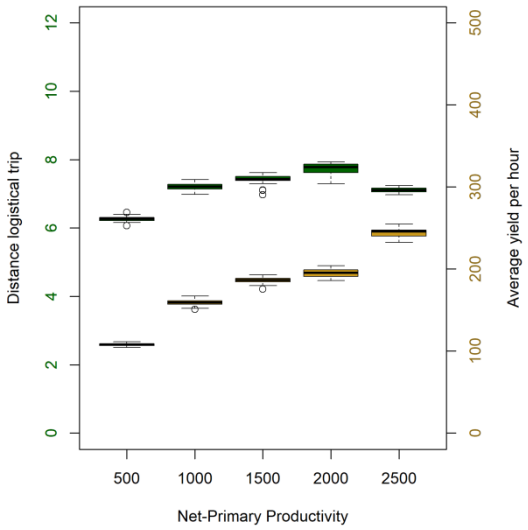


Fig. 7: Average distance moved per logistical trip and the average yield per hour with changing base resource availability.

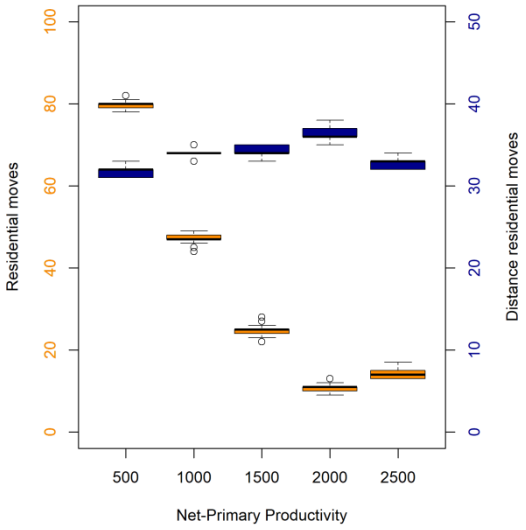


Fig. 8: Residential moves per year and the average distance moved per residential move with changing base resource availability.

## 2.2 NPP-Multiplicator (Env-6-9)

The NPP-multiplicator is the second factor determining the availability of resources; it has the same effect as net primary productivity. The agents travel further with a higher NPP-multiplicator and increase the average yield per hour (Fig. 9). The increased yield allows the group to stay longer at each location (Fig. 10). Again a very high resource amount results in the group performing shorter foraging trips (Fig. 9) and moving the residential camp more often (Fig. 10).

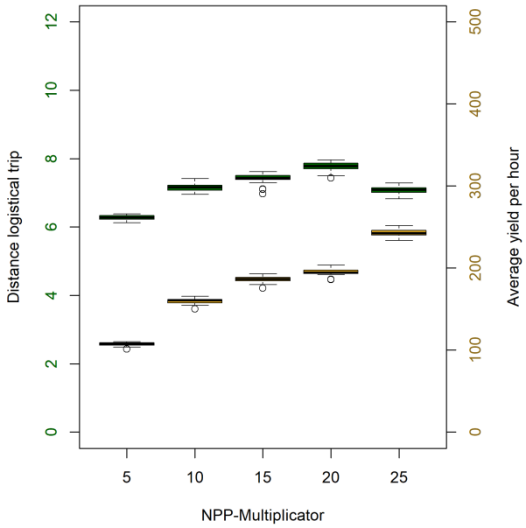


Fig. 9: Average distance moved per logistical trip and the average yield per hour with changing base resource multiplier.

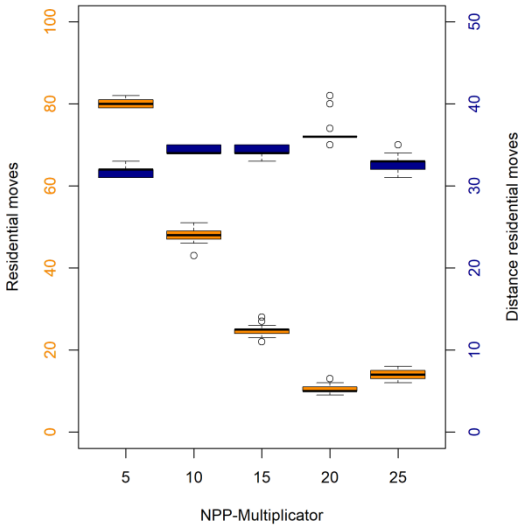


Fig. 10: Residential moves per year and the average distance moved per residential move with changing base resource multiplier.

## 2.3 Length of dry season (Env-10-13)

During the dry season the availability of seasonal resources with a higher energetic value is reduced. As a result the average yield decreases (Fig. 11), but the mobility pattern remains mostly unchanged. The foragers are able to thrive even during longer dry periods by relying on the non-seasonal resources.

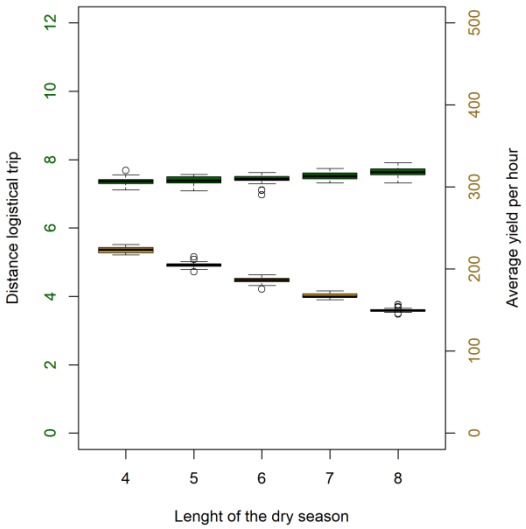


Fig. 11: Average distance moved per logistical trip and the average yield per hour with changing length of the dry season.

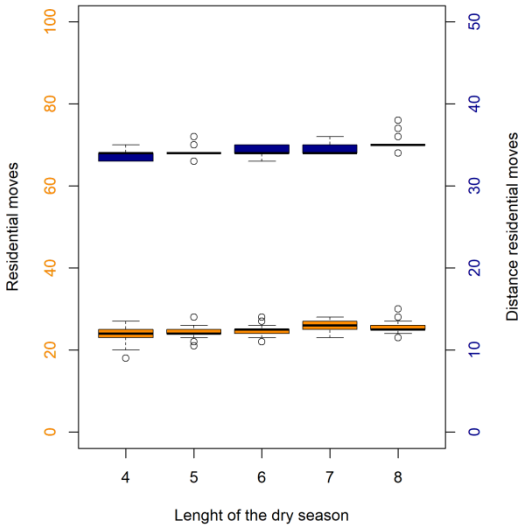


Fig. 12: Residential moves per year and the average distance moved per residential move with changing length of the dry season.

## 2.4 Productivity reduction in dry season (Env-14-17)

This factor determines the percentage by which the amount of available seasonal resources is reduced during the dry season. With overall fewer resources available during the dry season the average yield decreases (Fig. 13) which results in more frequent residential moves (Fig. 14). With a reduction by more than 50% the group moves substantially more often (Fig 14).

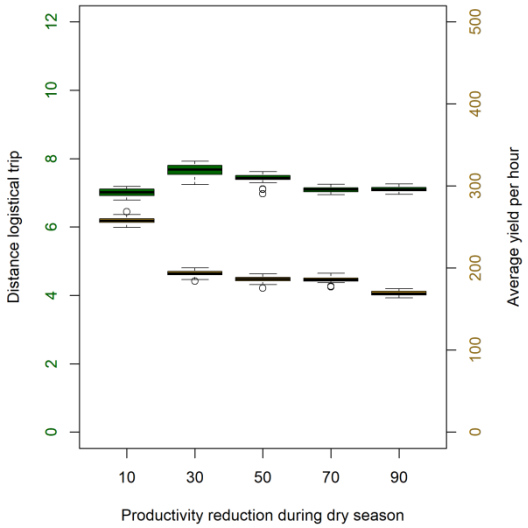


Fig. 13: Average distance moved per logistical trip and the average yield per hour with changing resource reduction during the dry season.

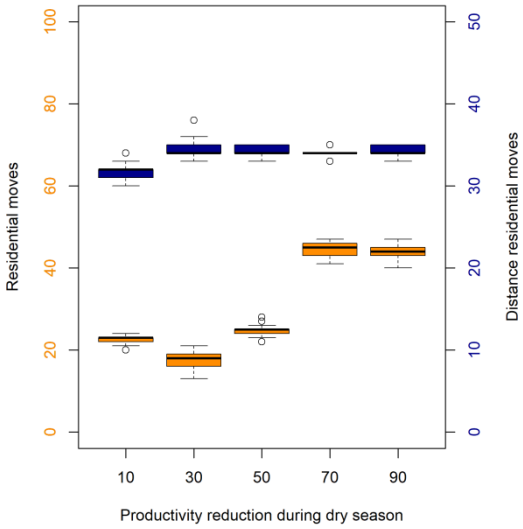


Fig. 14: Residential moves per year and the average distance moved per residential move with changing resource reduction during the dry season.

## 2.5 Occurrence of Resources (Env-18-21)

This factor determines the percentage of seasonal resources which are affected by the resource reduction during the dry season. With more of the high value but only seasonal available resources the average yield increases (Fig. 15). But the number of residential moves still increases as the dry season becomes more challenging for the group (Fig. 16).

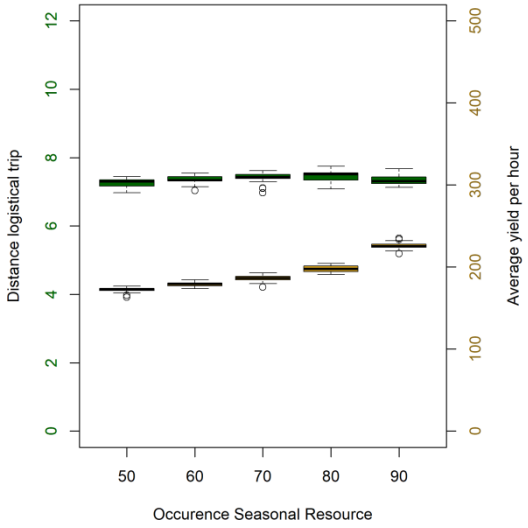


Fig. 15: Average distance moved per logistical trip and the average yield per hour with changing distribution of the two resources: seasonal and aseasonal.

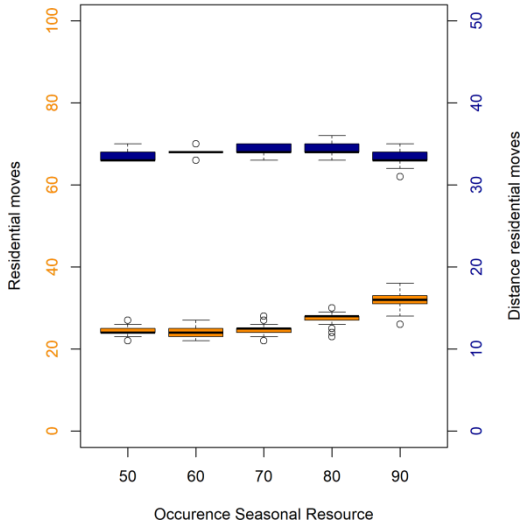


Fig. 16: Residential moves per year and the average distance moved per residential move with changing distribution of the two resources: seasonal and aseasonal.

## 2.6 Seasonal resource value (Env-22-25)

The foragers react to an increasing energetic value per unit of gathered resource by traveling further without substantially increasing the average yield per hour (Fig. 17). This allows the group to stay longer at each location although the number does not decrease further after an energy value of 140 or higher (Fig. 18). Again the foragers seem to struggle with exploiting resource rich environments, similar to the experiments with a high net primary productivity or high NPP-multiplicator.

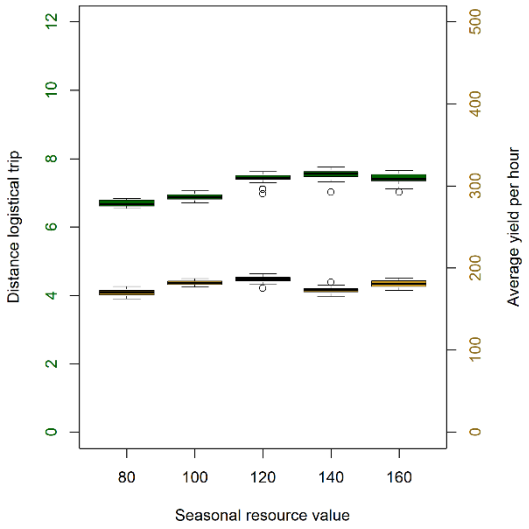


Fig. 17: Average distance moved per logistical trip and the average yield per hour with changing energetic value of the seasonal resource.

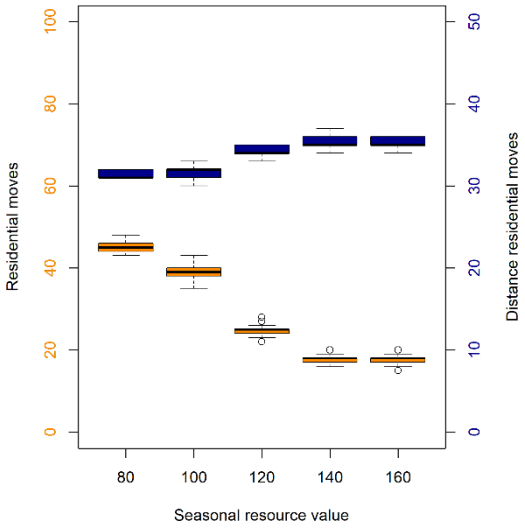


Fig. 18: Residential moves per year and the average distance moved per residential move with changing energetic value of the seasonal resource.

## 3. Bi-factorial analysis

As already stated, both the length of the dry season and how much the resources are reduced during this period influences the agent behavior (2.3 & 2.4). The reduction during the dry season seems to have a stronger effect on the group, as only a simultaneous occurrence of an extended dry season and a high resource reduction exerts a large effect on the group (Fig. 19).

The lower residential mobility with a resource reduction of 30% was already observed in the sensitivity studies (Fig. 14). The cause of this phenomenon is still unidentified; it is most likely the result of a problem occurring when exploiting environments with high availability of resources (2.1 & 2.2). This is presumably caused by the foragers gathering too many resources as surplus for sharing. Potentially the foragers need an option to gather fewer resources during periods with abundant resource supply while increasing the surplus amount they gather during periods of decreased availability of resources. This would allow them to forage optimally during both periods.

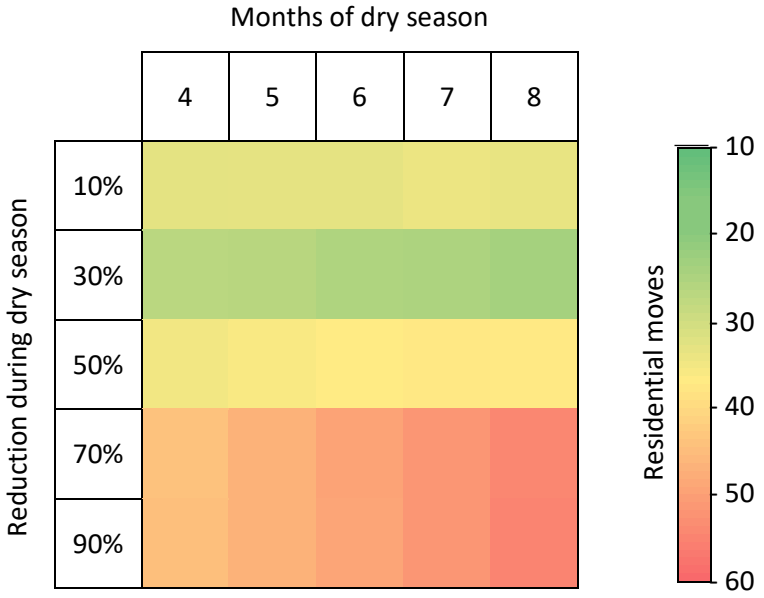


Fig. 19: Average number of residential moves per year with changing length of the dry season and the percentage the occurrence of seasonal resources gets decreased during these months.

## 4. Sources

Kelly, R. L. (1983). Hunter-Gatherer Mobility Strategies. Journal of Anthropological Research, 39(3), 277–306. https://doi.org/10.1086/jar.39.3.3629672