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## RANGING PATTERNS OF SERINGBARA CHIMPANZEES: METHODOLOGICAL INSIGHTS

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# RANGING PATTERNS OF SERINGBARA CHIMPANZEES: METHODOLOGICAL INSIGHTS

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## GENERAL PUBLIC RESUME

How animals use space is a crucial aspect of their behavioural ecology. The spatial patterns of a species affect feeding strategies, social organization, mating systems and conservation management. In order to satisfy the need of finding food, mates and shelters, the majority of free-ranging animals return to the same areas repeatedly during their lifetime. This revisited area that an individual uses to satisfy its necessities is considered its home range.

When animals live in groups, communities or pairs, they share a common home range for satisfying the needs of the social unit. And where the resources of the home range are limited and defendable, animals defend that area against neighbouring individuals. This is the case of wild chimpanzees (*Pan troglodytes*). They live in communities from about 20 to 150 individuals and each one has its own home range that the adult males jointly defend.

The current study on chimpanzee ranging patterns took place at the Seringbara study site, in the Nimba Mountains, Guinea, West Africa. The Seringbara chimpanzees are largely unhabituated to human presence, which meant that it was difficult to directly see the individuals and even harder to follow them. Thus, the dataset included, not only direct sightings, but also nests, faeces and motion triggered cameras. We aimed to describe which area of the study-site chimpanzees consider their home range, both across one entire year and accordingly to the 12 months. The analyses involved the three most qualified methods of territory estimations currently available, in order to better understand and to choose the most reliable results obtained with this new kind of dataset. In addition, we assessed how their feeding behaviour affects their ranging patterns. Chimpanzees are omnivorous, but their diet consists mostly of seasonally abundant fruits, which could reasonably affect ranging patterns.

The results showed that the Fixed Kernel method performed better than the others. The Seringbara chimpanzees apparently cover an area of approximately 30 km<sup>2</sup> over a study-site of about

38 km<sup>2</sup>. Comparing these values with estimates on communities of known size, we expect more than 100 chimpanzees present at the study-site. Our home range or core area estimates did not show distinct areas belonging to different communities. We could not prove any influence of fruit availability or diet components on ranging patterns. Nevertheless, some trends suggested that chimpanzees may enlarge their home range when they rely more on folivorous fibers and less on fruits. Our findings and a review of the literature agree on the complexity of the topic and stress the need of large sample sizes and of considering several influencing factors, across many years of study, in order to provide an exhaustive comprehension of the matter.

## **ABSTRACT**

Explaining where and why an animal species ranges across a certain area is very important to increase its predictability, to protect it, to understand how diseases or culture spread and many other aspects. The current research focused on the ranging patterns of chimpanzees living in the Seringbara study-site. It was intended to be a first study of this kind on chimpanzees unhabituated to human presence. Thus, the dataset was unique for its particular small size and the kind of data, which were acquired not only by direct sightings, as usual, but also by motion triggered cameras and through nest and faeces locations. This aspect brought to a parallel use of the three most used methods for territorial estimations, to better understand and choose the most reliable results. Once the estimations were done, food availability (from phenological transects) and diet (from faecal components) were analyzed as possible influencing factors of ranging patterns. The first step was the estimation of monthly and annual home ranges and core areas. Seringbara chimpanzees cover a vast area, from 20.50 km<sup>2</sup> to 35.73 km<sup>2</sup>, depending on the method used. The three methods, Minimum Convex Polygon, Grid Cell and Fixed Kernel, performed very differently. Only the Fixed Kernel did not correlate with sample size and it was considered the most reliable, even though with some reservations. Besides, fruit availability correlate neither with the four faecal components, percentage of THV fibers, percentage of seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.*, number of species and number of big seeds (>5 mm), nor with the estimates. Also, diet components did not clearly correlate with the size of home range and core area, but there was a positive trend between home range size and percentage of THV fibers (considered fallback food for periods of low fruit availability) and, reasonably, the size decreases when there are more big fruit seeds in the faeces, though not significantly so. In any respect, ranging patterns are such a complex topic that only the consideration of several influencing factors, across many years of study, may offer exhaustive comprehension of the matter.

## INTRODUCTION

A fundamental component of the analysis of the behavioural ecology of free ranging animal species is the description of their spatial patterns. Such information increases their predictability and supports possible strategies for the protection and the conservation of the species concerned. Free ranging animals need to move where they can find food, mates and safe places for resting and sleeping. The area that is chosen by the individual to satisfy these necessities can be defined as its home range (Börger et al., 2006; Burt, 1943 [quoted in Amsler, 2009; Boitani and Fuller, 2000]; Lehmann and Boesch, 2003; Mizutani and Jewell, 1998). The knowledge of where individuals range in a certain period or season can deepen our awareness of their needs and preferences. In particular, understanding the determinants of animal densities is becoming more and more significant, since ecologists are requested to apply their knowledge to assist conservation biologists to provide informed management plans for endangered species (Chapman et al., 2003). In addition, the composition of animal home ranges in a landscape has important effects on infectious diseases, cultural trait transmissions and interactions with neighbouring individuals. Therefore estimating and locating home ranges of animals is very important (Kouakou et al., 2011).

When the resources of the home range are limited and defensible, animals adopt territorial behaviours against their neighbouring conspecifics (Mitani and Rodman, 1979). Usually primates occupy relatively stable home ranges throughout the year and they show a large spectrum of intensity of territoriality (Mitani and Rodman, 1979). Chimpanzees (*Pan troglodytes*) give a special importance to territorial defence. They are gregarious animals that live in communities comprising multiple adult males, adult females and immature individuals. Each community has its own home range that the adult males jointly defend (Amsler, 2009; Herbinger et al., 2001; Mitani and Watts, 2005; Watts and Mitani 2001; Wilson and Wrangham, 2003). On one hand, group living facilitates access to resources and increases predator avoidance, on the other, the competition over food and mates and the probabilities of contagion of diseases rise between the individuals of the group (Chapman et al., 1995; Lehmann and Boesch, 2004). In order to balance these costs and benefits of group living, chimpanzees frequently change their spatial cohesion and individual membership in subgroups over time, in a social structure called fission-fusion society (Aureli et al., 2008; Lehmann and Boesch, 2004). This flexible system permits them to form small parties (subgroups) pursuing food availability or receptive females, whilst maintaining the stability of the group (Hashimoto et al., 2001; Lehmann and Boesch, 2004; Matsumoto-Oda et al., 1998).

Currently, wild chimpanzees have been reported inhabiting around 40 sites, spread throughout 21 African countries. These include: canopy rainforests, woodlands and areas dominated by grassland

(Schoeninger et al., 1999). Since the late 1950s, studies at long-term field sites have shown that the behaviour of chimpanzees differs in a variety of ways from one field site to another (Goodall, 1994). All communities of wild chimpanzees share the same social structure, the majority of displays and calls, an omnivorous diet characterized by strong frugivorous preferences (Conklin-Brittain et al., 1998; Furuichi et al., 2001; Koops, 2011; Mitani et al., 1999; Newton-Fisher et al., 2000) and some other behaviours like nest building (Brownlow et al., 2001) and tree buttress drumming (Arcadi et al., 2004). Nevertheless, more than 50 years of study on wild chimpanzees (Mitani et al., 2002) bring most attention to their high capacity to adapt to different environments and highlight important cultural differences existing between communities, within the four subspecies (*P. t. troglodytes*, *P. t. schweinfurthi*, *P. t. verus*, *P. t. ellioti*). Examples concern variations in group size, which can vary from about 20 to 150 individuals (Mitani 2006; Lehmann and Boesch, 2003) suggesting differences in social structure, diversities in common behaviours and presence of exclusive behaviours across communities (Whiten et al., 1999). This variety names each community potentially exceptional and stresses the need of study and preservation of all wild populations.

Substantial variations between communities of chimpanzees affect also their ranging patterns (Amsler, 2009; Baldwin et al., 1982; Basabose, 2005; Chapman and Wrangham, 1993; Doran, 1997; Emery Thompson et al., 2007; Herbinger et al., 2001; Lehmann and Boesch, 2003; Lehmann and Boesch, 2005; Murray et al., 2008; Newton-Fisher, 2000; Newton-Fisher, 2003; Williams et al., 2004; Wrangham et al., 2007). Several elements have been suggested to influence this variation: community size, intergroup relationships and food availability (Adams, 2001; Amsler, 2009; Clutton-Brock and Harvey, 1977; Milton and May, 1976; Swihart et al., 1988). Such variation in ranging patterns and the interplay between influencing factors make space use a complicated topic. Group living and social structure, similarly to habitat use and ranging patterns, vary as a result of numerous factors, and food availability is surely a fundamental one (Chapman et al., 1995; Di Fiore, 2003; Doran et al., 2004; Herbinger et al., 2001; Li et al., 2010; Potts et al., 2009; Wrangham et al., 1993). The reason is that primates need to be able to cope periods of relative low abundance of their preferred food in order to avoid negative impacts on health and reproduction. To do so, they must be able to alter their dietary composition or activity patterns or both, and change habitat use and ranging patterns accordingly (Felton et al., 2008). Hence food availability is considered a critical factor determining primate abundance (Balcomb et al., 2000; Di Fiore, 2003; Harvey and Clutton-Brock, 1981; Lehman, 2004; Vedder, 1984).

In the current study, I attempt to describe which area of the Seringbara study site, in the Nimba Mountains, Guinea, West Africa, chimpanzees (*Pan troglodytes verus*) consider their home range. Moreover, I aim to assess how their feeding behaviour affects their ranging patterns. In particular, I will

consider whether or not correlations exist between location, shape and dimension of the monthly home ranges and/or core areas with values of monthly fruit availability and monthly percentages of diet components (from faeces). Previous studies regarding chimpanzees about these topics considered individuals habituated to human presence. Since Seringbara chimpanzees are unhabituated to humans, we thus had to use different sources of data in addition to direct observations, like nests, faeces and videos from motion triggered cameras. The uniqueness of the dataset required an analysis of the methods of area estimation to better understand the different aspects that they show and which one is the most reliable.

Territorial estimations have been performed with a number of methods, varying because of differences in data collection, in the availability of analytical tools and/or in the personal preferences of researchers (Bermejo, 2004; Cipolletta, 2003; De Luca et al., 2009; Doran-Sheehy et al., 2004; Fashing, 2001; Hansteen et al., 1997; Kolodzinski et al., 2011; Newton-Fisher, 2003; Twinomugisha and Chapman, 2007; Vedder, 1984). Different techniques of estimation applied to the same sample may produce different results, and a qualitative hierarchy of methods is still debatable (Amsler, 2009; Anderson, 1982). Furthermore, other aspects such as sampling effort, study length and sampling regime may also influence results, and standardizing these factors across studies is often difficult (Börger et al., 2006).

This research considers three methods to examine GPS points and, map unidentified chimpanzees across time (months and year) and space (inside the Seringbara study site): the Minimum Convex Polygon (MCP), the Grid Cell and the Fixed Kernel.

The first method, the Minimum Convex Polygon, creates the smallest polygon of convex corners (all corners smaller than 180°) which includes all observed points. The area within the polygon is the estimated home range size. The simplicity of this method is definitely appealing, nevertheless it is unfortunately sample size biased: usually a larger amount of collected points gets a larger estimated surface of home range (Anderson, 1982; Börger et al., 2006). In addition, the shape of the home range is forced to be a convex polygon, which is an unreasonable assumption (Anderson, 1982).

The second method is another simple and intuitive way to estimate home ranges, the Grid Cell. It is based on the density of data in each cell of a grid superimposed on the studied area. In contrast with the MCP, this method is sensitive to the intensity of use of the territory, but it is similarly biased by sample size. In fact, without constant animal tracking the resulting ranging analysis could even result in discontinuous areas. Moreover, the estimated area is composed by all the entire cells where at least one location is recorded. Therefore, the method is particularly sensitive to the length of the grid square (Newton-Fisher, 2003). This method is often used in territory size estimations but it seems more

advantageous for representing habitat usage than for home-range estimation (Mizutani and Jewell, 1998).

Third, the Fixed Kernel is considered the most accurate method currently available to estimate home range sizes (Börger et al., 2006; De Luca et al., 2009; Seaman and Powell, 1996). When estimating home ranges, the density at any location should ideally be an estimation of the amount of time spent there by the subject (population, group or individual). This Kernel method consists of placing a kernel (a probability density) over each collected GPS point in the sample. Interpolating the kernels of all points, considering the distance between them, the Fixed Kernel method creates concentric contour lines, which include the area of sequential probabilities of finding a point, over the research field. In this way, observations that are closer to a point of evaluation contribute more to the estimate than those ones that are farther (Seaman and Powell, 1996; Worton, 1989). One crucial step of this method is the determination of the width of the kernels, because wide kernels allow more influence of distant data, but narrow kernels reveal more small-scale details of the data structure. In the Adaptive Kernel method, the width of each observation point varies depending on the density of points (or intensity of usage). However, the Fixed Kernel method is considered more accurate and less biased than the Adaptive Kernel method (Spearman and Powell, 1996; Worton, 1995).

The area identified with these three methods includes intensively used spaces and wide peripheral parts of the ranges, which chimpanzees patrol and aggressively defend from conspecifics of other communities (Herbinger et al., 2001). These intensively used areas, or core areas, are used exclusively by territory owners, while edge areas can be shared between neighbouring communities. In particular, researchers in Mahale and Gombe, Tanzania, have recognized overlapping zones involving 30-50% of the total home range (Herbinger et al., 2001). Between these areas, the preferred spaces result in a clumped, often multinuclear, pattern of range use, covering 7 to 32% of the total home range (Newton-Fisher, 2000). Therefore, in the current study, each home range estimation is expanded with the identification of the core area because the analysis of these core areas will add details to the ranging patterns of Seringbara chimpanzees.

In addition, the methodological analysis concerns the concept of autocorrelation between consecutive locations coming from the same individuals. In fact, the independence of data in analyses regarding ranging patterns is both defined as crucial (Herbinger et al., 2001, Newton-Fisher, 2003) or as negligible (Barg et al., 2005; Blundell et al., 2001; De Solla et al., 1999) in literature. Motion triggered cameras collected data that may be autocorrelated, because of the impossibility to distinguish each chimpanzee individually. Consequently, each analysis will be performed with the whole dataset and, then, with the dataset excluding data from the cameras. This investigation will also help the description of the influence of sample size on the methods of estimation.

In chimpanzees, foraging behaviour can vary considerably over small spatial and temporal scales (Chapman et al., 2002; Koops, 2011). In fact, omnivory with frugivorous preferences is consistent across all populations and habitats (Basabose, 2002), but other aspects, such as consumption patterns, dietary variety or fruit and leaf ratios differ between sites, between seasons or even between years at the same site (Newton-Fisher, 1999). The study of nutritional ecology has proven useful for understanding many aspects of primate behaviour and ecology and is a valuable tool in primate conservation (Chapman et al., 2003). A clear and complete overview of dietary habits and variants of chimpanzees require the analysis of their diet in every study site. Unfortunately, not all field sites have habituated individuals that yield direct observations on feeding behaviours; some need to infer data about the diet of chimpanzees from indirect sources: mainly feeding remnants and faeces (McGrew et al., 2009). Since habituation is not always possible and it is a process that needs many years of field work, faecal analysis have been a valuable tool for preliminary dietary data for more than 40 years (McGrew et al., 2009, Basabose, 2002). Thus, the diet, as reflected in faecal components of Seringbara chimpanzees, is taken in account as possible influencing factor of ranging patterns.

Some researches argue that chimpanzees may actively chose their fruit species instead of just consuming them opportunistically and proportionately with their abundance, complicating the link between diet and seasonal ripening (Basabose, 2002; Moscovice et al., 2007). Hence, in order to study feeding ecology, diet has to be linked to food availability, so as to discern possibilities, choices and strategies involved in feeding behaviour. Since chimpanzees are highly frugivorous, the food availability of their home ranges is most often measured as tree fruit availability (Balcomb et al., 2000; Basabose, 2002; Basabose, 2004; Furuichi et al., 2001; Hashimoto et al., 2003; Koops et al., 2013). In tropical Africa, seasonal variation in tree fruit availability has been reported in the majority of chimpanzee study sites (e.g., Kahuzi, DRC (Basabose, 2002), Kalinzu Forest, Uganda (Furuichi et al., 2001), Lope Reserve, Gabon (Tutin et al., 1991), Bossou, Guinea (Yamakoshi, 1998) and Seringbara (Koops et al., 2013)). Even though large local variations are present, the majority of field sites are characterized by one or two periods of fruit scarcity per year (Furuichi et al., 2001). In particular, chimpanzees living in evergreen rainforests experience seasonal variation in rainfall and temperature, resulting in distinct and predictable periods with fluctuating production, duration and synchrony of food resources (Felton et al., 2008). The studies concerning these areas mainly analysed fruit availability with phenology transects (Balcomb et al., 2000; Basabose, 2002; Koops, 2011; van Leeuwen et al., 2012), which has been the same technique involved in this study.

Tree fruit availability is assumed an influencing factor of ranging patterns. Since chimpanzees are highly frugivorous, seasonal fruit scarcity affects survival, party size and social structure of communities (Furuichi et al., 2001). The temporal and spatial variations in fruit availability affect the



frequency of use of different habitat types in chimpanzee home ranges (Basabose, 2005; Basabose and Yamagiwa, 2002; Doran, 1997; Newton-Fisher, 2003). Nevertheless, the relation between fruit scarcity and actual changes in the home range or the core area of the community is unclear. The same relations between ranging patterns and fruit availability have been studied throughout diverse areas and, sometimes, they concluded with different or even opposite results. When fruit are scarce, Kahuzi chimpanzees, in D. R. C., seem to enlarge their range area, while Ngogo chimpanzees, in Uganda, decrease it (Basabose, 2005; Amsler, 2009). In Tai National Park, in Ivory Coast, home range sizes or core area locations seem not to be affected by fruit availability (Herbinger et al., 2001; Lehmann and Boesch, 2003), but individuals modify group sizes according to it (Doran, 1997; Herbinger et al., 2001). Kibale chimpanzees, Uganda, intensively used stable favorite areas over a 9-year period (Emery Thompson et al., 2007), while, in Budongo Forest, Uganda, seasonal variations in food abundance may have pushed male chimpanzees to vary the amount of time spent in their core areas (Newton-Fisher, 2000).

Consequently, ranging patterns of chimpanzees appear to be influenced by fruit abundance only in some studies. The causes can be diverse: different methods of estimation, different levels of fruit availability, different fruit species and different local environmental influencing factors (Börger et al., 2006; Chapman et al., 1994; Hashimoto et al., 2003; Potts et al., 2009; Adams, 2001). However, probably one of the main causes of these differences resides in the remarkable capacities of chimpanzees to adapt to different conditions (Börger et al., 2006; Adams, 2001). Therefore, even in presence of seasonal fluctuations of fruit availability and monthly variations in the diet of chimpanzees, predictions about the influence of the availability of fruits on ranging are very difficult to make.

Lastly, this research aims to improve searching efficiency for future data collection. Therefore, data collected will be related to the intensity of the search effort. The analysis will help to understand whether chimpanzees were wherever the teams looked for them, whether the teams should intensify their efforts to collect more data, whether it is possible to choose some areas where to focus on or whether chimpanzees were avoiding the most visited areas by humans. In general, being a study about ranging patterns on unhabituated individuals, it is important to know whether and how it is possible to improve the encounter frequencies at the Seringbara study-site.

Concluding, using three different methods of both home range and core area estimation, I am expecting to obtain a clear overview of which parts of the surveyed area the chimpanzees consider their home range. Comparing results with studies about ranging of chimpanzees of other communities of known size, we could formulate some hypotheses about the number of chimpanzees that lives in the Seringbara study-site. Perhaps, it will be possible to add new evidence to the presence of at least two chimpanzee communities at the Seringbara Study Site, confirmed during the last decade, through direct

observations, nest counts and genetic analyses (Koops, 2011; Koops et al., 2012). The identification of core areas could clearly help the distinction between territories of neighbouring unhabituated communities. In fact, without the possibility to differentiate individuals and with a homogeneous visual continuum when estimating the home ranges, the identification of the most used areas may be decisive to identify a “no-go-zone”, mostly avoided by individuals on both sides of a boundary because of the risk of encountering hostile neighbours (Wilson et al., 2007). So far, attempts to recognize distinct communities have usually required habituation of each chimpanzee group to the presence of humans, which is a long process that normally takes 5-7 years of constant work (Boesch and Boesch-Achermann, 2000 [quoted in Kouakou et al., 2011]). Therefore, the development of faster approaches to distinguish and locate neighbouring social units is an important aim (Kouakou et al., 2011). Moreover, identification of core areas adds details to a study focused on territory use. Chimpanzees may vary the monthly dimension and/or location of home ranges or core areas inside a stable home range. These variations over time may be linked not only to influencing factors mentioned above, but also to seasonal differences in the dispersion of individuals of a community (party-sizes in a fission-fusion society).

Phenological data of the Seringbara study site from previous years have revealed high fruit availability during the dry season (December, January and February) and increasing fruit scarcity that climaxes in the rainy season (Koops, 2011; Koops et al., 2013; van Leeuwen et al., 2012). I expect this seasonal pattern of fruit production to be confirmed. In the previous analyses, these differences in monthly fruit availability were not correlated with the number of fruit species per faecal cluster (Koops et al., 2013). Nevertheless, there was a trend of negative correlation between fruit availability and THV (terrestrial herbaceous vegetation) fiber percentage in the faeces (Koops, 2011; Koops et al., 2013). Moreover, literature offers a very limited set of comparable studies with faecal analyses on chimpanzees (McGrew et al., 2009). Therefore, frugivory preferences will presumably correlate chimpanzee assumption of fruits with fruit availability positively, but it is hard to define a clear prediction about the composition and the seasonality of Seringbara chimpanzee diet.

Then, in case of correlation between variations of one or more parameters of ranging patterns (home range or core area, dimension or location) and tree fruit abundance fluctuations and/or the diet of these primates, this research is providing findings about the ecology of chimpanzees that may contribute to quantify the variety and the availability of floristic species in our area of study on a small scale. It could help to identify the strategies of the chimpanzees to adapt to seasonal changes. In any circumstance, it is an investigation to delineate the importance of fruits, fallback or not, for Seringbara chimpanzees.

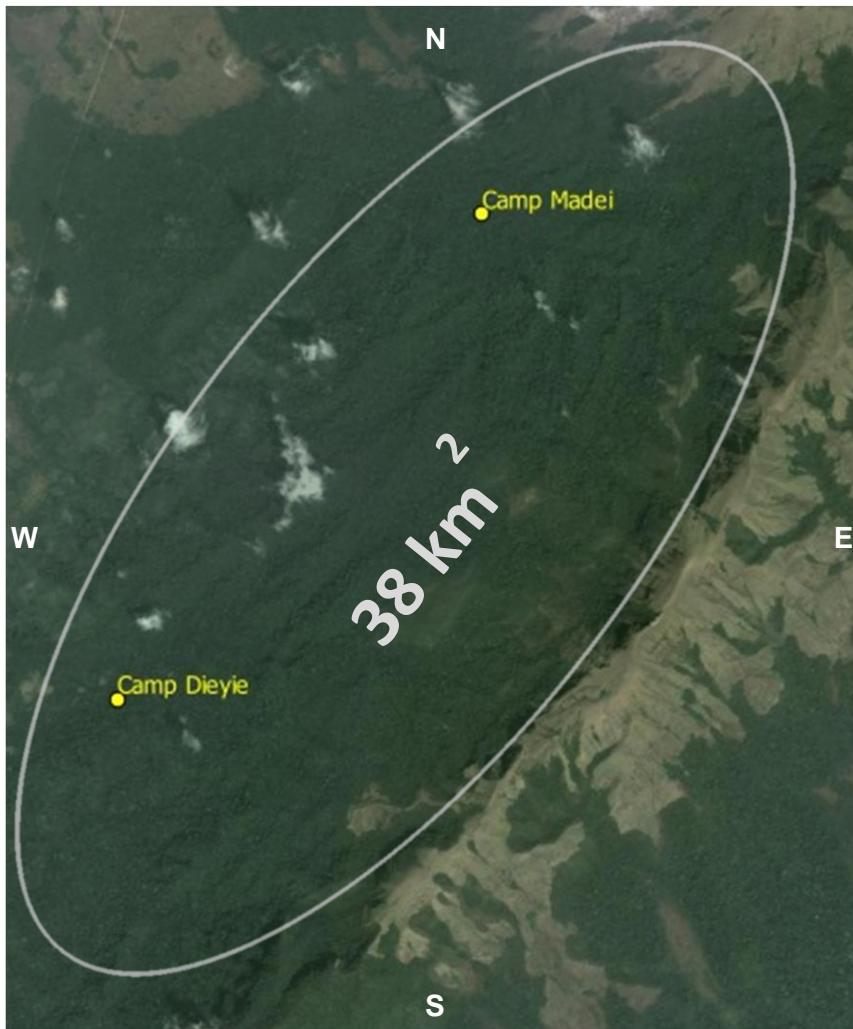
In literature, home range has been seen small in presence of high food supply, for example in the Budongo Forest, in Uganda (Newton-Fisher, 2003), or, on the other side, also particularly large territory size has been attributed to high food supply, for example in Taï National Park, Côte d'Ivoire (Herbinger et al., 2001). Accordingly, the Seringbara chimpanzees could either decrease or increase sizes of their home range or their core area during period of fruit abundance. In the first case, the largest home ranges and/or core areas would be in August/September, monthly sizes of home range and/or core area would be negatively correlated with monthly fruit availability and numbers of fruit species in faeces, but positively correlated with monthly percentages of folivorous fibers in faeces. While, if Seringbara chimpanzees increase sizes of their home range or their core area during period of fruit abundance, I am expecting the opposite: the largest home ranges and/or core area in January/February, monthly sizes of home range and/or core area would be positively correlated with monthly fruit availability and numbers of fruit species in faeces, but negatively correlated with monthly percentage of folivorous fibers in faeces.

## **MATERIALS AND METHODS**

### STUDY SITE

The Seringbara study-site is part of an extensive region: the Nimba Mountains. The whole Nimba range is a transboundary massif that crosses Guinea, Côte d'Ivoire and Liberia, covering 171 km<sup>2</sup> (Kormos et al., 2003). The Seringbara study-site takes its name from the nearest village at the foothills: Seringbara (71 37050.000N, 81 27044.700W) (Koops et al., 2007), in south-eastern Guinea, West-Africa. The study-site extent is about 38 km<sup>2</sup> of Guinean territory, within a strict nature reserve that protects approximately 127 km<sup>2</sup> in Guinea and 50 km<sup>2</sup> in Ivory Coast. The Guinean part was accepted as a Biosphere Reserve in 1980, and UNESCO listed the Nimba Mountains as a World Heritage Site (Lamotte, 1998).

The Nimba Mountains climb from around 600 m above sea level up to 1.752 m, which is the highest peak, named Mont Richard-Molard. The area is covered by tropical rain forest. The composition is mostly primary forest but also secondary forest, riverine forest, terrestrial herbaceous vegetation (THV) and, especially above 1000 m, montane grasslands and high altitude savannahs (Koops, 2011). African equatorial forests are characterized by two seasons: one wet season and one dry season. The Seringbara study site has a dry season (rainfall <60mm) of 3 months, from November until January and a wet season (rainfall >60mm) of 9 months, from February until October (Koops et al., 2012).



**FIGURE 1.** Map of the Seringbara study-site. (yellow points: base camps)

Mean daily temperatures oscillate between 20 and 22°C all year round: in the wet season, the highest temperatures are at low altitude (670m) and the lowest at high altitude (1170m) while the pattern is reversed in the dry season (Koops et al., 2012). Mean relative humidity changes from 96% at low altitude during the wet season to 45% at high altitude in the dry season. Highest values were at low altitude across seasons (Koops et al., 2012).

The Nimba Mountains exhibit great topographical diversity and a remarkable faunal and floral variety, as well as high occurrences of

endemisms. Therefore, the Nimba Mountains are significant in the context of the worldwide biological diversity (Kormos et al., 2003).

The montane topography and the general uniqueness, as only mountain research field in West-Africa and settlement of several endemic species, of the Seringbara study-site make the area an exceptional chimpanzee study site. Therefore, research on the Nimba chimpanzees offers an important new source of information on West African chimpanzees (Koops, 2011).

### STUDY SPECIES

Chimpanzees (*Pan troglodytes*) include four recognized subspecies: *P. t. ellioti* (Cameroon and Nigeria), *P. t. schweinfurthii* (eastern Africa), *P. t. troglodytes* (central Africa), *P. t. verus* (western Africa). Nowadays chimpanzees are considered an endangered species by the International Union for the Conservation of Nature (IUCN) and Natural Resources Red List (<http://www.iucnredlist.org/details/15933/0>, 2008). In 2003, the total population size was estimated

between 172,700 and 299,700 individuals, making chimpanzees the most abundant and widespread great ape on Earth (Kormos et al., 2003). Nevertheless, the communities are seriously decreasing and the decays that have occurred are expected to persist (Oates, 2006). The western African subspecies (*Pan troglodytes verus*) is very rare or close to extinction in Burkina Faso, Ghana, Guinea-Bissau and Senegal and survives mainly in Côte d'Ivoire, Guinea, Liberia, Mali and Sierra Leone (Humble and Kormos, 2011). This wide distribution and the fact that IUCN classifies them as at a high risk of extinction are the result of an increasingly fragmented habitat (Balcomb et al., 2000). At this time, the subspecies counts between 21,300 and 55,600 individuals (Kormos et al., 2003). It is thought to have recently decreased by 90% in Côte d'Ivoire (Campbell et al., 2008) and findings are expected to be similar in Guinea (Kormos and Kormos, 2011).

In the Seringbara study-site, the first survey of chimpanzees was in 1976. At first, Sugiyama visited the area and interviewed people from the adjacent villages, supporting the hypothesis of a seasonal presence of chimpanzees. Then Shimada (2000) carried out a pilot study in two periods of 1999, in the framework of an extensive survey among Nimba mountains. He heard vocalizations and he found nests and feeding remains at the Seringbara site, suggesting the permanent presence of at least one chimpanzee community. Research efforts were gradually intensified in the Seringbara forest, until 2003, when Koops and Humle established a more permanent research site (Koops, 2011). Since then, the searching activity gradually became almost continuous. In approximately 10 years, chimpanzees came to be more tolerant to researchers' presence, increasing the frequency and duration of sightings and decreasing the approach distance (Koops, 2011 and personal observations). Genetic analysis revealed the presence of at least two communities in the Seringbara study-site, identifiable also during field activities: one in the smaller North-Eastern area and one in the larger South-Western area (Koops et al., 2012).

## DATA COLLECTION

Data collected were part of a long-term continuous collection that has been taking place since 2011. Data considered in this study were collected from May 1<sup>st</sup>, 2012 until April 31<sup>st</sup>, 2013. Different groups of research assistants participated in data collection: J. Caraway, W. Edwards, M. Fitzgerald and P. Le Sommer in May-October, 2012; M. Fitzgerald, D. Hassler, N. L. James, P. Le Sommer, D. Montanari and I. Velez del Burgo Guinea in November, 2012 – March, 2013 and D. Hassler, N. L. James, D. Montanari and I. Velez del Burgo Guinea in April, 2013. Every day, apart from very rare exceptions, at least two research teams were surveying the Seringbara study-site. Each team was composed of at least one researcher assisted by at least one local guide. Seven guides worked on the project: Fromo Doré, Kassié Doré, Nema Gamy, Ce Sami, Doro Zogbila, Fokayé Zogbila and Yon Zogbila. During the day, teams communicated using walkie-talkies. Each research assistant spent 10

days out of 15 working in the field and groups alternated their schedules to guarantee a continuous research presence in the Seringbara study site.

The data sources of this research are GPS location and exact (for direct sightings and motion triggered cameras) or estimated (for faeces and nests) time of the transit of the chimpanzee in that point of: direct observations, nests, faeces and videos by motion triggered cameras. We use a GPS (Garmin GPSMAP 62) to track our daily movements. During the day the team was walking in the forest on usual opened paths or, sometimes, penetrating in the dense bush. Each movement needed to be as silent as possible in order to hear screams and other noises made by chimpanzees and to prevent to be heard by them. When chimpanzees were localized through visual or auditory evidences, the team tried to approach them and, thus, to follow them as long as possible. While walking, the whole team looked continuously around, searching for nests in the tree canopy and faeces on the ground.

At the time of a direct sighting, the team was reporting a description of the event, explaining the number of seen individuals, time, location and habitat. When a trace was found the team noted GPS location and time of the event.

Nest age was assessed by checking the condition of the composing leaves and branches: range 1 was assigned to nests 1 or 2 days old and range 2 was assigned to nests from 3 to 7 days old. Needing a certain precision of chimpanzee transit time estimation, nests estimated to be older than 1 week were not considered.

In case of faeces, only samples estimated to be not older than 1 day were considered, because of a need of precision for the time of chimpanzee transit, similarly to old nests exclusion, and because faecal analyses needed to take place before the fast decomposition of the faeces.

During the whole year, from 13 to 16 motion triggered cameras (Bushnell Trophy Cam XLT 8MP Trail Cameras) were constantly active on frequently used chimpanzee trails. The devices were checked once or twice per month. Batteries and internal memory card were substituted. Then the cameras were linked back to the trunk with a resistant cord. Motion triggered cameras recorded videos of 1 minute. Occasionally chimpanzees remained in the videotaped area for a longer period, causing consecutive sessions of 1 minute videos. In these videos, the individual identification of chimpanzees was difficult: a chimpanzee that has already passed in front of the camera could hardly be differentiated from a new recorded one. For this reason, each individual in every scene was scored.

#### HOME RANGE AND CORE AREA ESTIMATION

After the data collection, I had 12 monthly and 1 annual samples of data of GPS points, locating chimpanzees over the Seringbara study-site through direct sightings, nests, faeces or motion

triggered cameras. Each sample was processed with 3 different methods of home range estimation and 3 corresponding methods for core area estimation. The choice of the parameters for extracting core areas was based on literature: they should provide comparable estimates covering approximately one third of the original home range (Amsler, 2009). These three methods were used to analyze data collected during the whole year. Next, they were applied to data divided per “month” (the term “month” is referred to a period of 30 days, in order to have balanced samples in terms of time available for collecting data). The year was divided in 12 consecutive intervals of 30 days, leaving 5 days at the end of the year for the analyses concerning the whole year. I. E.: September is from Aug, 29<sup>th</sup> until Sep, 27<sup>th</sup> and March is from, Feb, 25<sup>th</sup> until Mar, 26<sup>th</sup>).

#### *Minimum Convex Polygon*

This method of estimation considers as home range the area included by the smallest polygon with convex corners containing all the locations of the sample.

The core area is estimated with the same kind of polygon over a subsample of the original dataset. It consists of the 75% of points of the original sample. The subset of points is generated calculating the center of the area of use, in other words the arithmetic mean of all coordinates, then dropping the farthest point from the center. These two steps are repeated until reaching the amount of locations corresponding to the 75% of the original amount, following the so-called floating arithmetic mean method.

The extrapolation of the subsample is processed with a program created in software R, version 3.0.2. Both MCPs, of the original sample and of the “R subsample”, are calculated with the “Convex Hull” feature of software QGIS, version 2.0.

#### *Grid Cell*

The Grid Cell method consists of superimposing a grid with a mesh of chosen dimensions over the area containing samples of the locations of chimpanzees. Then, the density of locations is counted in each quadrat, expressing the pattern of range use. The implementation of this method is frequent and intuitive (Basabose, 2005; Chapman and Wrangham, 1993; Lehmann and Boesch, 2003), but its common problem concerns the determination of grid cell size. In fact, large sizes bring detail loss and small sizes can intensify variability in quadrat counts, increasing difficulties in range pattern interpretation (Amsler, 2009). Studies on ranging patterns of big mammals with grid cell methods have mainly used grids of 250m or 500m per side (Amsler, 2009; Basabose, 2005; Emery Thompson et al., 2007; Lehmann and Boesch, 2005; Lehmann and Boesch, 2003; Mizutani and Jewell, 1998). In this

case, home range and core area estimations are based on grid cells of 500m sides, due to the small sample size of each month.

In order to extrapolate core areas from the home range estimations, I consider core areas as “portions of the animal’s home range that exceed the equal-use pattern” (Samuel et al., 1985), in other words core areas consist of only the cells with a density over the average density of the grid cells of that home range estimation. Practically, the dimension of the sample is divided by the number of cells constituting the home range estimate (with density >0), to obtain the average density of a hypothetical equal-use pattern. The core area of the home range is formed by the cells exceeding that density.

The grid cell is created as an additional layer in QGIS, software version 2.0 (“Create Grid Layer”, plug-in MMQGIS), subsequently I counted the density per cell with the Analysis Tool “Points in Polygon” and, then, highlighted cells of the home range and cells of the core area.

#### *Fixed Kernel*

Kernel estimators are among the more reliable methods to determine home ranges (Seaman and Powell, 1996; Worton, 1987; Worton, 1995). The method consists of superimposing a regular fine grid over the area and in estimating the intensity of territory use at each grid intersection from the density of locations in the bordering cells (Amsler, 2009; Worton 1989). These estimated values permit to link areas of equal density and to create concentric percent volume contours, or isopleths, interpolating them (Barg et al., 2005; Seaman and Powell, 1996). These sequential isopleth values provide the likelihood that an individual is in a particular area. The Fixed Kernel method is more precise and less influenced by sample size than the MCP (Barg et al., 2005; Blundell et al., 2001; Börger et al., 2006; Seaman et al., 1999; Worton, 1987) and it estimates a smoother shape of the area than the Grid Cell method and the percent volume contours contrast anomalous values (Amsler, 2009; Seaman and Powell, 1996; Worton, 1989). In our Kernel analyses the optimal smoothing parameter is chosen with the process of least squares cross validation (LSCV). It provides the quantity of smoothing that coincides with the smallest mean integrated square error value of the estimate. This mean is commonly considered as calculating the best value for the smoothing parameter for multimodal data (Amsler, 2009; Barg et al., 2005; Seaman and Powell, 1996; Worton, 1989). Home range boundaries are limited at the 99<sup>th</sup> density percent volume contours, based on literature and on the relatively small dimension of the samples of our study (Amsler, 2009; Barg et al., 2005).

The core area is considered the area included by the 75<sup>th</sup> density isopleth.

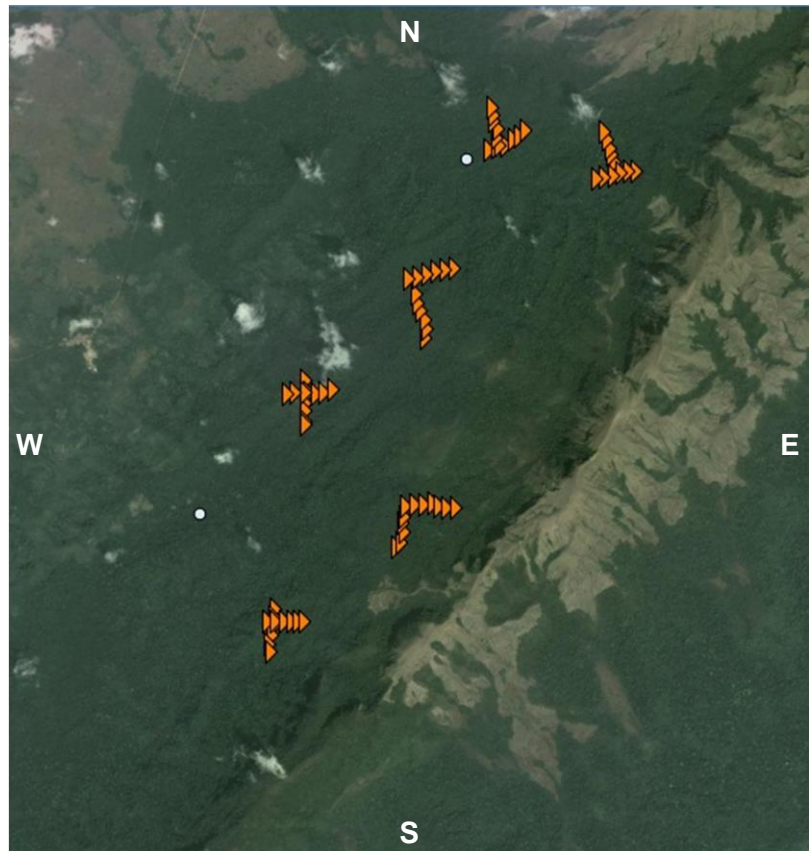
The Fixed Kernel estimation with smoothing parameter chosen by LSCV is computed by GME software (Geospatial Modelling Environment), “kde” feature, which creates a layer displayable by



ArcGIS 10.0. Percent volume contours are drawn by GME, “isopleth” feature, and later opened over related kernel layer in ArcGIS 10.0.

## PHENOLOGICAL TRANSECTS

From May until December 2012, researchers monthly checked 4 transect locations (4 km in total). Then, in January 2013, 4 transects were added in 2 new locations further south, in order to have a more balanced overview of the area (6 km in total). Every location counted 2 transects: one with a North-South orientation and one with an East-West orientation. Transects are 500 m long and it includes every tree less than 5 m away from the line, belonging to a chimpanzee food species and with a DBH (diameter at breast height) longer or equal than 10 cm (in order to exclude tree too young to produce fruits) (Chapman et al., 1992; Koops, 2011). Hence, all these trees had a known DBH, measured before starting with the phenological data collection. A couple of hours per month were dedicated to the survey of each phenological transect. Equipped with binoculars, all members of the team were analyzing the crowns of the selected trees in



**FIGURE 2.** Map of the Seringbara study-site. (white points: base camps; orange triangles: 12 phenological transects)

A percentage range of the current fruit availability over an empirically estimated maximum capacity of fruit production was assigned to each tree (0 = 0% of fruits; 1 = 1 – 25 % of fruits; 2 = 26 – 50 % of fruits; 3 = 51 – 75 % of fruits; 4 = 76 – 100 % of fruits). The fruit availability score was further divided into the percentage range of ripe fruits versus unripe fruits, using the same categories.

These values were processed to calculate monthly fruit availability. The Fruit Availability Index (FAI) is calculated using the formula (Hockings et al., 2010; Koops, 2011; Koops et al., 2013; Takemoto, 2004):

$$FAI = \frac{\sum (P_i \times F_i)}{\sum (P_i \times 4)} \times 100$$

where  $P_i$  is the basal area  $\left(\pi \left(\frac{DBH}{2}\right)^2\right)$  of the tree  $i$  ( $\text{cm}^2$ ) and  $F_i$  is the ripe fruit availability percentage range of the tree  $i$  (0 – 4). FAI results are classified as high monthly fruit abundance if the value is greater than 1, while they are categorized as low monthly fruit abundance if the value is smaller than 1 (Koops, 2011).

#### FAECAL ANALYSIS

Information about chimpanzee diet is inferred from the analysis of fresh faecal samples, those judged to be maximum 1 day old. The collection was as much complete as possible. The faeces was stored in a plastic bag, weighed with a spring balance and entirely soaked in 95% ethanol for later analysis. Each sample was pre-soaked in water and sieved in a flat-bottomed sieve with a 1 mm mesh, in order to lose the soluble components of the faeces and to analyze the undigested parts (McGrew et al., 2009). The team scored the overall abundance of fruit remains and folivorous fibers (THV, leaves) over a percentage range scale (0 = 0% of all components; 1 = 1 – 25 % of all components; 2 = 26 – 50 % of all components; 3 = 51 – 75 % of all components; 4 = 76 – 100 % of all components), then of small seeds (i.e. *Ficus sp.*, *Musanga sp.*) and of mushroom remains. Next all seeds were counted and sorted per species and all insect remains found were scored. In this research, 4 dietary aspects are taken into account: the average percentage of THV fibers per faeces, the average rank score of the percentage of seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.* per faecal sample, the average number of species per faecal sample and average number of big seeds (>5 mm) per gram of faeces.

#### SEARCHING EFFORTS

The analysis of the relation between searching effort and amount of data collected is fundamental to evaluate the efficiency of our data collection and to plan improvements for future studies. Such investigation can be easily performed with the use of a grid superimposed on both the sample of GPS points constituting the paths of the chosen month or year and the sample of chimpanzee traces collected in the corresponding month or year. This procedure permits an immediate comparison in each cell between the number of points from recorded paths and those from data collection. In other words, it is a comparison between how much researchers investigated that area and how many results they obtained.

The very large number of GPS points collected for every daily path brought me to choose grids with a mesh of 250m instead of 500m, in order to execute more precise analyses. Nonetheless, during the considered year of research, team daily paths were recorded with different settings (maximum 500 gps points per track or a gps report every approximately 30 sec). This difference prevented me from an easy analysis of path point density over grid cells. Therefore, in order to establish whether or not there

was a relationship between searching effort and collected chimpanzee locations, each path was converted in grid cells 250m X 250m with value 1 if the team walked on that cell in that day and value 0 if the team did not. Then, the monthly searching efforts were estimated by overlapping all the grid cell areas, per team, per day, recorded in the month.

## DATA ANALYSES

Firstly, I considered a descriptive analysis of the estimates performed with the three different methods for home ranges and core areas of each month and of the whole year, to the extent of outlining ranging patterns of the chimpanzees that reside in the Seringbara study-site. Details will concern the percentage of the home range occupied by the relative core area.

Secondly, the analyses involve the comparison between methods over the same sample: of each month and of the whole year. The overall mean difference between the methods was quantified by the Paired Samples T-test or the Wilcoxon Matched Pair Test, depending on the normality of the distributions of data sets. These measures evaluate the degree of concordance between the estimates obtained with different methods. In addition, I used Pearson's correlation test between pairs of different methods to check if estimates of different methods were correlated. Then, I intersected each pair of estimates performed on the same sample of data in order to evaluate how much of the original two estimates the intersection was covering. This degree of overlap between pairs of estimates over each dataset, for both home ranges and core areas, is determined to evaluate the similarities between the 3 methods.

Next, Pearson's correlation values between monthly home range estimates per method and the monthly amount of data helped to explore the influence of the size of the sample on each method. It was not possible to include core area estimates and relative amount of included locations because core areas include, by definition, the biggest subsample of points per unit of area. Those areas are not including random unrelated GPS points. Therefore, data included in core area estimates would have spoiled the result of analyses of the influence of sample dimension on the methods of estimation.

Additionally, the 6 estimations (3 methods for the home range and 3 methods for core areas) of the whole dataset (year) are compared with the corresponding estimations of the dataset without motion triggered camera data, in order to test the effects of autocorrelation and subsampling. The necessity of scoring individuals every time they newly appear in front of a motion triggered camera cause problems of autocorrelation and overestimation of chimpanzees that crossed that location. Autocorrelation is implied every time the position of an individual at one sample point is affected by the position of the same individual at the previous sample point (Mizutani and Jewell, 1998). In order to avoid this situation, the original sample needs to be subsampled. The usefulness of subsampling is

questionable, because the position of an animal at time  $t$  may be or not be a function of its position at  $t-1$ , consequently, the assumption of independence among sequential positions of individuals for non-parametric home range analysis, like Kernel method, is also questionable (De Solla et al., 1999). Therefore, the analyses of the territory used by chimpanzees during the whole year and during each month were analyzed firstly with the entire sample and secondly with the sample without data from motion triggered cameras. Paired Samples T-test and Pearson's correlation test were involved for verifying how subsampling affected estimations by every method. A descriptive analysis of the differences within each estimate added further information.

The Pearson's correlation test was used to explore the relation between FAI and the four faecal components, and thus how fruit availability and diet were connected. In order to analyze the effect of fruit availability and diet on home range and/or core area sizes, the Pearson's correlation explored relations between home range and core area size estimates and FAI values, as well as between home range and core area estimates and faecal components.

The analysis of the relation between searching efforts and the amount of data collected involved a grid with two numbers per each cell: the number of visits by researchers and the number of data found in that cell. These results were used to verify possible Spearman's rank correlations between searching effort and actual results in each visited cell created over the Seringbara Study Site. Grid cells with more than 240 visits in the year and grid cells with more than 20 visits per month were excluded from samples because they were related to the camps where we were starting in the morning and coming back in the end of the day, so grid cells "overvisited" and surely without any chimpanzee traces.

All statistical tests were two-tailed. The test Shapiro-Wilk (more appropriate for small sample sizes than Kolmogorov-Smirnov) was used to verify the normality of data distributions.

## **RESULTS**

### **WITHIN METHODS**

The first step was to see which area of the Seringbara study site can be considered the home range and which one can be considered the core area of the chimpanzees that live there. Home range and core area estimates differed between months. The average dimensions of home range estimates over the 12 months were: 11.39 km<sup>2</sup> using MCP, 5.08 km<sup>2</sup> using Grid Cell and 25.24 km<sup>2</sup> using Fixed Kernel (TABLE 1). The estimated areas for the whole year were: 29.03 km<sup>2</sup> using MCP, 20.50 km<sup>2</sup> using Grid Cell and 35.73 km<sup>2</sup> using Fixed Kernel (TABLE 1). The exclusion of data from motion

triggered cameras slightly affected mean values (10.24 km<sup>2</sup> using MCP, 4.56 km<sup>2</sup> using Grid Cell and 24.71 km<sup>2</sup> using Fixed Kernel) and yearly estimates, with the exception of the value from Fixed Kernel method that definitely increased (29.03 km<sup>2</sup> using MCP, 20.25 km<sup>2</sup> using Grid Cell and 41.13 km<sup>2</sup> using Fixed Kernel) (TABLE 1).

Estimates of core areas differed, as well. Means between months were: 5.60 km<sup>2</sup> using MCP, 1.48 km<sup>2</sup> using Grid Cell and 8.37 km<sup>2</sup> using Fixed Kernel, while yearly estimates were: 16.43 km<sup>2</sup> using MCP, 6.75 km<sup>2</sup> using Grid Cell and 13.39 km<sup>2</sup> using Fixed Kernel (TABLE 2). Exclusion of data from motion triggered cameras changed mainly in the annual estimate calculated with Kernel method (monthly means: 4.32 km<sup>2</sup> using MCP, 1.54 km<sup>2</sup> using Grid Cell, 8.12 km<sup>2</sup> using Fixed Kernel; yearly estimates: 17.55 km<sup>2</sup> using MCP, 7.75 km<sup>2</sup> using Grid Cell, 17.06 km<sup>2</sup> using Fixed Kernel) (TABLE 2).

The annual estimates were consistently larger than the monthly estimates for what concerns the MCP and the Grid Cell methods, while there are 3 months with Fixed Kernel estimates larger than the related annual one.

The core area was, on average, 46.79% of the home range assessed with MCP, 29.21% with Grid Cell and 33.66% with Fixed Kernel (without MTC data, respectively: 39.02%, 34.93%, 33.14%).

Both categories home ranges and core areas did not show eventual “empty” border lines between communities. A careful look to all the estimates over the map of the Seringbara study site

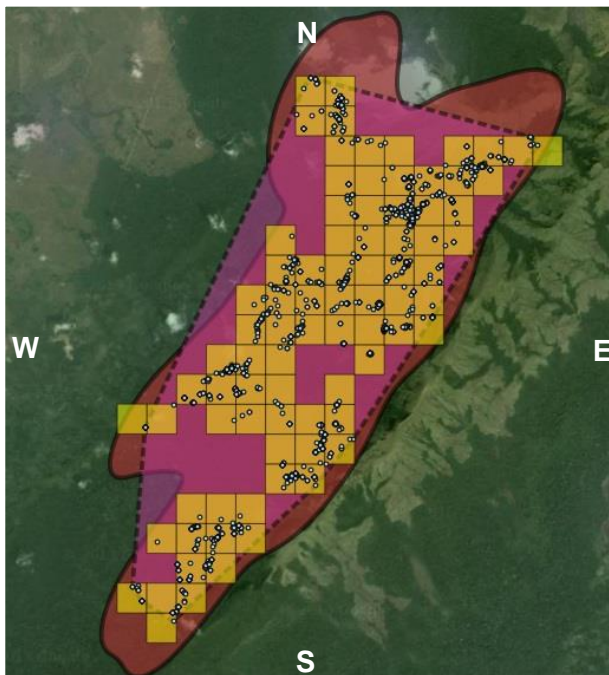


FIGURE 3. Annual home range estimates (pink polygon: MCP method; yellow cells: Grid Cell method; continuous black line: Fixed Kernel method)

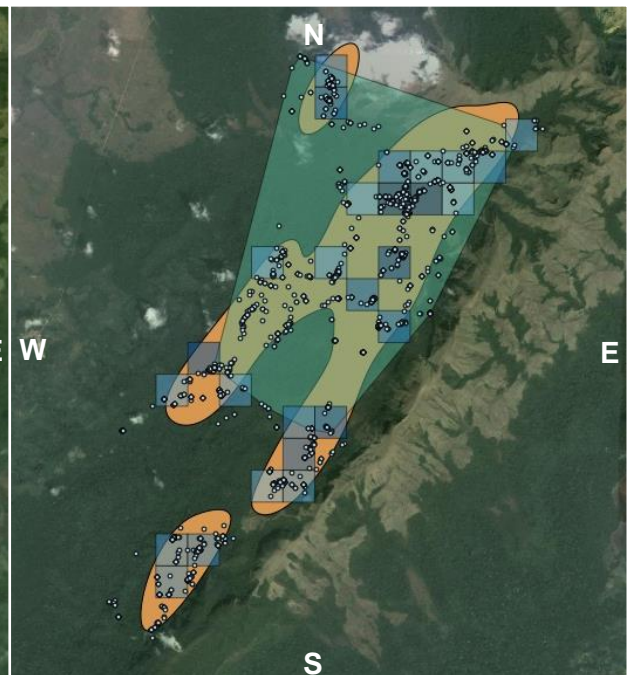


FIGURE 4. Annual core area estimates (green polygon: MCP method; blue cells: Grid Cell method; orange areas: Fixed Kernel method)

delineates a continuum of findings over the area, without any recurrent spatial separation between group of traces.

**TABLE 1. Home range estimates (km<sup>2</sup>). (*stdev* standard deviation)**

HR	<i>With motion triggered cameras</i>				<i>Without motion triggered cameras</i>			
	MCP	GC	Kernel	n°data	MCP	GC	Kernel	n°data
May	14.26	4.75	32.18	86	14.26	4.25	32.63	84
June	3.88	1.75	11.67	57	3.88	1.50	11.95	46
July	7.92	3.50	17.27	114	7.03	3.25	17.88	64
August	11.67	4.25	29.38	133	11.67	4.00	39.78	79
September	13.54	4.00	43.33	176	13.29	3.00	47.29	84
October	16.13	3.50	35.45	188	9.48	2.75	22.82	88
November	13.24	7.25	19.96	288	13.24	7.00	22.97	201
December	14.68	8.50	24.17	314	14.68	8.00	24.23	308
January	5.90	4.00	17.39	124	4.36	3.25	13.80	95
February	14.88	9.25	29.64	285	14.88	8.75	30.95	248
March	10.06	5.00	21.66	222	9.20	4.50	19.34	158
April	10.49	5.25	20.81	159	6.93	4.50	12.93	96
Year	29.03	20.50	35.73	2171	29.03	20.25	41.13	1394
<i>mean</i>	11.39	5.08	25.24		10.24	4.56	24.71	
<i>stdev</i>	3.85	2.20	8.98		4.00	2.22	11.04	

**TABLE 2. Core area estimates (km<sup>2</sup>).**

CA	<i>With motion triggered cameras</i>			<i>Without motion triggered cameras</i>		
	MCP	GC	Kernel	MCP	GC	Kernel
May	7.43	1.25	10.65	7.93	1.25	10.70
June	0.77	0.50	3.68	0.27	0.50	3.28
July	2.71	1.25	5.25	1.83	1.25	5.25
August	2.42	1.25	7.86	2.27	2.00	13.24
September	8.88	1.25	14.89	12.32	1.25	14.96
October	13.52	0.75	9.67	2.36	0.75	6.49
November	5.37	2.50	6.81	3.22	2.50	7.63
December	5.68	2.75	8.72	5.30	2.50	8.55
January	3.62	1.25	7.23	1.26	1.00	5.13
February	9.32	2.50	12.13	9.30	2.25	12.64
March	2.74	1.50	6.94	3.77	1.75	5.66
April	4.72	1.00	6.63	1.96	1.50	3.96
Year	16.43	6.75	13.39	17.55	7.75	17.06
<i>mean</i>	5.60	1.48	8.37	4.32	1.54	8.12
<i>stdev</i>	3.63	0.72	3.08	3.69	0.66	3.90

#### BETWEEN METHODS

Next, I aimed to determine when comparing the monthly estimates of the different methods provide different home range and core area estimates. The mean differences in all pairs of methods, considering or not data from motion triggered cameras resulted very ample (Paired Samples T-test:

home ranges,  $p < 0.001$ ; core areas,  $p < 0.05$ ). The Fixed Kernel estimates are larger than the corresponding MCP and Grid Cell estimates, in all the values of home ranges and in the majority of the values of core areas. In every case, MCP estimates are larger than the corresponding Grid Cell estimates (TABLES 1 and 2). However, estimates from different methods were often varying accordingly. Home range estimates by MCP and Fixed Kernel were strongly correlated, estimates by MCP and Grid Cell were weakly correlated and estimates by Grid Cell and Fixed Kernel were not correlated (Pearson's correlation:  $N = 12$ ,  $r = 0.767$ ,  $p = 0.004$ ;  $N = 12$ ,  $r = 0.594$ ,  $p = 0.042$ ;  $N = 12$ ,  $r = 0.127$ ,  $p = 0.693$ ). The same situation occurred excluding data from motion triggered cameras in datasets, but with a stronger correlation between MCP and Grid Cell (Pearson's correlation:  $N = 12$ ,  $r = 0.735$ ,  $p = 0.006$ ;  $N = 12$ ,  $r = 0.699$ ,  $p = 0.011$ ;  $N = 12$ ,  $r = 0.152$ ,  $p = 0.638$ ). Then, in core areas, the analysis of the correlation in pairs of methods was significant only between MCP and Fixed Kernel (Pearson's correlation:  $N = 12$ ,  $r = 0.741$ ,  $p = 0.006$ , including motion triggered cameras data or,  $N = 12$ ,  $r = 0.804$ ,  $p = 0.002$  without motion triggered cameras) (TABLE 9).

Another approach to evaluate the correspondence between methods applied to the same sample is to check how much area the estimates share. Each estimate was intersected with another one from a different method on the same sample of data, the resulting area was then expressed as a percentage of both the original estimates (FIGURE 5, TABLES 3 and 4). The shared area, or the area of overlap, between different estimates from the same dataset showed that estimates made by Fixed

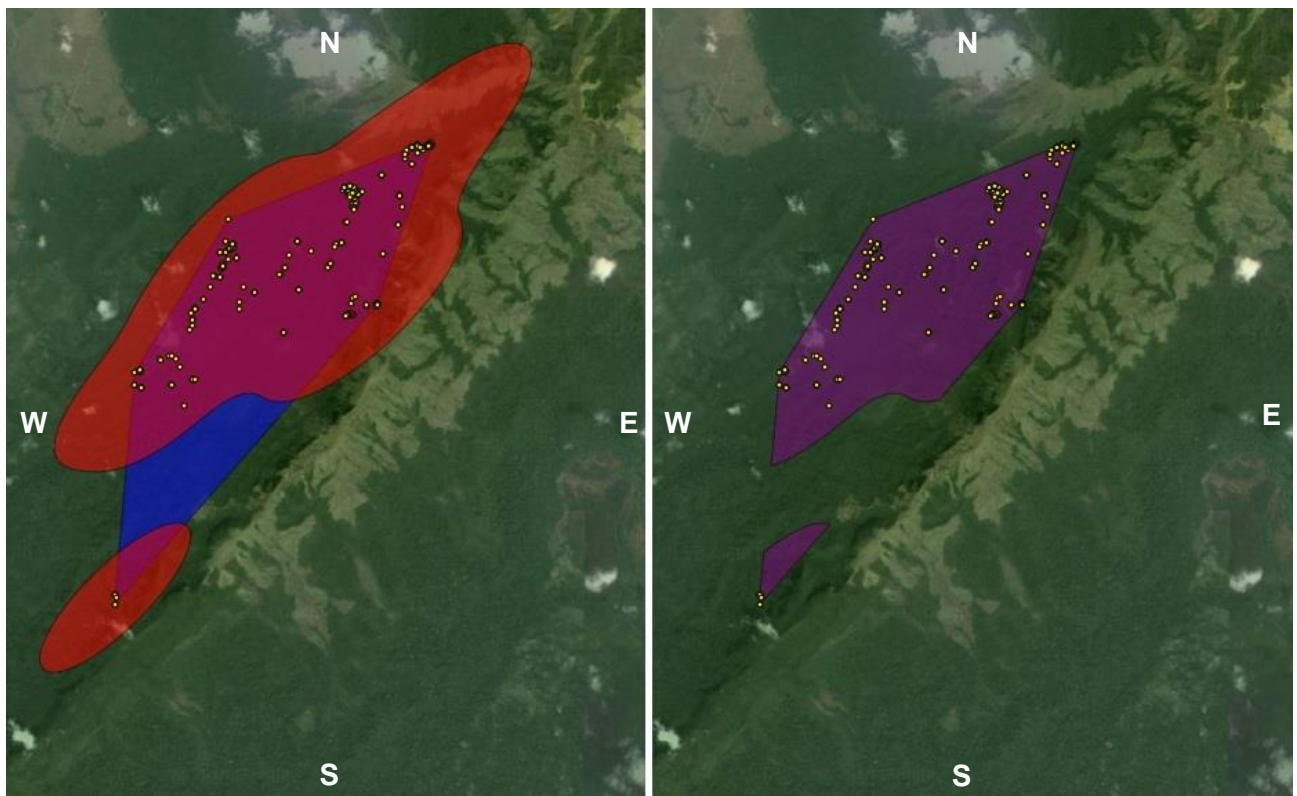


FIGURE 5. Left side: MCP estimate (blue polygon) and Fixed Kernel estimate (red shape) with the data collected in December. Right side: the intersection between the two, MCP-Kernel (purple area). The purple area is 80.51% of the blue polygon and 48.90% of the red shape (see TABLE 3).

Kernel method were including areas estimated with the other two methods (MCP home ranges [and core areas] are included in Kernel estimates for, on average, 93.34% [70.79%] , and Grid Cell home ranges [and core areas] are included in Kernel estimates for, on average, 98.50% [91.16%]) (TABLEs 3 and 4). These results also confirmed that the Fixed Kernel estimations were larger than the others, especially if compared to Grid Cell estimations (only 23.96% [18.64%] of the area overlapped) (TABLEs 3 and 4).

**TABLE 3. Percentages of the home range estimates overlapped with the corresponding estimates by different methods.**

<i>Percentages</i>	MCP	GC	MCP	Kernel	GC	Kernel
<b>HR</b>	<b>MCP-GC</b>		<b>MCP-Kernel</b>		<b>GC-Kernel</b>	
May	23.06	69.25	99.01	43.88	94.74	13.98
June	26.04	57.73	82.63	27.47	100.00	14.99
July	30.94	70.02	93.89	43.07	100.00	20.27
August	25.57	70.21	89.77	35.66	100.00	14.47
September	17.14	58.01	98.77	30.85	100.00	9.23
October	13.67	63.01	92.67	42.17	99.58	9.83
November	43.24	78.99	88.12	58.46	96.00	34.87
December	44.36	76.62	80.51	48.90	99.71	35.07
January	44.94	66.33	100.00	33.95	99.52	22.89
February	47.97	77.15	99.10	49.74	99.70	31.12
March	34.76	69.96	99.53	46.24	99.95	23.07
April	36.15	72.22	96.10	48.43	99.64	25.14
Year	64.95	91.97	93.34	75.85	98.50	56.52
<i>mean</i>	34.83	70.88	93.34	44.98	99.02	23.96
<i>stdev</i>	14.21	9.18	6.49	12.63	1.69	13.09

**TABLE 4. Percentages of the core area estimates overlapped with the corresponding estimates by different methods.**

<i>Percentages</i>	MCP	GC	MCP	Kernel	GC	Kernel
<b>CA</b>	<b>MCP-GC</b>		<b>MCP-Kernel</b>		<b>GC-Kernel</b>	
May	5.80	34.48	74.54	51.99	89.52	10.51
June	38.13	58.80	98.05	20.57	100.00	13.60
July	27.40	59.45	87.21	45.01	99.76	23.73
August	25.79	49.89	98.97	30.45	100.00	15.91
September	5.62	39.88	45.50	27.12	98.21	8.24
October	1.65	29.74	27.74	38.80	99.64	7.73
November	22.69	48.73	80.06	63.13	70.64	25.93
December	21.00	43.38	77.59	50.53	88.81	28.00
January	12.89	37.34	76.49	38.28	92.90	16.05
February	14.87	55.41	74.33	57.09	90.35	18.62
March	19.01	34.74	63.26	24.99	94.38	20.40
April	7.21	34.02	58.46	41.59	77.69	11.72
Year	24.70	60.10	58.04	71.20	83.16	41.92
<i>mean</i>	17.44	45.07	70.79	43.13	91.16	18.64
<i>stdev</i>	10.60	10.92	20.13	15.33	9.31	9.54



## METHOD SUITABILITY

The dataset of this research was not only different from, but also definitely smaller than the datasets found in past studies about the same topic, in which the samples included only direct sightings of habituated chimpanzees. Therefore, having small sample sizes, the attention is carried on the independence of the values of these estimates from the size of the sample. The monthly numbers of data from all the 4 sources were normally distributed (see “n°data” in TABLE 1). The analysis of the influence of the sample dimensions on each method revealed that Fixed Kernel estimates were the only independent values from sample size ( $p > 0.05$ ), in contrast with MCP and Grid Cell ( $p < 0.05$ ) (Pearson’s correlation: MCP,  $N = 12$ ,  $r = 0.616$ ,  $p = 0.033$ ; Grid Cell,  $N = 12$ ,  $r = 0.873$ ,  $p < 0.001$ ; Fixed Kernel,  $N = 12$ ,  $r = 0.181$ ,  $p = 0.574$ ).

The topic of sample size is also central in the choice of including or excluding motion triggered cameras in home range and core area estimations. After the correlation between sample size and home range estimate, this analysis adds details to the ongoing discussion about sample dimension or independency of data. I performed several tests to compare the estimates made including data from motion triggered cameras with the corresponding estimates excluding those data (TABLE 1). The means of the differences between home range estimates including data from motion triggered cameras with the same estimates not including them, per method, were found strongly different from 0 in the Grid Cell method (Paired Samples T-test:  $N = 12$ ,  $t = -7.244$ ,  $p < 0.01$ ), almost significantly different from 0 in MCP estimates ( $N = 12$ ,  $t = -1.960$ ,  $p = 0.076$ ), and non-significantly different from 0 in Fixed Kernel estimates ( $N = 12$ ,  $t = -0.315$ ,  $p = 0.759$ ). Differences between means within core area estimation methods were not significant (Paired Samples T-test:  $p > 0.05$ ) (TABLE 2). Then the correlations between home range estimates within methods were all very strong (Pearson’s correlation:  $N = 12$ ,  $p < 0.01$ ). Between core area estimates were very strong for Grid Cell and Fixed Kernel methods (Pearson’s correlation:  $N = 12$ ,  $p < 0.01$ ), but not for MCP (Pearson’s correlation:  $N = 12$ ,  $r = 0.536$ ,  $p = 0.072$ ). Therefore, Fixed Kernel seems again the most solid and independent method from sample dimension. Nevertheless, subtracting the same estimations with the whole dataset with the corresponding subsample lacking motion triggered camera data, MCP varies on average  $1.25 \text{ km}^2$  in home range estimated areas and  $1.28 \text{ km}^2$  in core estimated areas, Grid Cell varies  $0.52 \text{ km}^2$  in home range estimated areas and  $0.06 \text{ km}^2$  in core estimated areas and Fixed Kernel varies  $0.62 \text{ km}^2$  in home range estimated areas and  $0.25 \text{ km}^2$  in core estimated areas (TABLE 5).

**TABLE 5. Differences between estimates including motion triggered cameras and corresponding estimates excluding motion triggered cameras. (n°data=difference between two sample sizes, in other words, number of data collected by motion triggered cameras per sample)**

<i>Differences</i>	Home range				Core area		
	<b>MCP</b>	<b>GC</b>	<b>Kernel</b>	<b>n°data</b>	<b>MCP</b>	<b>GC</b>	<b>Kernel</b>
May	0.00	0.50	-0.45	2	-0.50	0.00	-0.05
June	0.00	0.25	-0.28	11	0.51	0.00	0.40
July	0.89	0.25	-0.61	50	0.88	0.00	0.00
August	0.00	0.25	-10.41	54	0.15	-0.75	-5.38
September	0.25	1.00	-3.95	92	-3.45	0.00	-0.07
October	6.65	0.75	12.63	100	11.15	0.00	3.17
November	0.00	0.25	-3.01	87	2.15	0.00	-0.82
December	0.00	0.50	-0.06	6	0.38	0.25	0.17
January	1.54	0.75	3.58	29	2.36	0.25	2.10
February	0.00	0.50	-1.32	37	0.01	0.25	-0.51
March	0.86	0.50	2.32	64	-1.03	-0.25	1.28
April	3.56	0.75	7.88	63	2.76	-0.50	2.67
Year	0.00	0.25	-5.40	777	-1.12	-1.00	-3.67
<i>Mean</i>	1.25	0.52	0.62		1.28	-0.06	0.25
<i>Stdev</i>	2.02	0.25	5.81		3.53	0.30	2.19

#### FAI AND FAECES VALUES

In addition, this research considers possible influences of fruit availability and diet of chimpanzees on their ranging patterns. Diet was inferred through faecal analyses and the numbers of collected faeces, per month, from May to April, were: 35, 22, 14, 22, 10, 22, 79, 133, 20, 94, 33, 40. In regard to this, chimpanzees could vary their diet accordingly to fruit availability, but, in the Seringbara study site, monthly FAI values did not correlate with monthly values of each faecal component (TABLE 6).

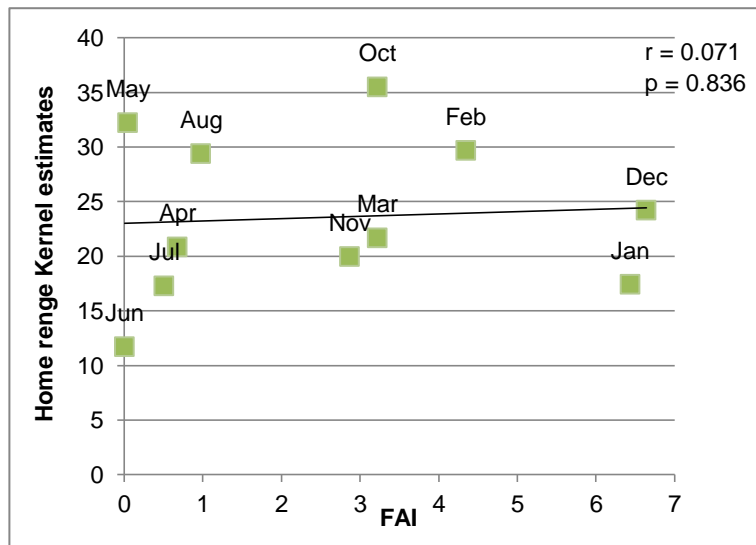
**TABLE 6. Results of Pearson's correlation test between fruit availability and diet components.**

	<i>Pearson's correlation test</i>			
	<b>THV fibers</b>	<b><i>Ficus sp., Nauclea sp., Musanga sp.</i></b>	<b>Number of species</b>	<b>Big seeds</b>
<b>FAI</b>	$r = -0.340, p = 0.306$	$r = -0.444, p = 0.171$	$r = 0.437, p = 0.178$	$r = -0.343, p = 0.302$

Next, fruit availability was tested with variations in size of home ranges and core areas estimated: FAI did not correlate with any of the home range or core area estimates. Nevertheless, Grid Cell home range and core area estimates showed a positive trend accordingly with FAI values, while MCP and Fixed Kernel estimates did not result correlated with FAI values at all, in both home ranges and core areas (TABLE 7, FIGURE 6).

**TABLE 7. Results of Pearson's correlation test between influencing factors and estimates of home ranges and core areas.**

Fruit availability		Pearson's correlation test		
		MCP	Grid Cell	Fixed Kernel
FAI	HR	$r = 0.225, p = 0.505$	$r = 0.548, p = 0.081$	$r = 0.071, p = 0.836$
	CA	$r = 0.262, p = 0.437$	$r = 0.591, p = 0.055$	$r = 0.349, p = 0.293$
Diet components				
THV fibers	HR	$r = 0.275, p = 0.386$	$r = -0.344, p = 0.273$	$r = 0.568, p = 0.054$
	CA	$r = 0.298, p = 0.347$	$r = -0.227, p = 0.478$	$r = 0.375, p = 0.229$
<i>Ficus sp.</i> , <i>Nauclea sp.</i> , <i>Musanga sp.</i>	HR	$r = -0.129, p = 0.689$	$r = -0.293, p = 0.356$	$r = 0.158, p = 0.623$
	CA	$r = -0.286, p = 0.368$	$r = -0.079, p = 0.806$	$r = 0.056, p = 0.863$
Number of species	HR	$r = -0.561, p = 0.058$	$r = -0.250, p = 0.434$	$r = -0.366, p = 0.242$
	CA	$r = -0.386, p = 0.215$	$r = -0.129, p = 0.690$	$r = -0.226, p = 0.481$
Big seeds	HR	$r = -0.381, p = 0.222$	$r = -0.203, p = 0.526$	$r = -0.493, p = 0.103$
	CA	$r = -0.180, p = 0.575$	$r = -0.319, p = 0.312$	$r = -0.455, p = 0.138$



**FIGURE 6. Graph showing the relation between fruit availability and home range estimates made with Fixed Kernel method.**

Subsequently, the monthly average of: the fiber score, the number of species per sample, the number of seeds per gram and the rank score for little seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.* were tested in relation to all the monthly estimates, as the values of FAI. None of the faecal components correlated significantly with monthly estimates of home ranges or with monthly estimates of core areas. Nonetheless, Fixed Kernel estimates of home ranges showed a positive trend with the leaf fiber percentage in the faeces (Pearson's correlation:  $N = 12, r = 0.568, p = 0.054$ ) and almost a negative trend with the number of big seeds per gram of faeces (Pearson's correlation:  $N = 12, r = -0.493, p = 0.103$ ). Moreover, MCP estimates of home ranges showed a negative trend with the number of species per faecal sample (Pearson's correlation:  $N = 12, r = -0.561, p = 0.058$ ) (TABLE 7, FIGURE 7).

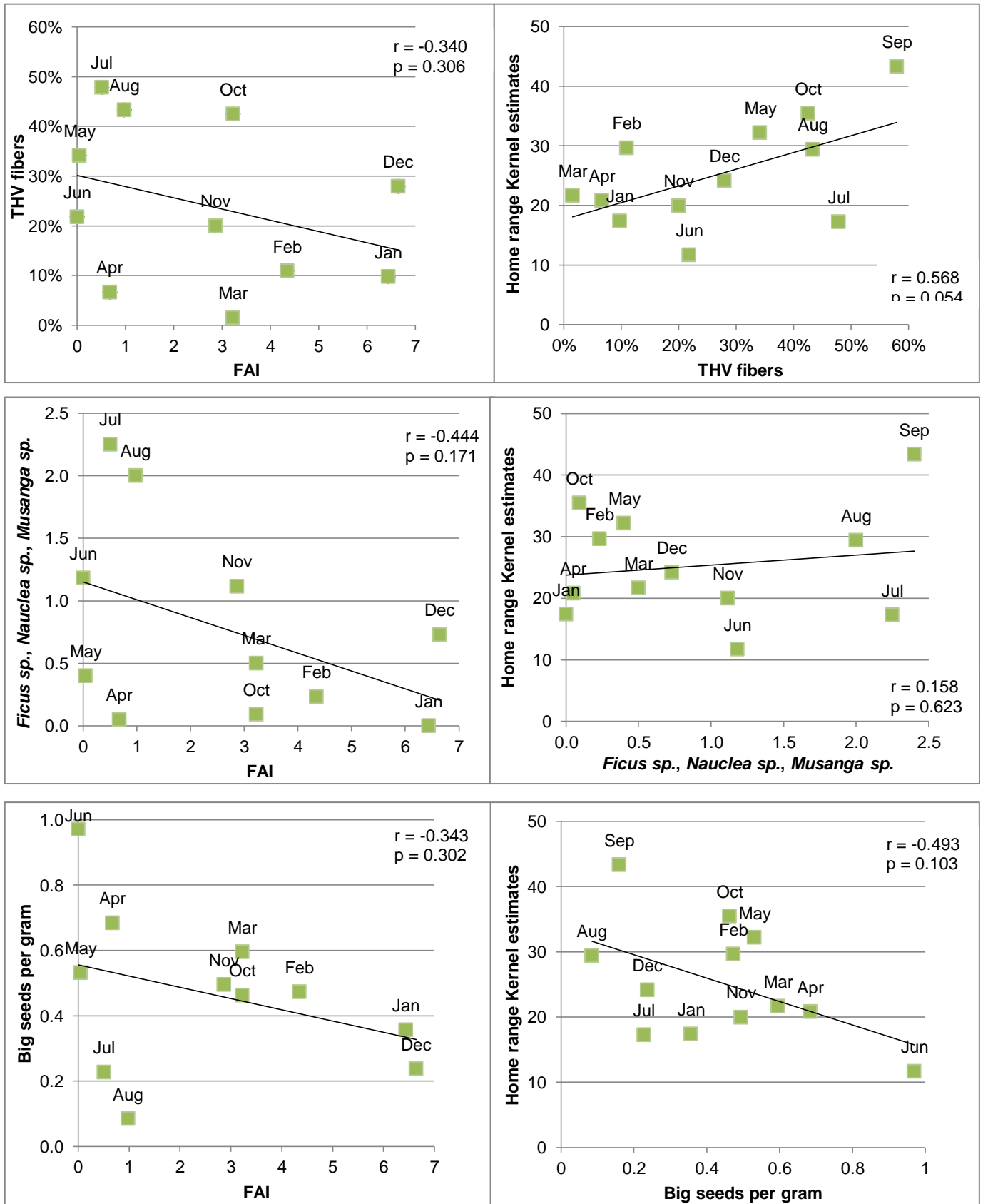


FIGURE 7. Graphs showing the relation between fruit availability and 3 diet components (on the left) and the relation between 3 diet components and home range estimates made with Fixed Kernel method (on the right).

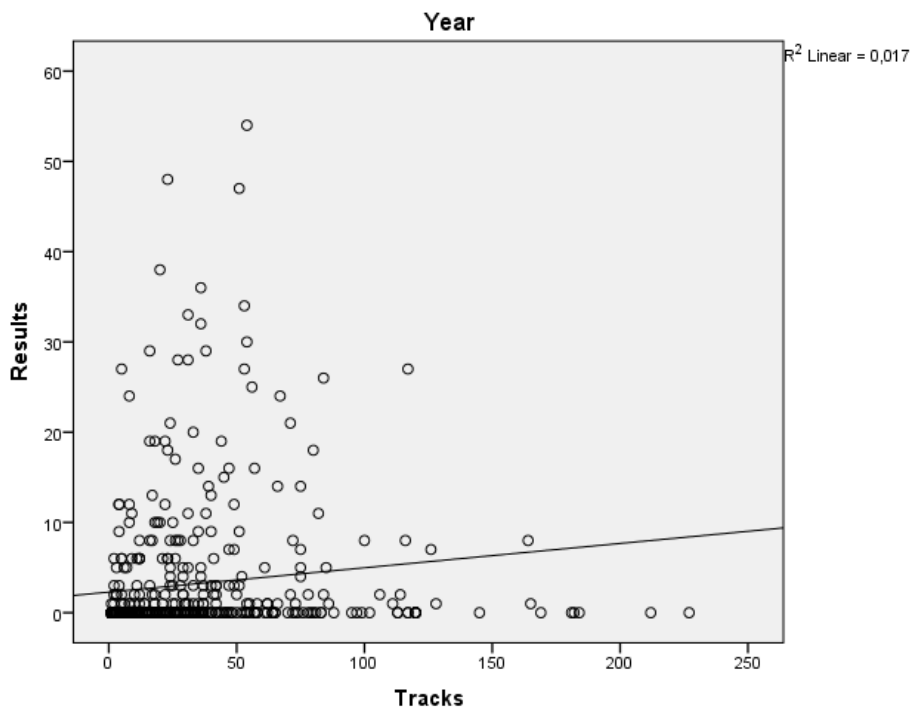
SEARCH EFFORT

Finally, the data collected were related to the sampling effort spent to obtain them. The amount of data per grid cell, expressed as the numbers of visits per grid cell in every month and in the year, were not normally distributed. An analysis of correlation between the number of visits and the number of collected data per cell found significant results ( $p < 0.05$ ) in the annual sample and in all monthly samples with the exception of the month of May (TABLE 8, FIGURE 8). Search effort is positively correlated with the number of data collected.

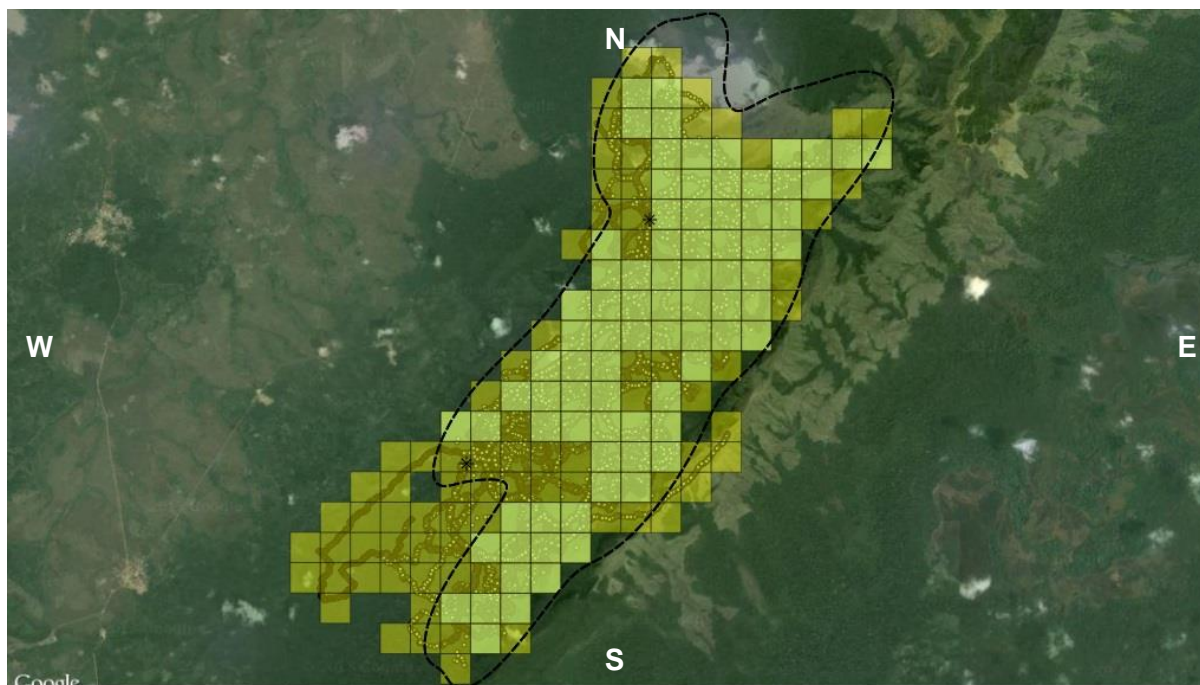
**TABLE 8. Results of Spearman's correlation test between searching effort and results per cell.**

	<i>Spearman's correlation test</i>		
May	N = 214	$\rho = 0.096$	$p = 0.163$
June	N = 227	$\rho = 0.157$	$p = 0.018$
July	N = 197	$\rho = 0.213$	$p = 0.003$
August	N = 251	$\rho = 0.207$	$p = 0.001$
September	N = 218	$\rho = 0.135$	$p = 0.046$
October	N = 211	$\rho = 0.194$	$p = 0.005$
November	N = 350	$\rho = 0.243$	$p < 0.000$
December	N = 280	$\rho = 0.291$	$p < 0.000$
January	N = 206	$\rho = 0.240$	$p = 0.001$
February	N = 300	$\rho = 0.255$	$p < 0.000$
March	N = 279	$\rho = 0.184$	$p = 0.002$
April	N = 275	$\rho = 0.247$	$p < 0.000$
Year	N = 508	$\rho = 0.362$	$p < 0.000$

Furthermore, an overview of the graphic estimates of the chimpanzee home range and the whole surveyed area reveals that we found traces over the big majority of our research site (FIGURE 9).



**FIGURE 8. Scatter charts relating annual searching efforts (Tracks) per cell with corresponding amount of annual data (Results) per cell.**



**FIGURE 9.** Searching effort grid cells (dark green: surveyed area; light green: cells with chimpanzee traces; black asterisks: base camps; dashed line: home range estimate with fixed kernel method)

## DISCUSSION

Researches about habitat use and ranging patterns of chimpanzees deepen our comprehension of the complexities of their behavior and ecology, including feeding strategies. This research is one of the former studies about ranging patterns of chimpanzees unhabituated to human presence. It considers habitat use in relation to fruit availability and food consumed, two of the most examined home range influencing factors in literature. At the end, this study should have shown some aspects about the ranging patterns of Seringbara chimpanzees and it should have explained whether the methods of estimation were reliable to investigate these patterns. Thirdly, the research aimed to explain whether we should firstly attempt to get large samples or independent data for the best expression of these methods of estimation. Then, it should have focused on the influence of fruit abundance and diet on ranging patterns. At last, we propose how to deepen our knowledge about ranging patterns, in future studies.

## RANGING PATTERNS

The home range estimated for the chimpanzees in the Seringbara study-site is 29.03 km<sup>2</sup> by MCP, 20.50 km<sup>2</sup> by GC and 35.73 km<sup>2</sup> by Fixed Kernel. Immediately, it is clear that the estimated size is similar to the total area of the surveyed site, of around 38 km<sup>2</sup> (FIGURE 1). Hence, the research teams found chimpanzees or their traces almost everywhere they looked for them (FIGURE 9). If we then relate these values with home range estimates of chimpanzees of other research fields, results in

Seringbara show a large area involved in chimpanzee activities. In fact, the largest habituated community (~150 chimpanzees) at Ngogo, Kibale National Park, Uganda, ranges over an area from 19.5 km<sup>2</sup> to 29.25 km<sup>2</sup> (depending on the estimation method) and the analyses of Herbinger (2001) and Amsler (2009) reported that home range size per habitat type tends to increase with the number of chimpanzees forming the community. Accordingly, ranging estimations are often compared in literature within similar habitat, because chimpanzees in dry environments with low vegetation cover wider home ranges than those living in rainy forests like in the Seringbara region. This could lead to the expectation of a large number of chimpanzees in Nimba mountains.

Nevertheless, Newton-Fisher (2003) affirmed that deducing population density from home range size is unlikely to be an accurate method in heterogeneous habitats. Over the years, literature has collected several studies about chimpanzee home ranges in different African locations, from moist forests to drier habitats. Estimates can vary from 3.10 km<sup>2</sup> for a community of Taï National Park, Côte d'Ivoire (Herbinger et al., 2001), to 278-333 km<sup>2</sup> for a community at Mt. Assirik, Senegal ([Baldwin et al., 1982, in] Basabose, 2005), with the majority of estimates sized between 10 km<sup>2</sup> and 40 km<sup>2</sup> (Amsler, 2009). These huge differences are due to the environment, lowland or high altitude, forest or savannah, but also to the community size, from 20 to 150 individuals, and to the method of estimation, Minimum Convex Polygon, Grid Cell or Statistical Methods. Aspects so relevant that is still unclear how much each of these factors contributes to the different home range or core area estimates.

Moreover, a crucial aspect needs to be considered in this research: genetic analyses revealed the presence of, at least, two communities on the Seringbara study-site (Koops, 2011; Koops et al., 2012). During data collection, discrimination between communities was not possible and GPS points did not show any possible avoided border area between home ranges. Apparently, the two or more communities are exploiting the study-site over connected areas, probably also slightly overlapped, like communities in Taï National Park, Côte d'Ivoire. There, neighbouring communities may cover their territories overlapping zones that can also include part of core areas (Herbinger et al., 2001).

The second critical issue concerning these estimations is the number of data collected. Other researches on habituated communities, comparing the same methods of home range size estimations, suggest that these methods yield similar results, with overlapping areas between methods covering always more than 87% of the estimate (Amsler, 2009). In fact, habituated chimpanzees permit to have definitely larger sample sizes, involving only on direct observations of known individuals.

## METHODOLOGICAL ISSUES

In this study, the results showed some correlations between methods, mainly between MCP and Fixed Kernel, but the comparisons between their means, both within home ranges and within core

areas, showed very important differences. Actually, the percentages of overlap between methods are consistent with these differences (TABLES 3 and 4). In fact, the average percentages of the areas calculated with MCP and Grid Cell were largely included in the area calculated with the Fixed Kernel method (93.34% and 99.02%), because the Fixed Kernel was definitely the largest and was pretty much always including the other estimates. The remaining average percentages of the home range estimates overlapped with the corresponding estimates by different methods ranged between 23.96% and 70.88%. The situation is even emphasized with the average percentages of the core area estimates overlapped between methods, which ranged from 17.44% and 45.07% (70.79% and 91.16%, for MCP in Kernel and Grid Cell in Kernel).

In respect to these circumstances, also the interpretation of the results related to core area estimations is difficult. In fact, core areas occupy a percentage of the related home range that seems, on average, comparable with other studies: 46.79% with MCP, 29.21% with Grid Cell and 33.66% with Fixed Kernel instead of 39%, 33% and 34% found by Amsler (2009) at Ngogo, Uganda, or 50% found by Herbinger et al. (2001) with MCP, at Tai, Côte d'Ivoire. Consequently, these techniques of core areas estimations seem in general quite steady over small samples and comparable between themselves. The closest values to the percentages found in literature concern the Fixed Kernel method, possibly because it is the only method independent from the small sizes of the datasets of this research. However, the core area estimates show large differences between methods (Paired Sample T-test) and significant differences between means of core area sizes calculated with different methods have been revealed in studies with larger samples on habituated chimpanzees, as well (Amsler, 2009). Besides, the concept of a shared core area itself, of the whole community, is arguable. For example, each individual could maintain its own core area avoiding overlap and competition, as it has been seen for mother chimpanzees at Gombe and for females at Kibale (Emery Thompson et al., 2007). Concluding, to the greatest extent, these estimates offer more a draft of the pattern of space used by Seringbara chimpanzees than a realistic overview of the areas of the Seringbara study-site that hosts the 75% or more of chimpanzee monthly or annual activities.

Outcomes presented here demonstrated that, with a small sample size, the various home range and core area estimation techniques do not perform similarly and they are hard to interpret. The Minimum Convex Polygon method is simple, intuitive and does not consider many methodological factors, aspects that would make it a suitable method for comparison between researches. Unfortunately, by definition, it produces convex polygons that could overestimate the included area (Anderson, 1982). Moreover, the calculated home range sizes resulted correlated with sample sizes, as already proved in literature (Anderson, 1982; Börger et al., 2006). The Grid Cell method pointed out a very accurate selection of used areas by chimpanzees. In literature grid cell dimensions vary between



250 and 500 meters per side (Amsler, 2009; Basabose, 2005; Chapman and Wrangham, 1993; Herbinger et al., 2001) and, even if 500m cell sides were applied, Grid Cell estimates were strongly biased by the small sample sizes. Home ranges were often composed by discontinuous areas and apparently largely underestimated (many estimates less than half of the size of MCP and Fixed Kernel estimates). As found in literature, this method seemed suited to depict habitat usage more than home range (Mizutani and Jewell, 1998). Estimates calculated with Fixed Kernel method were expected to be the most factual available for home range sizes (Börger et al., 2006; De Luca et al., 2009; Seaman and Powell, 1996). They were, indeed, the only independent values from sample size (Pearson's correlation test between estimated values and sizes of the correspondent sample).

Nevertheless, Fixed Kernel estimations become bizarre, too, when the sample is small, for example: monthly home range estimates (May 32.18 km<sup>2</sup>, October 35.45 km<sup>2</sup>, September 43.33 km<sup>2</sup>) as large as or even larger than the annual estimate (35.73 km<sup>2</sup>) (TABLE 1). This happens because GPS data that are closer to a point of evaluation contribute more to the estimate than those ones that are further away (Seaman and Powell, 1996; Worton, 1989). Therefore, the addition of points close to another one already set can increase the precision of the estimation in that site and decrease the total area estimated initially.

#### AUTOCORRELATION

In the current study, the independence of data in the samples was taken into account because statistical methods, such as Fixed Kernel, are only suitable to samples of independent data (Herbinger et al., 2001). However, literature is recently suggesting that, in territory estimations, subsampling data to reduce autocorrelation mainly reduces the estimate made with non-statistical methods (MCP and Grid Cell), especially when sample sizes are modest (Barg et al., 2005; Blundell et al., 2001; De Solla et al., 1999). Animal ranging can be seen as a non-independent phenomenon.

Next, the number of GPS chimpanzee locations was reduced from 2171 to 1394, through subsampling the dataset from data collected by motion triggered cameras, in order to avoid autocorrelation between subsequent videos that could have affected data from the cameras (TABLE 5). This procedure substantially scaled further down the estimates calculated using every dataset. Again, the smallest variations were found in the Fixed Kernel method, which confirmed to be more robust to sample size changes (TABLE 5).

The results of this study indicated that progresses in territory estimations are mainly a matter of sample size. Therefore, especially when non-statistical methods are applied, all locations collected, even at short time intervals, can be involved in the estimation to better cover the area where chimpanzees range (Amsler, 2009). However, Fixed Kernel method is maybe susceptible to subsampling only with

very small sample sizes, as the monthly estimates larger than the annual one suggest. Thus, the seeking of independence can be debatable and the most important goal is to increase the amount of data collected. In the Seringbara study-site, the intensification of the searching efforts is surely a solution to get better home range and core area estimates (TABLE 8).

## INFLUENCING FACTORS

Considering that chimpanzees center their diet mainly on ripe-fruits, fruit shortage affects not only survival, but also party composition and social structure (Furuichi et al., 2001; Tutin et al., 1991; Wrangham et al., 1998). Chimpanzees vary their ranging patterns in accordance to spatial and temporal variations of fruit presence at several sites (Basabose, 2005; Clutton-Brock and Harvey, 1977; Doran, 1997; Matsumoto-Oda et al., 1998; Nakamura et al., 2013; Newton-Fisher et al., 2000; Potts and Lwanga, 2013). For this reason, this study analyzed monthly fruit availability (through the FAI) and diet, measured through faecal components, to highlight possible relations with estimates of home ranges and core areas.

The transect data of this study followed the expectations based on previous researches on the Seringbara study-site: a normal distribution of FAI values with the highest outcomes in December, January and February (the dry season) (Koops, 2011; van Leeuwen et al., 2012). However, this distribution, which presents high fruit availability from October to March, does not completely coincide with the distribution found by Koops (2011) at Seringbara, with high fruit availability from December to May (FIGURE 11). In addition, FAI values did not correlate with any of the faecal components chosen, indicating that fruit availability does not substantially influence the diet of Seringbara chimpanzees, in contrast to what found in the majority of studied fields (Basabose, 2002). Nevertheless, looking at the bar-graph of the monthly average percentage of THV fiber per faecal sample, a certain continuum, which peaks with the highest value in September and the lowest in March, is recognizable (FIGURE 12). Apparently, the diet becomes richer in THV fibers when fruits are scarce, even though the correlation between the two parameters is not significant (FIGURE 7.1, TABLE 6). This should be consistent with a significant increase of herbaceous food eaten during fruit scarcity in several other sites (Basabose, 2002; Furuichi et al., 2001). A similar situation is noticeable in the bar-graph realized for monthly average rank score of the percentage of seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.* per faecal sample, where the approximate gradual increase has its highest values between July and September and the lowest in January, with an anomalous low value in October (FIGURE 13). As THV, the fruits of *Ficus sp.* and *Musanga sp.* are considered fallback food which chimpanzees depend on during fruit scarcity (Furuichi et al., 2001; Hashimoto et al., 2001; Koops, 2011). Therefore, their intake reasonably increases when general fruit availability is low (FIGURE 7.3). These descriptive analyses are to indicate that certain predictable trends may be demonstrated in future studies. In fact, if

the monthly amount of faeces is considered (number of faeces per month, from May to April: 35, 22, 14, 22, 10, 22, 79, 133, 20, 94, 33, 40), 6 months have less than 23 faeces and a more intense searching activity could provide other details about the correlation between fruit availability and Seringbara chimpanzee diet.

FAI did not correlate with any home range or core area estimation and, looking at the calculated probabilities of the Pearson's correlation tests, it could seem that the Grid Cell method is the best method to highlight these relations in future studies because of trends showed in the results of the analyses ( $N = 12$ ,  $r = 0.548$ ,  $p = 0.081$  and  $N = 12$ ,  $r = 0.591$ ,  $p = 0.055$ ) (TABLE 7). Nevertheless, these results may not show a real phenomenon, because Grid Cell estimations are very susceptible to sample size, which presents the highest values in December, November, February and March (TABLE 1) and it is easier to find traces when the weather is not extremely rainy. Accordingly, FAI is higher during the dry season (FIGURE 11) because of the ripening seasonality of the majority of species. Therefore, the Grid Cell estimates could have a positive trend of correlation with FAI because of this combination of causes.

Comparing on a month-by-month basis, faecal components were all varying independently from home range and core area sizes. However, there was a trend of a positive correlation between monthly home range estimates by Fixed Kernel and the percentage of THV fibers in the faeces (Pearson's Test:  $N = 12$ ,  $r = 0.568$ ,  $p = 0.054$ ) and, accordingly, there was a non-significant negative correspondence between the same estimates and monthly average numbers of big seeds ( $>5\text{mm}$ ) per gram of faeces (Pearson's Test:  $N = 12$ ,  $r = -0.493$ ,  $p = 0.103$ ) and a positive non-significant correspondence between that estimates and monthly average rank score of the percentage of seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.* per faecal sample (Pearson's Test:  $N = 12$ ,  $r = 0.158$ ,  $p = 0.623$ ) (TABLE 7, FIGURE 7). In conclusion, territory use and home range patterns of Seringbara chimpanzees are not distinctly influenced by fruit abundance. Nevertheless, the Fixed Kernel method shows a trend of expansion of home range size when chimpanzees rely more on THV fibers (and more on *Ficus sp.* and *Musanga sp.* and less on other fruits). In fact, both THV and the fruits of *Ficus sp.* and *Musanga sp.* are considered fallback foods for chimpanzees during fruit scarcity (Furuichi et al., 2001; Hashimoto et al., 2001; Koops, 2011). In any case, even in presence of seasonal fluctuations of fruit availability and monthly variations in the diet of chimpanzees, influences of fruit availability and consume on territory use are very difficult to describe with indirectly obtained data.

Literature theorizes that primate ranging behavior is different for frugivorous and folivorous species. Leaves are usually more abundant and evenly distributed than fruits are, so a more frugivorous diet should bring to longer travel per day and larger home ranges (Adams, 2001; Basabose, 2005). At Taï, Côte d'Ivoire, the chimpanzee travel distances were smaller during periods of fruit scarcity, when

they rely more on figs and leaves (Doran, 1997). Then, Tai chimpanzees also showed that they vary monthly range sizes and the pattern of use of the range just slightly (Herbinger et al., 2001; Lehmann and Boesch, 2003). In like manner, a study on Ngogo chimpanzees found no significant relations between monthly territory sizes and monthly fruit availability, regardless of the area estimation method applied (Amsler, 2009). At Mahale Mountains, chimpanzees varied the area used in the season of low availability of the fruits of *Saba camorensis* between years (Nakamura et al., 2013). Similarly, results about Kahuzi chimpanzees suggested that they were more likely to visit new areas when fruits were scarce, however without increasing the home range during high fruit availability (Basabose, 2005).

In other chimpanzee researches, the correlation between seasonal fruit availability and weight of fruit component in faeces has been intricate to determine. In fact, when fruits are rare, chimpanzees increase search efforts to maintain relatively high their fruit consumption (Wrangham et al., 1998). For instance, at the Montane Forest of Kahuzi, D. R. C., during scarcity of ripe fruits, the chimpanzees rely on leaves and pith as fallback foods, but they continue to look for fig fruits, which are a year round staple fruit component of the diet (Basabose, 2002). The same study did not reveal a correlation between the fruit availability index and the number of fruit seeds in the faeces. Again, in the fecal samples collected in the Rubondo Island, Tanzania, the number of fruit species per sample remained constant across seasons (Moscovice et al., 2007). There, during the low tree fruit availability season, fallback foods like leaves and pith did not increase significantly as dietary components (Moscovice et al., 2007).

In conclusion, it seems that territory use and home range patterns of chimpanzees are influenced by fruit abundance and diet only in some African regions. There is not enough evidence to suggest that these factors influence the home range size in the Seringbara study-site. On the other hand, some trends and descriptive analyses prevent a certain exclusion of fruit availability and diet components from being influential on ranging patterns

The results obtained in the Seringbara study-site and those coming from different sites indicate that there are several reasons why studies of the same relations across different areas have reached different, or even opposite, conclusions. First of all, methods for estimating fruit availability or home range patterns or territory use are often different across sites, while they should be standardized before discussing or comparing the different results (Börger et al., 2006; Chapman et al., 1994; Hashimoto et al., 2003). Secondly, fruit abundance is thought to be an influencing factor only where and when the minimum of monthly fruit availability is low. The Seringbara study-site could be one of those sites where the minimal monthly fruit abundance is high enough to not be an influencing factor. There, ranging patterns also during the lower fruiting season may be determined by factors other than fruit abundance (Hashimoto et al., 2003). Thirdly, ranging may depend on the overall richness of the habitat:

for instance, chimpanzees ranging in marginal savannah areas move over a much larger territory than those in more fertile forest environments (Amsler, 2009). Fourth, another cause is the assumption that all fruits are functionally equivalent, but chimpanzees have preferences and some species are more crucial than others in the diet (e. g.: *Saba Camorensis* in Nakamura et al., 2013). In addition, a species providing fruits during times of high fruit abundance should not be considered as critical to survival as one providing fruit during an extended period in which no other fruits are ripening (Potts et al., 2009). In fact, variances in density of these two kinds of species across sites can induce vast dissimilarities in ranging patterns and/or in diets between chimpanzee communities. Fifth, it may be easy to reduce the size of a territory when food is abundant, but it may not be easy to enlarge it when food is scarce; therefore, animals could respond to these environmental fluctuations in other ways than varying their territory (Adams, 2001). Lastly, chimpanzees may balance food scarcity with fission-fusion subgrouping and modifying party size, avoiding changes in size or position of home ranges and/or core areas (Amsler, 2009; Basabose, 2004; Chapman et al., 1995; Matsumoto-Oda et al., 1998; Mitani et al., 2002), even though a previous study on the Seringbara study-site did not show correlation between party size and fruit abundance (van Leeuwen et al., 2012). Thus, these causes may explain why the Seringbara chimpanzees did not vary their home range size accordingly with fruit availability or fruit income. However, from a broader point of view, all these arguments can be seen as part of the remarkable capacities of chimpanzees to adapt to different conditions.

## FUTURE

Summarizing, this study was an attempt to understand better how Seringbara chimpanzees use their territory and how fruit availability influences them, without a proper habituation of the animals to human presence. Other studies about ranging patterns with a similar dataset were not found in literature. The sum of data sources (direct sightings, nests, faeces and motion triggered cameras) and dimensions of data samples were unique, therefore an analysis of the estimation methods of home range and core area was desirable. Working with such small samples, the Fixed Kernel method was far more accurate and informative than the others. Also, the Fixed Kernel method seemed more appropriate than the others to show possible correlations between variations in territorial estimates and variations in fruit availability and diet components. Nevertheless, monthly sample sizes were probably too small for having reliable results, regardless to the method used. Moreover, discerning traces belonging to chimpanzees of one community from individuals of another one was not possible for the teams collecting data. This lack moved the focus of the analysis from the concepts of home range and core area, characteristic of the community, to the identification of which areas are surely used and which are probably the most used by the chimpanzees of all communities living in the Seringbara study-site.

Data were collected almost all over the territory explored by researchers (FIGURE 9). This suggests a dependence of the estimates from searching effort for collecting data, supported by the annual and monthly analyses of correlations between number of visits and number of traces through a cell by cell comparison (TABLE 8, FIGURES 8 and 10). Therefore, an enlargement of the area researched would most probably bring to an enlargement of the estimated chimpanzee territory.

The methodological issue related to the estimation of home ranges and core areas suggested the use of Fixed Kernel analyses in similar researches but we can definitely assert that it is difficult to obtain reliable results on ranging patterns dealing with chimpanzees unhabituated to human presence. This can be even more problematic over a large area where surely more than one community is living, as in the Seringbara study-site. However, a full habituation process is presumably not needed for answering our questions. Habituation is an important goal for studying many other behavioural and ecological aspects of the life of chimpanzees, but it is a long process and the discovery of alternative expedients to rapidly locate social groups and determine their movements across territories is obviously an interesting aim to chase. In this study case, an intensification of research activities in order to offer larger monthly samples to Fixed Kernel analyses (TABLE 8, FIGURES 8 and 10), with the help of DNA analysis from faeces and hairs, could probably lead to interesting outcomes about chimpanzee ranging patterns and about social and ecological factors influencing territory use in the Seringbara study-site.

Nevertheless, it is also true that the more researchers follow chimpanzees, the more they can spoil their voluntary and spontaneous ranging patterns. The elusiveness of Seringbara chimpanzees to human presence can influence their use of the territory. During this research the predation avoidance has never been taken as an influencing factor of chimpanzee ranging patterns, because leopards are supposed extinct and other non-human predators able to feed on chimpanzees are absent (Koops, 2011). However, illegal hunting activities are still considerable (personal observations). Even if hunters do not target chimpanzees as prey, all animals may reasonably be scared by gunshots or hindered by traps. For this reason, they can similarly avoid researchers and, above all, the areas surrounding the two camps established in the Seringbara study-site. Therefore, human pressure may also be linked to local population density and it could influence the size and/or the location of home range and/or core area (Newton-Fisher, 2003).

Motion triggered cameras may be a key means to study behaviours and ecology of unhabituated chimpanzees. In fact, when following animals is not possible, the motion triggered cameras can offer an important source of data about animal positions, moreover without influencing behaviours and interfering with those locations through human presence. Therefore, even if motion triggered cameras have never been used to study chimpanzee ranging patterns, their usage should be implemented and

further investigated. Chimpanzees seem to pay almost no attention for the cameras and an intensification of their employment in spread areas, in order to equally cover the whole territory, is desirable to deepen our knowledge of their territory use, in addition, obviously, to their behaviours, group compositions or appearance.

A second useful possibility could be radio tagging techniques. Radio tagging mammals is an extensively used technique for behavioural and ecological studies and it occurs to be crucial when dealing with elusive animals or in difficult field conditions. In our case, this tool would permit us to have constant tracking data about individuals, without interfering with them through our presence and escaping the delay for the habituation process. Nevertheless, only few researches on primates rely on that, since the majority of the species live in consistent and recognizable groups over permanent quite small home ranges (Fedigan et al., 1988). Therefore, their study can be pursued avoiding expensive technology, which needs invasive means as shooting tranquilizers, surely a counterproductive action for the habituation process.

In any case, a complete overview of home ranges of chimpanzees require several years of data collection. In fact, between years, annual home range size varied in several chimpanzee research sites. The greatest annual estimate was 63% larger than the smallest, at Mahale. Similarly, the ratio is 45% at Gombe, 39% at Kanyawara, 82% at Ngogo, 70% at Budongo, and 53% at Tai North (Nakamura et al., 2013). Thus, all these long term study-sites revealed important changes in annual territorial estimations of communities. Chimpanzees often modify their annual home range size, sometimes to a large extent and there may be numerous causes for these variations across years. Particularly, data from Mahale indicated an average annual home range covering the 70% of total home range estimated in 16 years and 11 years were necessary to reach the 95% of the overall estimate (Nakamura et al., 2013). This clearly proposes the insufficiency of periods of 1 year to estimate the potential home range size of a chimpanzee community (Nakamura et al., 2013). During a given year, some areas in the home range are apparently not visited. Moreover, comparisons of the same months across years can reveal many aspects, for example: in which seasons they annually move more, visiting different and maybe new places, or in which period they rely always on the same area, permitting many new insights, as a possible easier identification of the influencing factors of ranging patterns.

Further studies should also keep considering that the investigation of the influencing factors of chimpanzee ranging patterns is very difficult. In general, territorial estimations are such a complex topic that analyses of single influencing factors of ranging patterns are often inconsistent between different study areas. A myriad of elements can affect their choices in spatial movements: ecological, like food density and distribution (Chapman et al, 1995) or predation pressure; demographic, involving community size; related to sex ratio (especially to the number of reproductive females); social, regarding

relationships within and between groups; cultural, cooperative hunting or culturally transmitted abilities that open to new resources (Doran, 1997). As a deduction, only studies considering several spheres of influence on ranging patterns, across many years of study, can better contribute to more reliable results, to deepen our knowledge of the topic and to explain the differences between results in similar studies in similar sites.

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## APPENDICES

### Time intervals description:

May: May 1<sup>st</sup>, 2012 – May 30<sup>th</sup>, 2012

June: May 31<sup>st</sup>, 2012 – June 29<sup>th</sup>, 2012

July: June 30<sup>th</sup>, 2012 – July 29<sup>th</sup>, 2012

August: July 30<sup>th</sup>, 2012 – August 28<sup>th</sup>, 2012

September: August 29<sup>th</sup>, 2012 – September 27<sup>th</sup>, 2012

October: September 28<sup>th</sup>, 2012 – October 27<sup>th</sup>, 2012

November: October 28<sup>th</sup>, 2012 – November 26<sup>th</sup>, 2012

December: November 27<sup>th</sup>, 2012 – December 26<sup>th</sup>, 2012

January: December 27<sup>th</sup>, 2012 – January 25<sup>th</sup>, 2013

February: January 26<sup>th</sup>, 2013 – February 24<sup>th</sup>, 2013

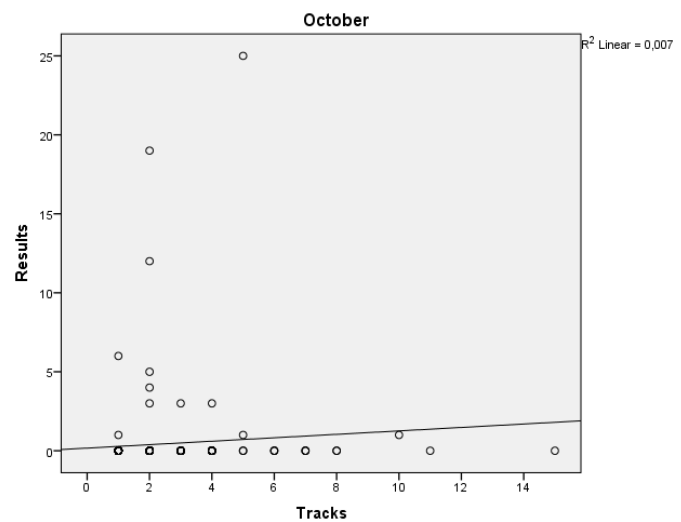
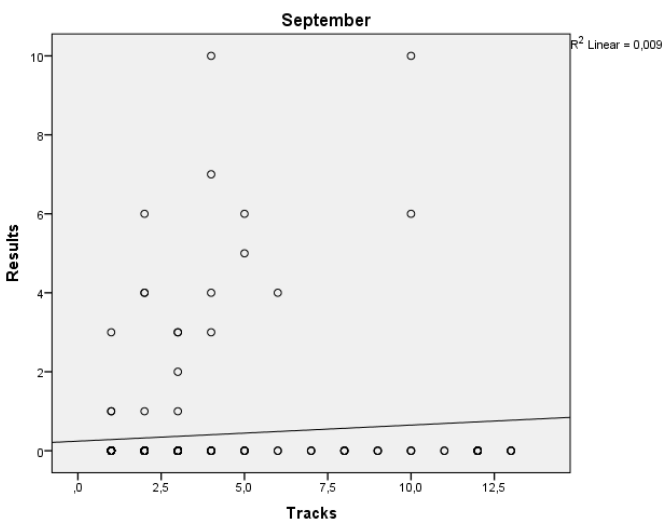
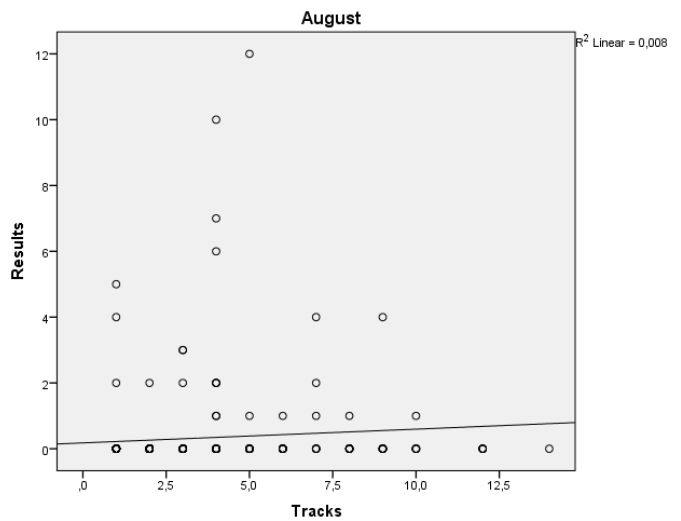
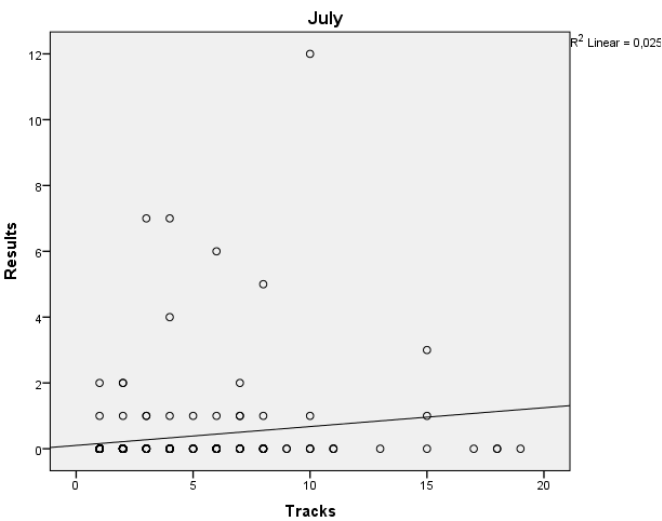
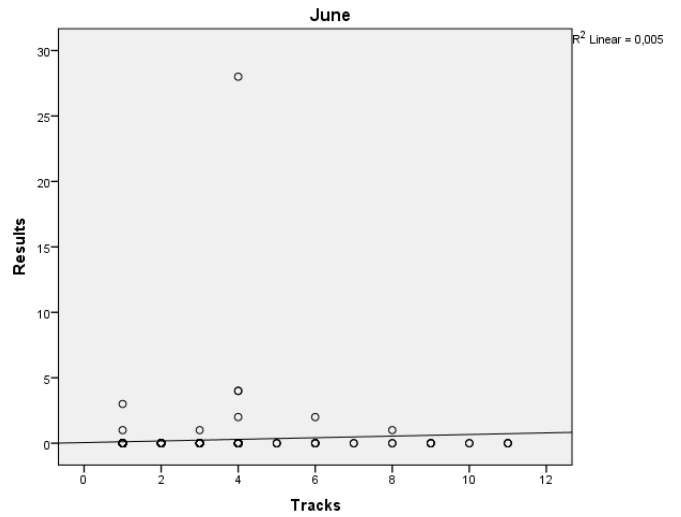
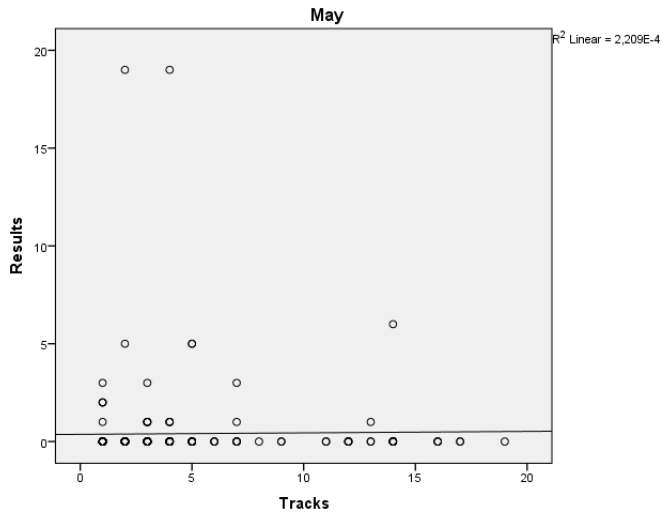
March: February 25<sup>th</sup>, 2013 – March 26<sup>th</sup>, 2013

April: March 27<sup>th</sup>, 2013 – April 25<sup>th</sup>, 2013

Year: May 1<sup>st</sup>, 2012 – April 30<sup>th</sup>, 2013

**TABLE 9. Results of Pearson's correlation test between methods for core area estimates.**

	<i>Pearson's correlation test</i>	
	<b>With motion triggered cameras</b>	<b>With motion triggered cameras</b>
<b>MCP – Grid Cell</b>	$r = 0.127, p = 0.634$	$r = 0.268, p = 0.400$
<b>MCP – Fixed Kernel</b>	$r = 0.741, p = 0.006$	$r = 0.804, p = 0.002$
<b>GC – Fixed Kernel</b>	$r = 0.255, p = 0.423$	$r = 0.393, p = 0.206$



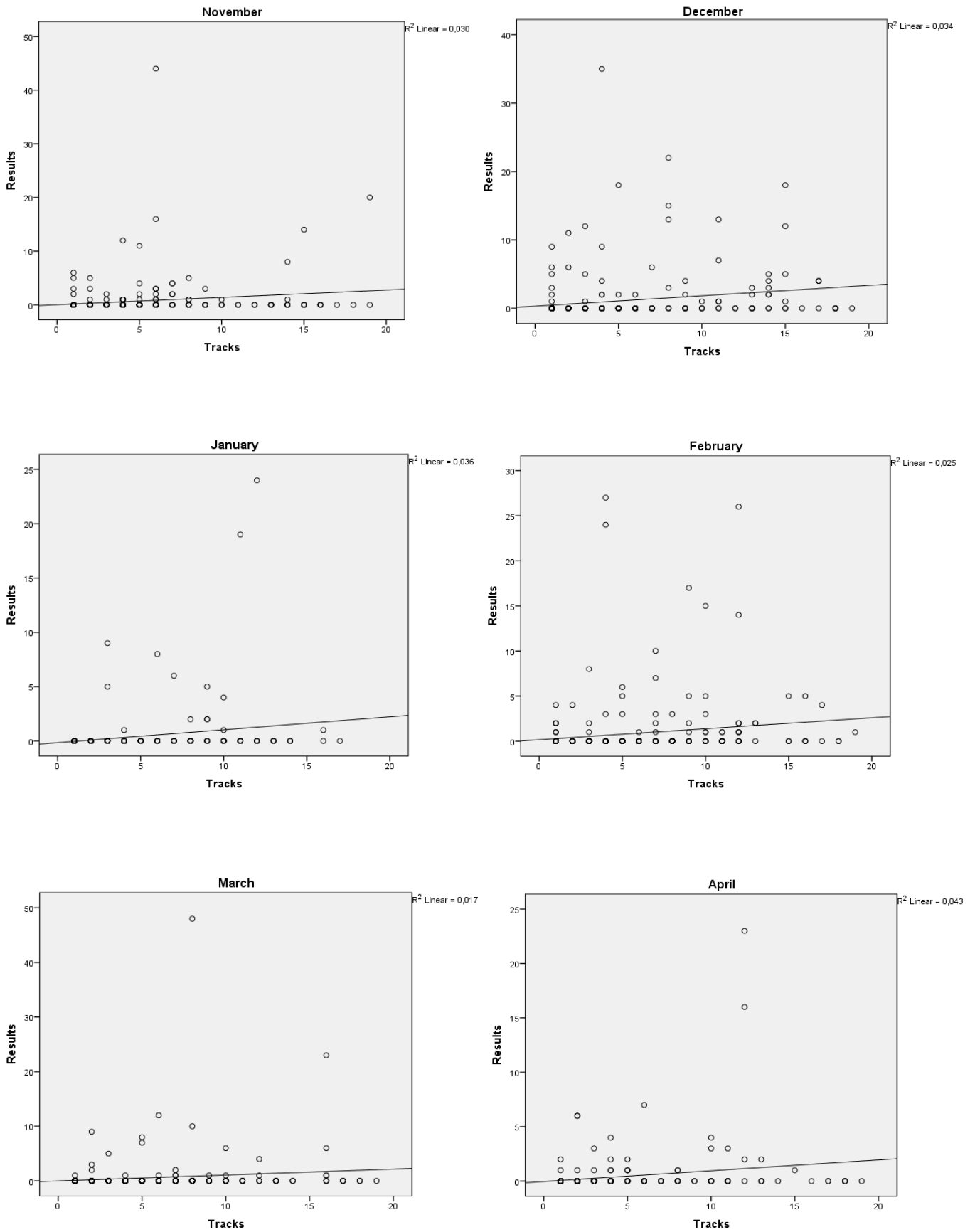


FIGURE 10. Scatter charts relating monthly searching efforts (Tracks) per cell with corresponding amount of monthly data (Results) per cell.

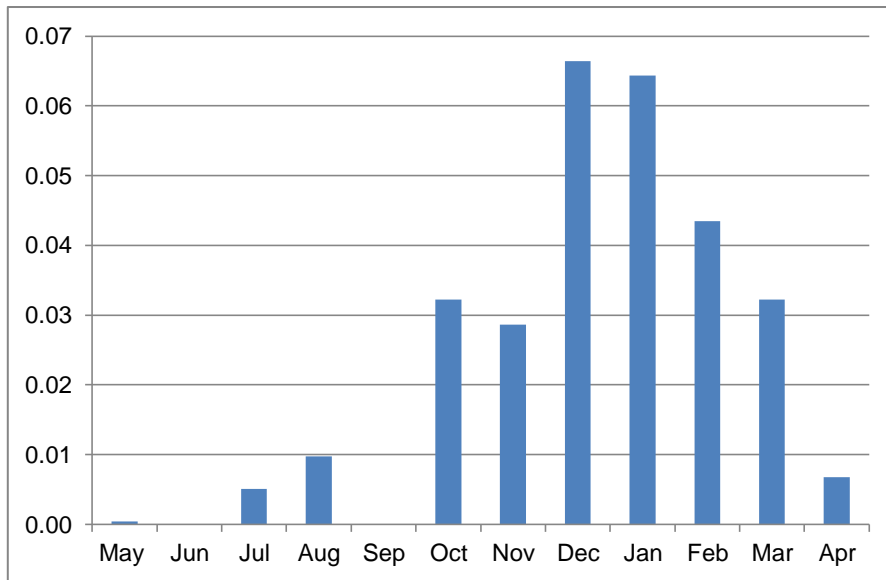


FIGURE 11. Monthly FAI (no data were collected in September)

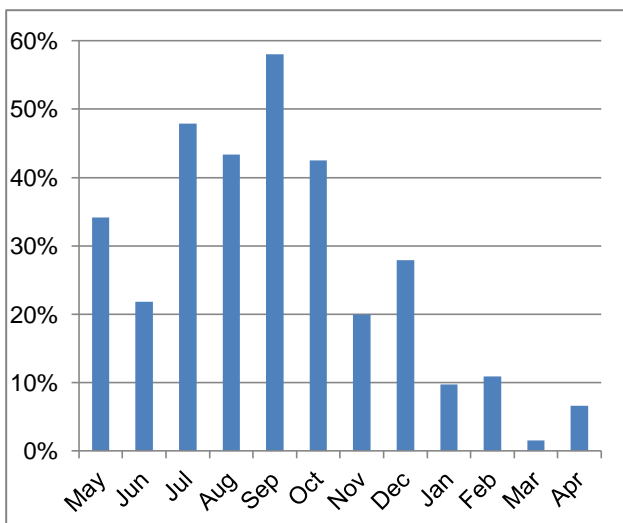


FIGURE 12. Monthly average percentage of THV fibers per faecal sample.

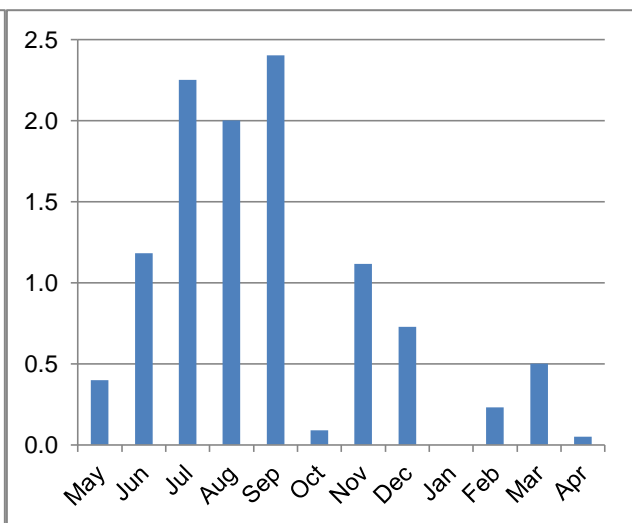


FIGURE 13. Monthly average rank score of the percentage of seeds of *Ficus sp.*, *Nauclea sp.*, *Musanga sp.* per faecal sample.

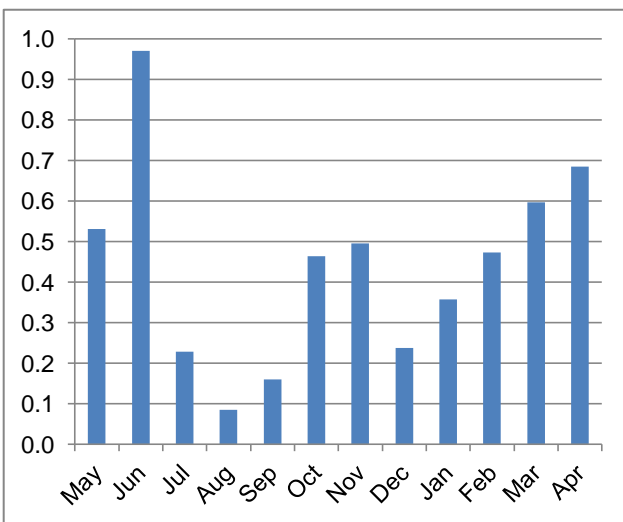


FIGURE 14. Monthly average number of species per faecal sample.

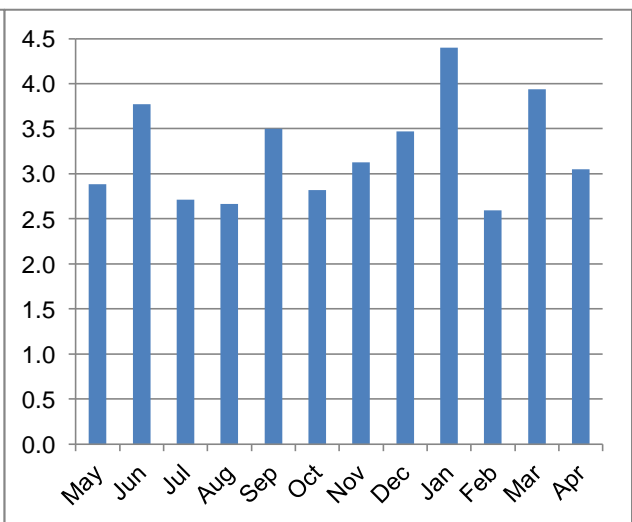


FIGURE 15. Monthly average number of big seeds (>5mm) per gram of faeces.