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Use of stone hammer tools and anvils by bearded capuchin monkeys over time and space: construction of an archeological record of tool use

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A B S T R A C T

Wild bearded capuchins (*Sapajus libidinosus*) in the cerrado (seasonally dry savannah-like region) of Brazil routinely crack open several species of palm nuts and other hard encased fruits and seeds on level surfaces (anvils) using stones as hammers. At our field site, their nut cracking activity leaves enduring diagnostic physical remains: distinctive shallow depressions (pits) on the surface of the anvil, and cracked shells and stone hammer(s) on or next to the anvil. A monthly survey of the physical remains of percussive tool use at 58 anvils in our study site over a 36-month period revealed repeated use, seasonal consistency, temporal variation, landscape-scale patterning, appearance of new hammers and transport of existing hammers to new anvil sites. Artefactual evidence of the temporal and spatial pattern of tool use collected in the survey is in correspondence with concurrent direct observation of monkeys using and transporting tools at this site. Shell fragments endure for years above ground, suggesting that they may also endure in the strata around anvil sites. The bearded capuchins provide an opportunity to study the construction of percussive tool sites suitable for archeological investigation concurrently with the behavior responsible for the construction of these sites. We suggest several lines of inquiry into tool sites created by capuchin monkeys that may be useful to interpret the archeological evidence of percussive tool use in early humans. Archeologists should be aware that transported stone materials and artificial durable landscape features may be the result of activity by non-human animals.

1. Introduction

Pitted and battered stones have been found at several archeological sites dating from the African Early Stone Age (e.g., Leakey, 1971; Mora and de la Torre, 2005). Pitted stones may reflect the production of bipolar stone flakes (Jones, 1994), and some pitted stones may also be the product of cracking nuts (Goren-Inbar et al., 2002). The latter argument was supported by taphonomic data and experimental efforts to knap flakes using the prevailing basalt stone at Gesher Benot Ya'aqov (Israel). Goren-Inbar et al. (2002) found fossil nuts of several species, including wild almonds (*Amygdalus communis*, which has a very tough shell) together with pitted hammers and anvils in the Middle Pleistocene sequence of the Gesher Benot Ya'aqov site. When the authors experimentally flaked stones using basalt cobbles from this site, they produced shallow pits with rough interior surfaces. Some of their pitted stones had this appearance, but others had deeper, rounder, and smoother pits. Goren-Inbar et al. (2002) argued that the latter pits were not likely the result of knapping stone flakes, but were likely the result of pounding nuts on an anvil surface. Thus, they concluded, the inhabitants of Gesher Benot Ya'aqov probably used stone tools for both activities, and perhaps others as well (see also Spears, 1975, cited by Goren-Inbar et al., 2002).

Living species of non-human primates such as chimpanzees, capuchin monkeys and macaques also use percussive tool technology to crack nuts, hard seeds, and mollusks (e.g., *Pan troglodytes* Boesch and Boesch-Achermann, 1983; Matsuzawa, 2001; *Sapajus libidinosus* Spagnoletti et al., 2011a, 2012; *Macaca fascicularis aurea* Gumert et al., 2009, 2011; see Fig. 1). To the extent that their percussive activity produces enduring artifactual remains, present-day sites of tool use by these species provide opportunities for investigation of site formation processes relevant to understanding

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Fig. 1. An adult male bearded capuchin monkey uses a stone weighing 1920 g to crack open a nut (Photograph by E. Visalberghi).

the archeological record of percussive tool use. One key behavior exhibited by both extant stone tool-using non-human primates and tool-using hominins is heterogenous landscape use, and this behavior naturally produces spatial and temporal clusters of durable remains. The patterning of these clusters is influenced by environmental cues such as the presence of suitable tool materials and proximity to water and food sources, as well as social factors such as territoriality and group size. In deriving suitable strategic models for hominin behavior from living primates, therefore, an important first step is to collect data on when and where such non-human primate activities are taking place.

In this article we provide an illustration of non-human primate archaeological evidence and how it may change through time, and establish that capuchins' archeological evidence reflects their behavior. Having done so we suggest that capuchins are of additional archaeological interest because we can compare their stone and anvil tools with hominin technology.

We report evidence from a 36-month survey of hammer stones and anvils used by wild bearded capuchin monkeys (*S. libidinosus*) to crack palm nuts and other hard seeds and fruits. Our study population inhabits the Cerrado of Brazil, a seasonally dry, savannah-like region (Oliveira and Marquis, 2002) that provides excellent conditions for site discovery and preservation, and for direct observation of capuchin tool use. We have investigated several aspects of the tool-using behavior of two groups of bearded capuchins and the physical characteristics and spatial distribution of anvil sites and hammer stones used by our study population (cites; see www.ethocebus.org).

Visalberghi et al. (2007) described the percussors, anvils and the use-wear pitted depressions on anvils produced by capuchins' percussive tool use, concluding that they are similar in many respects to those described by Goren-Inbar et al. (2002) for humans and to those described for chimpanzees (Boesch and Boesch-Achermann, 1983; Sakura and Matsuzawa, 1991; see also Kortlandt, 1986; Kortlandt and Holzhaus, 1987). To summarize our main findings, the capuchins at our study site use both log and sandstone anvils, with anvils being typically fixed and immovable in the landscape. Pits are evident in both materials, forming rapidly in the softer sandstone anvils (Haslam, unpublished data). Capuchins use hammers weighing on average about one kg and the items they crack most often, palm nuts, are more resistant to cracking than macadamia nuts (Visalberghi et al., 2008). Stones large enough and hard enough to use as hammers are rare in our field site (Visalberghi et al., 2009a) and field observation as well as *ad hoc* experiments demonstrate that capuchins select and transport stones whose functional features (e.g., friability and weight) are effective to crack open nuts (Fragaszy et al., 2010a; Visalberghi et al., 2009b). Shells of nuts that were cracked at an anvil and not deliberately removed by the capuchins remain either on the anvil or in the immediate area (Haslam, 2012), and their decomposition is inhibited by the free-draining sandy soils and generally dry conditions. Hammer stones are typically also left on or adjacent to the anvils. This system provides nearly ideal circumstances for preservation of a distinct archeological record of tool use and site formation.

Spagnoletti et al. (2011b) report that over a period of twelve months (1709 h of observation) capuchins belonging to two groups at Fazenda Boa Vista cracked palm nuts on at least 109 different anvils throughout an area of 9 km^2, and that these anvils accommodated 572 episodes of tool use (5.2 tool episodes per anvil). Thus we know that the monkeys in this region crack palm nuts habitually and often re-use the same anvil site. Here we approach the topic of re-use of anvil sites from a different perspective, asking how re-use of anvils may contribute to site construction.

2. Methods

2.1. Site

Our site is located at Fazenda Boa Vista and adjacent lands (hereafter, FBV) in the southern Parnaíba Basin (9°39′ S, 45°25′ W) in Piauí, Brazil. FBV is a flat plain (altitude 420 m asl) punctuated by sandstone ridges, pinnacles and mesas rising steeply to 20–100 m above the plain. Sedimentary rocks of two formations occur in the southern Parnaíba Basin: Sambaíba Formation (age Triassic, 250–200 Ma) covers the Pedra de Fogo Formation (age Permian, 250–300 Ma) (DNPM, 1973). The Sambaíba Formation comprises white to reddish fine-grained sandstones with abundant cross-beddings. The lowermost part of the Sambaíba Formation, which is in contact with the Pedra de Fogo Formation, is marked by a conglomeratic level with pebbles of siliceous rocks. The conglomerate contains rounded quartzite blocks and pebbles that loosen from the matrix due to weathering. These rounded stones are favored as hammer stones by the capuchins, and because of their conglomerate source they are naturally concentrated in the cliff-plateau and talus zones (Visalberghi et al., 2009a).

The Pedra de Fogo Formation comprises interbedded sandstones, siltstones and shales; sandstones are white to yellowish, fine-grained, while siltstones are reddish to purple. There are some beds of limestone and anhydrite toward the top of the formation. The sandstone ridges are heavily eroded and at the lower elevations are cut by small water courses that have running water only after rainfall. The flat open woodland is dissected in areas by gullies that can reach 5 m in depth. The sandstone escarpments often have vertical faces with fields of boulders at the foot, evidence of occasional shearing failure of the rock face.

The plain (even where grazed) is open woodland; the ridges are more heavily wooded. Palms are abundant in the open woodland. Local practice is to burn grazing lands at intervals; the woodlands reflect frequent irregular burning. Climatic data collected in FBV between June 2006 and August 2008 evidenced a dry season (from May to September with mean monthly rainfall of 5.5 mm) and a wet season (from October to April with mean monthly rainfall of 181 mm) (Spagnoletti et al., 2012). The area is lightly populated by humans, and contains cultivated areas, wetlands, private lands where cattle graze and some less disturbed woodland areas.

2.2. Behavioral data

The behavior and ecology of two groups of *S. libidinosus* at this site have been studied since May 2006. In this report, we will refer to two years of behavioral/ecological data collected by Michele Verderane and Noemi Spagnoletti (from May 2006 through April 2008; Spagnoletti et al., 2012) which were collected concurrently with part of our anvil survey. The range of these two groups included most of the anvils in our survey; the remainder were located in an adjacent region (noted as MS). In MS we often encountered another group of capuchins. Data collected during observations of the monkeys included the groups' location and activity throughout the day, with particular attention to nut-cracking behavior. Spagnoletti et al. (2011a) also identified, as possible, the location of the anvil, the nuts cracked and the weight and material of the hammer stone used per cracking episode recorded during a 12-month period overlapping with our survey.

2.3. Survey of anvils

Anvil sites were identified on the basis of our previous experience at this site (Fragaszy et al., 2004) by the joint presence of two of the following three elements: a) a potential hammer stone (hard stone weighing 150 g or more on the putative anvil or nearby (within 2 m), b) distinctive shallow pitted depressions (1–2 cm deep) on the upper surface of the anvil (hereafter pits), and c) the presence of cracked palm shells on or near the anvil (Fig. 2).

The anvils surveyed were located along four different ridges (denoted as MZ, ML, MM and MS in Fig. 3). We initially surveyed 40 of the 42 anvil sites described by Visalberghi et al. (2007) in regions ML, MM and MS. Subsequent direct observation of the monkeys (Spagnoletti et al., 2011a) indicated that capuchins of both groups used anvils outside the area we had previously surveyed. Therefore, in February 2006 we added 18 new anvil sites to our sample (see MZ anvils in Fig. 3), for a total of 58 anvil sites. Thus, we have 36 consecutive months of data collected for 40 anvils (1440 samples) and 24 consecutive months of data collected for an additional 18 anvils (432 samples) for a total of 1872 samples. The 58 anvil sites were revisited in June 2011, 2.5 years after the last survey sample and the same data were collected at this time as during the previous visits. It is possible, but very unlikely that there was human disturbance of anvil sites during our study, as humans rarely travel through these remote areas, and they do not routinely crack nuts when they do pass through remote areas. We cannot exclude human use in the deeper past of the same anvil sites used by the monkeys during our survey.

2.4. Procedure

The monthly survey of anvils began in February 2005 and continued through January 2008 (36 months). For each anvil, we took the location using GPS (Garmin 60CSx). Each hammer present at each anvil was weighed, marked and its lithology determined. Hammer stones were marked indelibly with a permanent pen and re-marked as needed on subsequent monthly visits. Shells on the anvil were identified by species on each visit. For a description of the appearance of shells after capuchins have cracked nuts on an anvil, see Spagnoletti et al. (2011a). New hammer stones found on

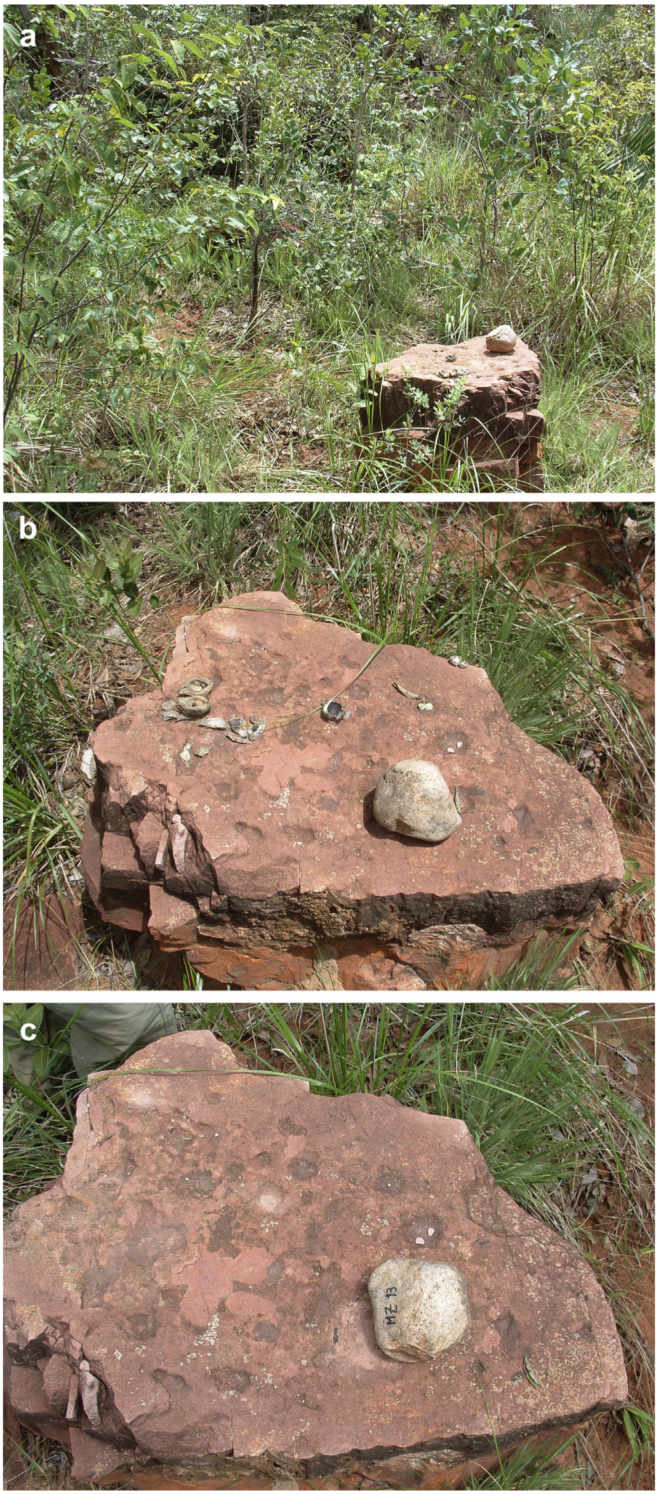

Fig. 2. Anvil site MZ13. Each month we visited each anvil site to gather indirect evidence of tool use by scoring whether the hammer had been displaced from the position in which we left it after the previous visit (upper left). The anvil site as it appears when we arrive to it (upper right). There are cracked shells on the anvil surface and the stone has been moved from the position in which we left it (bottom). All the shells have been removed and the hammer re-positioned (Photos by E. Visalberghi).

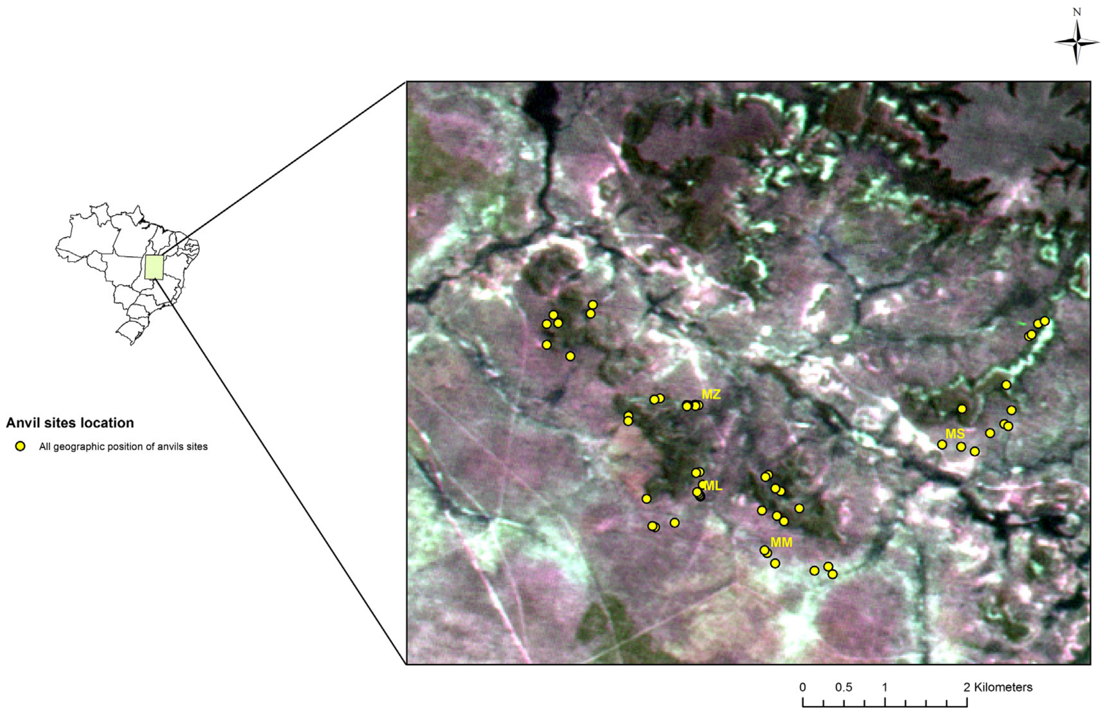

Fig. 3. Satellite image of the study area showing the location of surveyed anvils. The shading in the image depicts vegetation; white is absence of vegetation, darker gray to black is heavy vegetation. The anvils are grouped according to the cliff that they are by: Anvils of the Morro de Zangado (MZ), anvils of the Morro das Lettras (ML), anvils of the Morro Familha M (MM), and anvils of the Morro Sovaco (MS). A symbol may indicate more than one anvil when the anvils are close to each other. Image courtesy of Dr. Andrea Presotto and Prof. Patricia Izar.

the anvil or in its vicinity after the initial survey were characterized by weight and material and marked in the same manner as the stones originally present, with an additional identifying number (e.g., a new, second stone at MM13 was numbered MM13 2). At each visit, a photo was taken upon arrival and a second photo taken before leaving, after brushing the anvil clear of shells and other debris and re-positioning the hammer stone(s) to a predetermined position for an archival record. In this way, we could compare the position of the hammer stone(s) at the end of each visit and upon arrival at the next visit, and we could determine if new nut shells or hammer stones were present at the next visit. Finally, on each visit, we searched for hammer-like stones within 5 m of each anvil.

On each visit, if the location of the hammer stone(s) had changed from the archival position(s) in the photograph from the previous visit, the anvil was evaluated as used, and given a value of 1. If there were also nut shells or shell remains of other fruits or seeds on the anvils, this was considered stronger evidence of use, and given a value of 2. The presence of shells without a change in the hammer location was not considered as evidence of tool use and given a value of 0. It is important to stress that our methodology provides a rather accurate measure of whether an anvil site was used at least once during the previous month, but it does not measure how many times, or how many individuals, used it.

We also noted when a hammer stone disappeared, and when this was the case we searched for it in a 10 m radius around the anvil. If we found it, we noted the distance from the anvil at which it was found and whether its new location was another anvil. If the hammer stone was found on the ground, rather than another anvil, it was re-positioned in the starting position on its anvil before we took the archival photo and left the anvil. If the hammer stone was absent, its absence was noted. We also noted when a hammer stone had broken (and in that case we weighed the parts) and when a new hammer-like stone was present on the anvil. Broken hammer stones and new hammer stones were weighed, marked and positioned on the anvil as the other hammer stone(s) before the archival photograph for that visit was taken.

2.5. Comparison of survey data and behavioral data

With the aim of assessing whether the survey data reflect actual behavior, the group monthly frequency of cracking episodes reported by Spagnoletti et al. (2012) was correlated with the proportional number of anvils showing evidence of use. To do this, we correlated the number of anvils per month with strong evidence of use with the rate of observed tool use episodes in the same months over a 12-month period.

2.6. Nut shell weathering

As a corollary project, we evaluated the effects of weathering (due to sun, rain, wind) and consumption by invertebrates on the appearance of palm nuts. In January 2005, palm nuts of the four species most commonly cracked by the capuchin monkeys at our site (tucum, *Astrocaryum campestre*; catulè, *Attalea barreirensis*; piassava, *Orbignya* sp.; and catulí, *Attalea* sp.) were collected and both intact and broken nuts were placed inside a wire-mesh enclosure (to prevent animals from taking or disturbing them) and left on a boulder in a lightly wooded area at the foot of a ridge (similar to the locations of anvils; see Fig. 4). Between January 2005 and June 2011, we regularly photographed and described the nuts' exterior appearance. Our goal was to provide a visual record of weathering of the shells so that we could judge the age of shell artifacts encountered on the anvils during our surveys.

2.7. Location of anvils in relation to sandstone ridges

As anvils are typically found adjacent to the large sandstone ridges (Visalberghi et al., 2007), we conducted an initial review of

Fig. 4. The wire-mesh enclosure where nuts and shells have been kept to reveal the effect of natural weathering.

the aspect of those anvils recorded in our survey as having strong evidence of use by the capuchins. Anvils were scored according to their cardinal or intercardinal direction from the nearest ridge, using satellite maps as a guide. The aim of this review was to discern capuchins' preferences for anvils with a given aspect, using frequency of use as an index of preference. Following a circular–linear correlation test to determine whether significant directionality was present in the sample, we conducted an exploration of the nature of such directionality by dividing the surveyed anvils in two groups: those that showed strong evidence of capuchin use in more than 50% of the survey months ($n = 15$), and those showing use in less than 50% of the survey months ($n = 43$). Rayleigh tests were used to detect deviation from uniformity.

3. Results

3.1. Anvil use

Overall, 57 of the 58 anvils surveyed showed strong evidence of being used to exploit hard-shelled foods. Anvils were used in all months (Fig. 5) and the median percentage of months in which each anvil was used (with scores of 1 or 2) was 35 (Min = 0%, Max = 83%: Range Interquartile = 30). One anvil (MM20) never showed signs of use whereas another (ML5) was used in 30 months out of 36. As shown in Fig. 6, the anvils of the different ridges were used to different extents (Kruskal–Wallis test: H (3, $N = 58$) = 11.4 $p = 0.0098$). Post-hoc analyses revealed that the 11 anvils in ML were used in more months than the 14 anvils in the MS ($N_{ML} = 13$, $N_{MS} = 14$, Mann–Whitney $U = 17.5$; $P < 0.0017$), whereas the other five comparisons were not significant. The frequency across months in which individual wood anvils were used did not differ from that of sandstone anvils ($N_{wood} = 7$ and $N_{sandstone} = 51$, Mann–Whitney $U = 106.5$; $P = 0.086$).

3.2. Comparison of survey data and behavioral data

We found a significant positive correlation between the number of surveyed anvils with strong evidence of use per month and the frequency of observed tool use in that month ($N = 12$; $r_s = 0.72$; $P = 0.008$). In contrast, the number of anvils with the weaker signal of tool use did not correlate with the frequency of observed tool use in that month ($N = 12$; $r = -0.18$; $p = 0.57$), nor did the sum of the number of surveyed anvils with strong and weaker evidence of tool use ($N = 12$; $r = 0,49$; $p = 0,11$). These findings indicate that surveying anvil sites is a reliable way to assess the relative frequency of tool use in capuchins only if strong evidence of tool use is used as the criterion.

3.3. Hammer stone disappearance, appearance, breakage and wear

Seventeen times (out of 1872 samples) during our survey, previously marked hammer stones were missing from the anvils where they had been photographed, and were not found within 10 m after searching. In two cases the hammers were brought back to the same anvil site by capuchins; this happened in MZ5 five months after the hammer stone disappeared and in MZ3B one month after the hammer stone disappeared. On nine occasions we found a new object at the anvil sites. In two of these cases, the objects were not suitable to crack nuts (a section of a branch at MM14; a small sandstone (250 g) at MS13). In the seven other cases stones of suitable material to serve as hammers were found; three were rather small (200–250 g); four others (found on four different anvils) were within two standard deviations of the average weight of the hammer stones found in this region (e.g., 500–1900 g; Fragaszy et al., 2010a). The four anvil sites where the new stones were found were used with a monthly frequency at or above the median value of monthly use (35%) for the full sample.

In 40 cases hammer stones were displaced from the anvil where they had been positioned the previous month but were found nearby. They were displaced an average of 3.1 m (max 15 m). In 7 out of the 40 cases they had been transported to another boulder and used there. None of these boulders had, to our knowledge, previously been used as an anvil. The farthest distance at which we found a hammer stone transported to a new boulder and used there was 10 m.

Some stones evinced wear from use as hammers. For example, the 2.5 kg stone of ML9 was slightly concave on the surface used to strike the nuts (as evident from residue of the nut on the stone) and

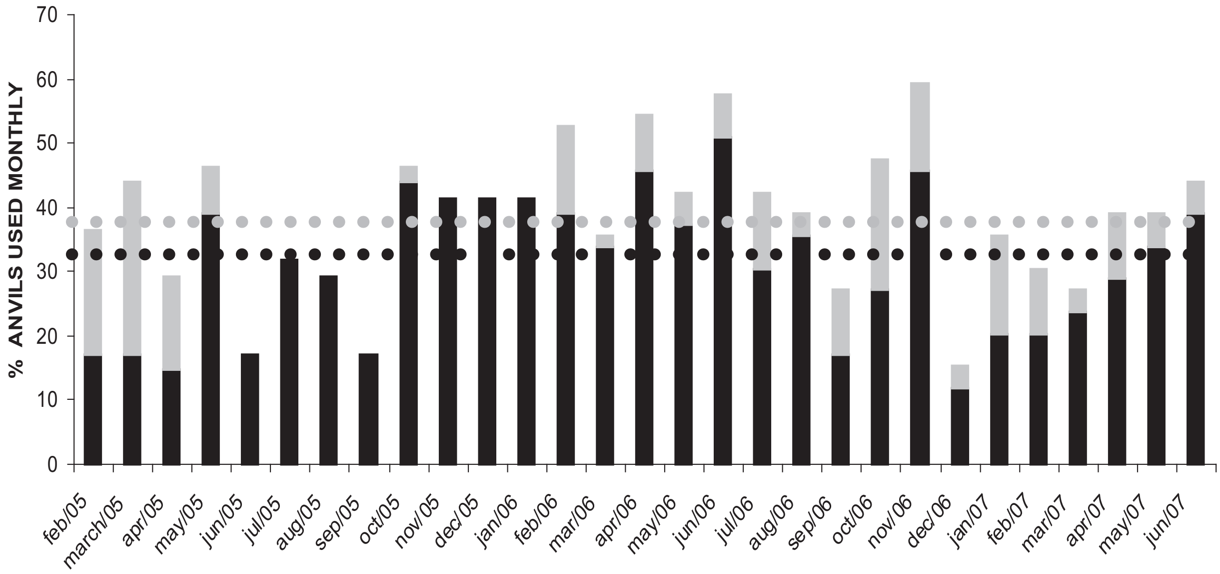

Fig. 5. Percent of anvils for which we have strong evidence (hammers moved and shells found on the anvils, in black) and weak evidence (hammers moved, in gray) of monthly use. The dotted horizontal lines indicate the average value for the strong evidence (black) and for the weak and strong evidence pooled (gray).

one edge was chipped. Breakage was a more common evidence of use. Fig. 7 shows the hammer stone of MZ9, broken into two pieces along a weak plane in the stone. This breakage is the result of forceful impact, almost certainly during its percussive use by a capuchin. However, there is no bulb of percussion or other features associated with deliberate stone flaking. While humans may produce both unintended and intended stone fracture, fracture resulting from capuchins' activities appears limited to the type of unintended damage seen on the MZ9 hammer stone.

3.4. Nut shell weathering

The shells of all nut species became grayer in the first several months after placement in the weathering station. After that, they persisted with minimal visible alteration in shape or surface texture over 6 years (see Fig. 8). We observed no further changes in shell coloration or cracking after four months except a gradual further graying.

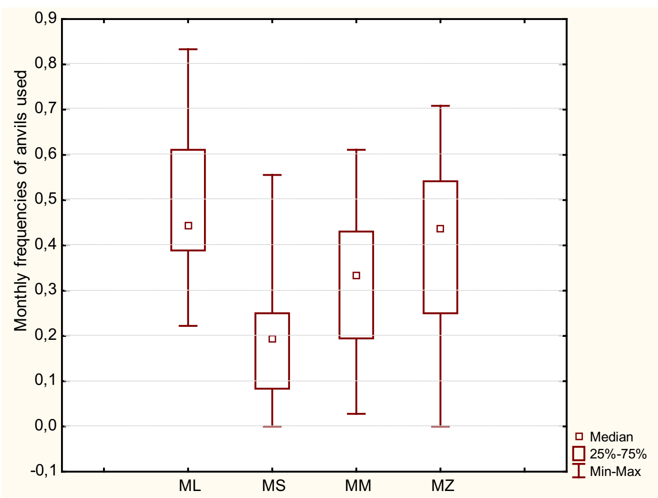

Fig. 6. Box-plots indicating use of anvil sites in the four areas surveyed.

3.5. Survey carried out in June 2011

In June 2011, 41 months after the last monthly survey (in January 2008), we surveyed all the anvil sites again using the same measurement procedure. For 40 anvils we found strong evidence of use (score = 2), for six there was weak evidence (score = 1), and in twelve there was no evidence of tool use. Five of these 12 anvils lacked a hammer stone (in one of these cases there were evident signs of recent fire); in four cases a few meters away from the original anvil site we found the original (marked) hammer stone on a new anvil, which had been used. In the remaining three cases the marked hammer stone was present on the anvil but there were no signs of use. We noticed that some new pits were present and that old pits had become deeper and larger in diameter in some anvils. We also discovered four new anvil sites (each with an unmarked hammer stone and nut shells) while we walked the path from anvil to anvil, as well as ten new hammer stones on the surveyed anvils. The hammer stone at MS14 presented a new pit in its surface.

3.6. Location of anvils in relation to sandstone ridges

We found a significant correlation between the aspect of an anvil and its frequency of use as measured by strong evidence (circular–linear correlation, rho = 0.567, $p < 0.001$). The mean aspect for all surveyed anvils was 56.3°, although both the short mean vector length ($r = 0.136$), and a Rayleigh test ($z = 1.065$, $p = 0.346$) confirm there was no significant directionality in the full dataset, when frequency of use is not taken into account. However, among the anvils with strong evidence for use in greater than 50% of the survey months, we found a significant departure from a uniform distribution, with a bias toward sites situated north and east of the sandstone ridges ($n = 15$; mean degrees: 39.7°, $r = 0.725$; Rayleigh test $z = 7.884$, $p < 0.001$). The anvils that were used in fewer than 50% of the survey months did not show a significant directional bias ($n = 43$; mean degrees: 174.1°, $r = 0.094$; Rayleigh test $z = 0.376$, $p = 0.689$). The overall correlation of aspect to use-frequency is therefore being driven by those anvils that were found to be used more often than not during the survey. Fig. 9 plots the frequency of strong evidence for anvil use against anvil aspect,

Fig. 7. Refitting hammer stone found on anvil MZ9.

illustrating the increased frequency of such evidence for those anvils with a northern to easterly aspect.

4. Discussion

4.1. Habitual anvil site use can be assessed by surveys

We surveyed activity at 58 anvil sites by marking hammer stone(s) at each anvil, positioning them precisely on the anvil, cleaning off all debris, taking an archival photograph of the site, and then revisiting each site monthly to note the position and identity of any stone on the anvil, and to evaluate the presence or absence of nut shells on the anvil. The anvils in our survey constitute only a small portion of the anvil sites used by the capuchin monkeys at our site. Each of the two habituated groups that we have followed on a systematic basis (Verderane, 2010; Spagnoletti et al., 2011a, 2012) has been seen using more than 100 anvils, and we are still encountering new anvil sites when we accompany the capuchins on their daily travels. Despite the large number of anvils used by the capuchins, our systematic survey over 36 consecutive months confirms that capuchins use anvils habitually (see also Spagnoletti et al., 2012) since 1/3 of the surveyed anvils were used monthly. Moreover, when we returned to the survey anvils 41 months after the last regular monthly check, we found 40 of the 58 anvils had been used in the relatively recent past (i.e., there were nut shells on the surface, together with one or more hammer stones, usually the marked hammer stone that had been there over the previously surveyed period). Thus this set of anvils showed remarkable persistence of tools and use across more than 6 years.

That capuchins' tool use to crack nuts can be inferred reliably by surveying anvil sites lends support to the use of this type of indirect evidence as an exploratory tool, to assess the occurrence of percussive tool use in areas where the capuchins are not habituated to human observers and/or the area is unfamiliar to the researchers, as has been done by Ferreira et al. (2010), Canale et al. (2009), and Langguth and Alonso (1997). We recommend this method to others looking for areas where capuchins use percussive tools to crack hard foods, with the proviso that joint presence of a hammer stone together with nut or seed shells on or next to a surface that could be used as an anvil must be the criterion to identify a used anvil with confidence. Pit formation is due to capuchin monkeys' preference to place nuts in pits more often than elsewhere on the anvil surface (Liu et al., 2011; Fragaszy et al., 2013), which appears to improve the efficiency of cracking compared to placement elsewhere (Fragaszy et al., 2010b).

At our site, pits are diagnostic of the use of a surface as an anvil, and pits persist even if shells and hammer stone are removed. Pits form in anvils in relation to the hardness of the anvil surface and the force of strikes used to crack the local foods. At our site, the palm nuts cracked by the capuchins are particularly large and hard and the prevailing sandstone boulders used as anvils are relatively soft (Visalberghi et al., 2007, 2008). Thus pits form readily from percussion in anvil surfaces at our site, but may not form quickly (or at all) at other sites where the prevailing substrate used for anvils is harder, and/or the items that are cracked are less resistant. Pits cannot be a required feature of a (hard) surface to identify it as an anvil.

4.2. Tool transport as revealed by survey data

The survey confirmed that the capuchins transport stones many meters on a regular, although infrequent, basis. Seventeen times hammer stones disappeared; forty times hammer stones were found moved from the anvil where we had left them the previous month, and seven of these forty times the hammer stone had been taken to another anvil site (which had been used in the previous month). Seven new stones of an appropriate lithology to serve as hammer stones appeared on survey anvils; four of these were of the mass normally used by adults (i.e., 500 g and larger). We often observed capuchins transporting hammer stones from one anvil to another for many meters, on the ground, up tree trunks and along branches. Behavioral observations and field experiments confirm that capuchins will carry stones in this weight range several meters to use them to crack nuts (Visalberghi et al., 2009a, 2009b; Massaro et al., 2012).

4.3. Correspondence between survey data and behavioral data

We took advantage of the concurrent observational data on the two groups of capuchin monkeys ranging in the area of our survey collected by Spagnoletti et al. (2011a) to determine the relationship

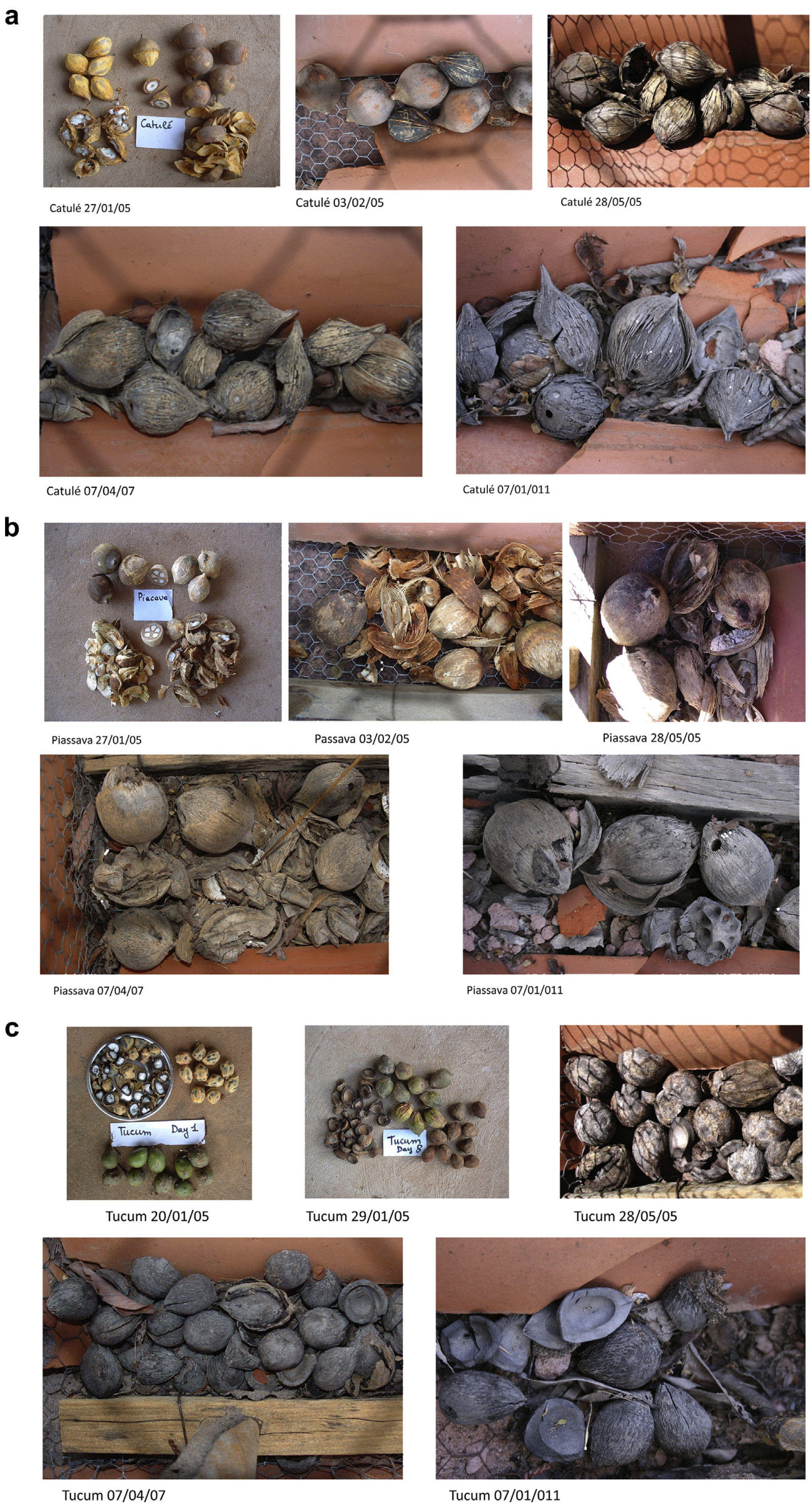

Fig. 8. Effects of natural weathering on (a) catulè, (b) piassava and (c) tucum nuts on day 1 (when they were collected) on day 8, 4 months later, 2 and a half years later and 6 years later.

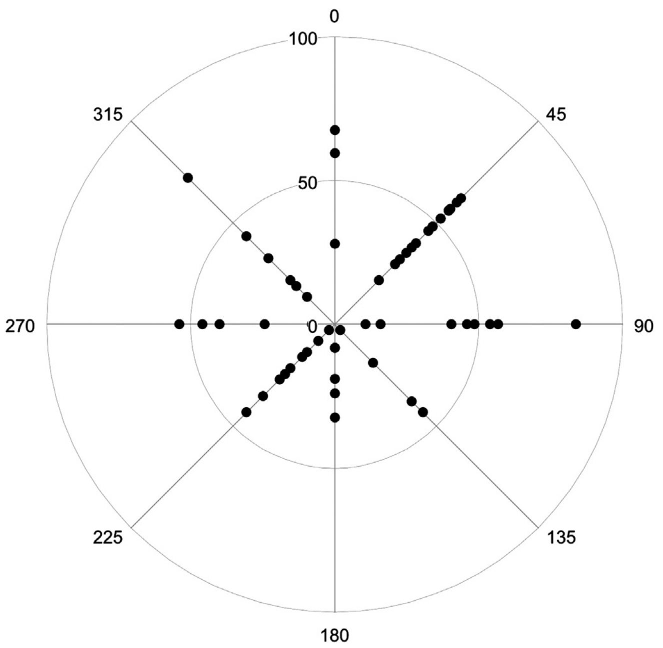

Fig. 9. Polar plot of the anvil survey data. For each anvil, the percentage of months with strong evidence of use by capuchins is shown (axes for 50% and 100% are marked) relative to the direction in degrees of each anvil from the nearest sandstone ridge.

between the survey data and observational data of cracking activity. The relative frequencies with which anvils showed strong evidence of tool use in our survey correlated significantly positively with the observed frequency of tool use episodes (at any anvil, including many not in our survey) in these same months that derived from Spagnoletti's direct observation of the capuchins. However, this was not the case if the evidence was not strong, i.e., if the criterion did not required the presence of shells as well as the displacement of the stone. Thus only the co-occurrence of these indirect cues during regular indirect surveys provides some information about the relative frequency of tool use across time in a given region. The rate at which new stones appear and known stones move from anvil to a new anvil or are lost, and the relative frequency of tool use across time are two aspects of tool use in a given area about which the survey method can provide useful information. Thus survey data can be used to track temporal changes in some aspects of tool using activity as well as to identify its occurrence.

4.4. Durability and wear in physical artifacts: anvils, hammers, shells

The three components of nut-cracking activity that we tracked in our survey (anvils, hammers, nut shells) all show strong persistence. All anvils of wood and stone in our survey were present in recognizable form at the end of the survey. Anvils did show signs of wear, however. Although we did not measure these changes, we observed that pits in frequently used anvils deepened and merged and new pits appeared over the three years of our study. Hammer stones, of hard stone, also persisted, generally without overt change. However, they also occasionally evinced wear, most obviously by breakage, which occurred a few times in our survey sample. We found evidence that hammer stones show other signs of use wear (chipping, formation of pits). Finally, nut shells persisted over more than six years in our weathering station, where they were protected from scattering by animals but were fully exposed to rain, wind and sun. They changed coloration for a few months after placement in the station, but after six years they looked largely the same as they had just four months after their placement in the station. They did not crack or decompose. Thus, the capuchins' system of tool use supports the creation of durable archeological sites. Future archeological excavations can target anvils showing evidence of repeated use (pitting) in areas with accumulating sediments. Most such anvils occur in the transition zone between plain and cliff (i.e. the talus), which is densely vegetated, supporting soil consolidation as well as sediment accumulation. A focus of future work will be dating the remains of shells and nut residue on stones encountered in the substrate during archeological excavation. Dating these materials will allow us to understand the antiquity of nut-cracking in this region.

4.5. Geographic bias in anvil use

The preferential use of anvils with a north-easterly aspect indicates that surface surveys and sub-surface archaeological exploration may have a higher success rate in finding extensively-used capuchin anvil sites if they concentrate on areas adjacent to the east and north of sandstone ridges. While the directional preference is clear, however, it does not reflect any presently-known differences in the distribution of resources around the ridges. We recommend that future analyses examine possible differences in environmental factors such as sunlight, temperature, wind and moisture between the north-east and other directions. Each of these factors can influence vegetation growth (both the species present and overall density) which in turn may be linked to food availability. Alternatively, the north-easterly preference may result from behavior such as predator avoidance or the position of capuchins' rest and sleeping areas. In any case, the geographical pattern in anvil use frequency seen at FBV demonstrates that landscape-scale behavioral patterning can be discerned from durable remains left by the capuchins, in the absence of direct observation. There is high potential, therefore, for tracking this pattern across space and time, and for comparison with similar heterogenous landscape use exhibited by other primates (including recent and ancient humans and our ancestors).

4.6. Capuchin stone tools and primate archeology

We have shown that bearded capuchin monkeys in a cerrado environment produced a record of stone tool-use that leaves a clear and patterned archaeological signature on the landscape. This finding bolsters the aims of primate archeology (Mercader et al., 2002, 2007; Haslam et al., 2009; Haslam, 2012) to reconstruct the technological evolution of non-human primates, and to identify those components of non-human technology that may provide insights into common features of hominin and animal tool use. Not surprisingly, paleoanthropologists have typically paid more attention to flaked stones than to stones that might have been used to crack open hard foods (but see Willoughby, 1985 for an exception), as the former provide unambiguous evidence of hominin activity. However, the interpretation of pounding tools, hammer stones and 'manuports' will need to take into account the possibility of non-human primate input to the archaeological record. This is especially true for non-flaked stones that either (i) show micro- or macro-pitting and abrasion consistent with pounding activity, (ii) are not found in association with flaked artefacts, or (ii) are older than the currently accepted advent of flaking some 2.6 million years ago (Semaw et al., 2003). The primary source of comparative data for archaeologists studying pounding tools has traditionally been West African chimpanzees (*P. troglodytes verus*), but the relatively recent discovery of stone tool use among wild monkey groups (Fragaszy et al., 2004; Visalberghi et al., 2007; Malaivijitnond et al.,

2007) has widened the base from which comparisons with our hominin ancestors may be drawn.

Archeology initially dealt almost exclusively with *Homo sapiens*, before expanding to investigate the behavior of our direct ancestors and their close relatives in the hominin lineage. Now, the field is expanding again, to explore species outside the hominins, beginning with members of the primate order (Mercader et al., 2007). Archaeological methodology is applicable to the material remains left by any animal, and where these remains include durable material culture we are given a direct window into the evolution of non-human behavior. This expanded perspective provides the benefit of a broader starting point from which to view our own technological evolution, as long as archaeological studies of animal tool use are not uncritically transferred to early hominins. Temporal and spatial analyses of the kind reported here for capuchin anvil use, as well as other recent landscape-scale studies of primate technology (e.g. Luncz et al., 2012), are moving us toward a more nuanced understanding of the alternative trajectories followed by tool-using primates. As a corollary, archaeologists must be aware that non-hominin transport and food processing activities can leave long-lasting landscape-wide behavioral evidence. Tool use by non-human animals contributes to the formation of the archaeological record in the present day, and there is no a priori reason to assume that it has not done so for at least as long as hominins have existed.

5. Conclusion

The current study has shown that the behavior of wild capuchin monkeys can be reconstructed from the durable remains left by their foraging activities, including the location and favored orientation of nut-cracking sites, and the transport of material to and from centralized nut processing locations. Ongoing research at FBV will continue to explore those components of capuchin tool use that are amenable to archaeological analysis. In particular, studies are required of the rate and patterning of wear development on anvils and hammer stones, excavation of debris from capuchins' pounding activities (including nut shells and stone fragments from damaged anvils), and transect surveys to explore further the distribution of anvils and their characteristics. Together with direct observation of capuchins' activities, these studies will permit the detailed reconstruction of wild capuchins' tool use across time and space, a prospect that even a few years ago would have been unimaginable.

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References

Boesch, C., Boesch, H., 1983. Optimisation of nut-cracking with natural hammers by wild chimpanzees. Behaviour 83, 265–286.

Canale, G.R., Guidorizzi, C.E., Kierulff, M.C.M., Gatto, C.A.F.R., 2009. First record of tool use by wild populations of the yellow-breasted capuchin (*Cebus xanthosternos*) and new records for the bearded capuchin (*Cebus libidinosus*). Am. J. Primatol. 71, 366–372.

DNPM, 1973. Parte das folhas SC. 23 Rio São Francisco e SC. 24 Aracaju; geologia, geomorfologia, solos, vegetacão e uso potencial da terra (mapa geológico 1: 1.000.000). Depto. Nacional de Produção Mineral, Projeto Radam, Rio de Janeiro, Brazil.

Ferreira, R., Emidio, R., Jerusalinsky, L., 2010. Three stones for three seeds: natural occurrence of selective tool use by capuchins (*Cebus libidinosus*) based on an analysis of the weight of stones found at nutting sites. Am. J. Primatol. 72, 270–275.

Fragaszy, D.M., Izar, P., Visalberghi, E., Ottoni, E.B., de Oliveira, M.G., 2004. Wild capuchin monkeys (*Cebus libidinosus*) use anvils and stone pounding tools. Am. J. Primatol. 64, 359–366.

Fragaszy, D.M., Greenberg, R., Visalberghi, E., Ottoni, E.B., Izar, P., Liu, Q., 2010a. How wild bearded capuchin monkeys select stones and nuts to minimize the number of strikes per nut cracked. Anim. Behav. 80, 205–214.

Fragaszy, D.M., Pickering, T., Liu, Q., Izar, P., Ottoni, E., Visalberghi, E., 2010b. Bearded capuchin monkeys' and a human's efficiency at cracking palm nuts with stone tools: field experiments. Anim. Behav. 79, 321–332.

Fragaszy, D., Liu, Q., Wright, B., Allen, A., Brown, C., Visalberghi, E., 2013. Wild bearded capuchin monkeys (*Sapajus libidinosus*) strategically place nuts in a stable position during nut-cracking. PLoS ONE 8 (2), e56182. http://dx.doi.org/10.1371/journal.pone.0056182.

Goren-Inbar, N., Sharon, G., Melamed, Y., Kislev, M., 2002. Nuts, nut cracking, and pitted stones at Gesher Benot Ya'aqov, Israel. Proc. Natl. Acad. Sci. U. S. A. 99, 2455–2460.

Gumert, M.D., Kluck, M., Malaivijitnond, S., 2009. The physical characteristics and usage patterns of stone axe and pounding hammers used by long-tailed macaques in the Andaman Sea region of Thailand. Am. J. Primatol. 71, 594–608.

Gumert, M.D., Hoong, L.K., Malaivijitnond, S., 2011. Sex differences in the stone tool-use behavior of a wild population of Burmese long-tailed macaques (*Macaca fascicularis aurea*). Am. J. Primatol. 73, 1–11.

Haslam, M., 2012. Towards a prehistory of primates. Antiquity 86, 299–315.

Haslam, M., Hernandez-Aguilar, A., Ling, V., Carvalho, S., de la Torre, I., DeStefano, A., Du, A., Foley, R., Hardy, B., Harris, J., Marchant, L., Matsuzawa, T., McGrew, W., Mercader, J., Mora, R., Petraglia, M., Roche, H., Visalberghi, E., Warren, R., 2009. Primate archaeology. Nature 460, 339–344.

Jones, P.R., 1994. In: Leakey, M.D., Roe, D.A. (Eds.). Olduvai Gorge Excavations in Bed III, IV and the Masek Beds: 1968–1971, vol. 5. Cambridge University Press, Cambridge, pp. 254–298.

Kortlandt, A., 1986. The use of tools by wild-living chimpanzees and earliest hominids. J. Hum. Evol. 15, 77–132.

Kortlandt, A., Holzhaus, E., 1987. New data on the use of stone tools by chimpanzees in Guinea and Liberia. Primates 28, 473–496.

Langguth, A., Alonso, C., 1997. Capuchin monkeys in the Caatinga: tool use and food habits during drought. Neotropical Primates 5, 77–78.

Leakey, M.D., 1971. Olduvai Gorge, Excavations in Beds I and II: 1960–1963. Cambridge University Press, Cambridge.

Liu, Q., Fragaszy, D., Izar, P., Ottoni, E., Visalberghi, E., 2011. Wild capuchin monkeys (*Cebus libidinosus*) place nuts in anvils selectively. Anim. Behav. 81, 297–305.

Luncz, L., Mundry, R., Boesch, C., 2012. Evidence for cultural differences between neighboring chimpanzee communities. Curr. Biol. 22, 922–926.

Malaivijitnond, S., Lekprayoon, C., Tandavanittj, N., Panha, S., Cheewatham, C., Hamada, Y., 2007. Stone-tool usage by Thai long-tailed macaques (*Macaca fascicularis*). Am. J. Primatol. 69, 227–233.

Massaro, L., Liu, Q., Visalberghi, E., Fragaszy, D., 2012. Wild bearded capuchin (*Sapajus libidinosus*) select hammer tools on the basis of both stone mass and distance from the anvil. Anim. Cogn. 15, 1065–1074.

Matsuzawa, T., 2001. Primate foundations of human intelligence: a view of tool use in nonhuman primates and fossil hominids. In: Matsuzawa, T. (Ed.), Primate Origins of Human Cognition and Behavior. Springer-Verlag, Tokyo, pp. 3–25.

Mercader, J., Panger, M., Boesch, C., 2002. Excavation of a chimpanzee stone tool site in the African rainforest. Science 296, 1452–1455.

Mercader, J., Barton, H., Gillespie, J., Harris, J., Kuhn, S., Tyler, R., Boesch, C., 2007. 4300-Year-old chimpanzee sites and the origins of percussive stone technology. Proc. Natl. Acad. Sci. U. S. A. 104, 1–7.

Mora, A., de la Torre, I., 2005. Percussion tools in Olduvai Beds I and II (Tanzania): implications for early human activities. J. Anthropol. Archaeol. 24, 179–192.

Oliveira, P.S., Marquis, R.J., 2002. The Cerrados of Brazil. Ecology and Natural History of a Neotropical Savanna. Columbia University Press, New York.

Sakura, O., Matsuzawa, T., 1991. Flexibility of wild chimpanzee nut-cracking behavior using stone hammers and anvils: an experimental analysis. Ethology 87, 237–248.

Semaw, S., Rogers, M.J., Quade, J., Renne, P., Butler, R.F., Dominguez-Rodrigo, M., Stout, D., Hart, W.S., Pickering, T., Simpson, S.W., 2003. 2.6-Million-year-old stone tools and associated bones from OGS-6 and OGS-7, Gona, Afar, Ethiopia. J. Hum. Evol. 45, 169–177.

Spagnoletti, N., Visalberghi, E., Ottoni, E., Izar, P., Fragaszy, D., 2011a. Stone tool use by adult wild bearded capuchin monkeys (*Cebus libidinosus*) frequency, efficiency and tool selectivity. J. Hum. Evol. 61, 97–107.

Spagnoletti, N., Visalberghi, E., Presotto, A., Fragaszy, D., Izar, P., 2011b. Do wild bearded capuchin monkeys (*Cebus libidinosus*) select anvils and habitat when using stone tools? Folia Primatol. 82, 354.

Spagnoletti, N., Visalberghi, E., Verderane, M.P., Ottoni, E., Izar, P., Fragaszy, 2012. Stone tool use in wild bearded capuchin monkeys (*Cebus libidinosus*). Is it a strategy to overcome food scarcity? Anim. Behav. 83, 1285–1294.

Spears, C., 1975. Hammers, nuts and jolts, cobbles, cobbles, cobbles: experiments in cobble technologies in search of correlates. In: Baker, C. (Ed.), Arkansas Eastman Archaeological Project. Arkansas Archeological Survey, Fayetteville, AK, pp. 83–116.

Verderane, M.P., 2010. Socioecologia de macacos-prego (*Cebus libidinosus*) em área de ecótono cerrado/caatinga. Ph.D. thesis. University of São Paulo.

Visalberghi, E., Fragaszy, D., Ottoni, E., Izar, P., de Oliveira, M.G., Andrade, F.R.D., 2007. Characteristics of hammer stones and anvils used by wild bearded capuchin monkeys (*Cebus libidinosus*) to crack open palm nuts. Am. J. Phys. Anthropol. 132, 426–444.

Visalberghi, E., Sabbatini, G., Spagnoletti, N., Andrade, F.R.D., Ottoni, E., Izar, P., Fragaszy, D., 2008. Physical properties of palm fruits processed with tools by wild bearded capuchins (*Cebus libidinosus*). Am. J. Primatol. 70, 1–8.

Visalberghi, E., Spagnoletti, N., Ramos Da Silva, E., de Andrade, F., Ottoni, E., Izar, P., Fragaszy, D., 2009a. Distribution of potential hammers and transport of hammer tools and nuts by wild capuchin monkeys. Primates 50, 95–104.

Visalberghi, E., Addessi, E., Spagnoletti, N., Truppa, V., Ottoni, E., Izar, P., Fragaszy, D., 2009b. Selection of effective stone tools by wild capuchin monkeys. Curr. Biol. 19, 213–217.

Willoughby, P., 1985. Spheroids and battered stones in the African Early Stone Age. World Archaeol. 17, 44–60.