Universidade Federal do Maranhão

Programa de Pós-Graduação em Biodiversidade e Conservação

SELEÇÃO DE FERRAMENTAS E CARANGUEJOS POR MACACOS-PREGO (*Sapajus libidinosus*) EM MANGUEZAL

JARDEANI MENDES DA SILVA

São Luís/ MA

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Dissertação apresentada ao Programa de Pós-graduação de Biodiversidade e Conservação da Universidade Federal do Maranhão como requisito parcial para obtenção do título de Mestre em Biodiversidade e Conservação.

Orientador: Prof. Dr. Ricardo Rodrigues dos Santos

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A grandeza de uma nação pode ser julgada

pelo modo que seus animais são tratados.

Mahatma Gandhi

Dedico

À minha maravilhosa

mãe Geane Mendes!

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RESUMO

Nos últimos anos, o estudo sobre o uso de ferramentas vem alcançado relevância em pesquisas relacionadas à evolução da inteligência em primatas. Entre os primatas neotropicais, os macacos-prego do gênero *Sapajus* têm se destacado pelo uso habitual de ferramentas na natureza como forma de facilitar o acesso aos recursos alimentares. Os macacos-prego utilizam ferramentas de quebra para consumir ampla variedade de alimentos. No Brasil, os estudos sobre uso de ferramentas em macacos-prego estão voltados principalmente para grupos que vivem no cerrado e na caatinga. Já em florestas inundáveis, como os manguezais, os registros são escassos. Neste estudo, objetivamos verificar como macacos-prego da espécie *Sapajus libidinosus,* que vivem em manguezal, selecionam ferramentas de quebra de acordo com o peso dos caranguejos consumidos e como se dá o uso de ferramentas dentre as diferentes classes etárias. Pressupomos que os caranguejos mais pesados são mais frequentemente consumidos com o auxílio de ferramentas. Supondo-se que o peso é uma variável que se correlaciona positivamente com o tamanho do caranguejo, e, portanto, com a rigidez do seu exoesqueleto, esperou-se que o uso de ferramentas fosse mais frequente em caranguejos que possuem maior peso por apresentar maior resistência de quebra. A resistência esteve associada aos quelípodos do caranguejo, os quais apresentam considerável quantidade de carne. Além disso, previmos que adultos usam ferramentas com mais frequências que subadultos e jovens, por possuírem maior peso corporal, mais experiência, e, portanto, maior habilidade e força para a atividade de quebra. A pesquisa foi realizada nos manguezais do rio Preguiças, na cidade de Barreirinhas, costa norte do Brasil. Realizamos um estudo experimental em ambiente natural com a utilização de plataformas de alimentação de madeiras fixadas nas raízes de *Rhizophora mangle.* As plataformas foram provisionadas com caranguejos da espécie *Ucides cordatus* juntamente com ferramentas confeccionadas com madeira. Foram obtidos registros de alimentação de um grupo representado por 16 animais, em que 8 deles foi observado o uso de ferramentas. Observamos que os animais não selecionam as ferramentas de acordo com o peso dos caranguejos, mas sim em relação ao quelípodo. O quelípodo, provavelmente, é a estrutura mais resistente do caranguejo. Além disso, encontramos diferenças significativas entre os pesos das ferramentas usadas por macacos adultos e subadultos, sugerindo que aqueles selecionam as ferramentas mais pesadas. Porém, não foi observado o uso de ferramentas entre os indivíduos jovens. Este estudo traz novas percepções ao contexto ecológico e evolutivo de *Sapajus libidinosus* com o uso de ferramentas em manguezal, pois diferentemente do que ocorre na caatinga e cerrado, onde as ferramentas são martelos de pedras e usadas para quebrar frutos, no manguezal, estes animais usam ferramentas de madeira de mangue para acessar recursos alimentares de origem animal.

Palavras-chave**:** Uso de ferramentas; Comportamento animal; *Ucides cordatus*; *Rhizophora mangle*.

ABSTRACT

In recent years, the study on the use of tools has reached relevance in research related to the evolution of intelligence in primates. Among the neotropical primates, the primates of the *Sapajus* genus have been distinguished by the habitual use of tools in nature as a way to facilitate access to food resources. The capuchin monkeys use great tools to consume a wide variety of foods. In Brazil, studies on the use of tools on bearded capuchin are mainly aimed at groups living in the cerrado and caatinga. In flooded forests, such as mangroves, records are scarce. In this study, we aimed to verify how *Sapajus libidinosus* monkeys living in mangroves select tools according to the weight of the crabs and how to use tools in the different age classes of these primates. We assume that heavier crabs are most often consumed with the aid of tools. Assuming that the weight is a variable that correlates positively with the development of the crab and, therefore, with the rigidity of its exoskeleton, it was expected that the use of tools would be more frequent in crabs of greater weight because it presents greater resistance to break. In addition, we anticipate that adults use tools with more frequencies than subadults and juvenile monkeys, because they have greater body weight, more experience and therefore greater capacity and strength for the breaking activity. The research was carried out in the mangroves of the river Preguiças, in the city of Barreirinhas, north coast of Brazil. We carried out an experimental study in a natural environment with the use of wooden feeding platforms fixed to the mangrove roots *Rhizophora mangle*. The platforms were provisioned with crabs of the species *Ucides cordatus* along with tools made with wood. The feeding records were obtained from a group represented by 16 animals, in which 8 of them were observed the use of tools. We observed that the animals do not select the tools according to the weight of the crabs, but in relation to the cheliped. The cheliped is probably the most resistant structure of the crab. In addition, we found significant differences between tool weights used by adult monkeys and subadults. This suggests that adults seem to use heavier tools than subadults. However, the use of tools was not observed in young individuals. This study brings new insights into the ecological and evolutionary context of *Sapajus libidinosus* with the use of tools in mangroves, because unlike what occurs in the caatinga and cerrado, where the tools are stone hammers and used to break fruits, in the mangrove, these animals use mangrove wood tools to access animal food resources like crab.

Keywords: Tool Use; Animal behavior; *Ucides cordatus; Rhizophora mangle.*

LISTA DE SIGLAS E ABREVIATURAS

CEUA - Comitê de Ética no Uso de Animais

cm - Centímetro

FBV - Fazenda Boa Vista

g – Grama

PNSC - Parque Nacional da Serra da Capivara

Kg - Kilograma

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CAPÍTULO I

1 APRESENTAÇÃO GERAL

Em macacos-prego, o uso espontâneo de ferramentas para a quebra de alimentos foi relatado pela primeira vez em dois grupos semi-livres de *Sapajus libidinosus* (Spix, 1823) (Cebidae), sendo descoberto mais recentemente em algumas populações selvagens no nordeste do Brasil (MANNU; OTTONI, 2009). Em áreas savanóides do Brasil, como na Caatinga e no Cerrado, *S. libidinosus* utiliza artefatos de pedra para quebrar e consumir frutos de palmeiras (e.g. FRAGASZY et al., 2004 b; MANGALAM; FRAGASZY, 2015; FALÓTICO; OTTONI, 2016).

O uso de ferramentas por primatas em florestas alagadas como o manguezal é registrado em *Macaca fascicularis aurea*, na Tailândia, em que o habitat estudado é formado por praias arenosas e costões rochosos. Nestes ambientes, as ferramentas de quebra consistem de pedras para auxiliar a quebra de mariscos (e.g. GUMERT; MALAIVIJITNOND, 2012). No Brasil, há registros para *S. libidinosus*, que quebram mariscos em raízes aéreas e troncos com o auxílio de pedaços de madeiras de mangue (CUTRIM, 2013; SANTOS et al., 2018).

As características morfológicas dos alimentos e os pesos das ferramentas podem influenciar na seleção do uso de ferramentas (FRAGASZY et al., 2010; SPAGNOLETTI et al., 2011). A preferência de macacos-prego no uso das ferramentas pode ser atribuída às ferramentas que possuem maior peso e à alimentos de menor resistência, o que deve minimizar o número de batidas durante o uso (FRAGASZY et al., 2010). O tamanho da ferramenta, o peso e a distância de transporte também influenciam na quantidade de energia que é despreendida durante uma determinada tarefa (LUNCZ et al., 2016).

A atividade de quebra de alimentos é provavelmente muito dispendiosa para os macacos-prego, mas principalmente para aqueles de menor tamanho corporal e/ ou menor habilidade (FRAGASZY et al., 2010). Os jovens parecem quase não usarem ferramentas, sendo as taxas de sucesso na obtenção de recursos alimentares bem maiores em adultos e subadultos (SPAGNOLETTI et al., 2011; FALÓTICO; OTTONI, 2016).

No presente estudo propomos que macacos-prego que vivem em manguezal selecionam ferramentas de acordo com o tamanho do recurso e que seu uso é mais frequente de acordo com o seu desenvolvimento ontogenético. Sendo o peso uma variável que se correlaciona positivamente com a idade do caranguejo, e, portanto, com a rigidez do seu exoesqueleto, sugerimos que ferramentas mais pesadas sejam mais frequentemente utilizadas para consumir caranguejos que possuem maior peso ou que estejam relacionadas ao uso em partes mais rígidas do exoesqueleto.

Propomos também que o uso de ferramentas seja mais frequente em adultos que nas demais classes etárias porque adultos possuem maior força e, possivelmente, maior habilidade para a atividade de quebra. Portanto, o presente estudo contribui com novas percepções ao contexto ecológico da espécie, visto que, traz novas informações sobre o comportamento alimentar de macacos pregos em condições ambientais e ecológicas até agora pouco estudadas.

2. REVISÃO BIBLIOGRÁFICA

2.1 Uso de Ferramentas em Primatas

Acreditava-se que o uso espontâneo de ferramentas era exclusivo aos primatas do velho mundo. Os chimpanzés têm sido tradicionalmente modelos referenciais para a investigação da evolução humana no contexto do uso de ferramentas por hominídeos (SPAGNOLETTI et al., 2011). Os chimpanzés, além de usarem ferramentas como pedras e pedaços de tronco na quebra de frutos, fabricam e modificam ferramentas como, por exemplo, gravetos para capturar formigas e cupins (NISHIDA, 1973). Contudo, embora *Sapajus libidinosus* seja distante filogeneticamente dos primatas do velho mundo, esta espécie também apresenta esse comportamento de forma habitual (FRAGASZY; BARD 1997; SPAGNOLETTI et al., 2011).

Os primatas não-humanos como os chimpanzés *Pan troglodytes verus* (Blumenbach, 1776) da África Ocidental, os macacos de cauda longa *Macaca fascicularis aurea* (Raffles, 1821) da Tailândia e os macacos-prego *S. libidinosus* do Brasil são três espécies que se destacam pelo uso habitual de ferramentas (HASLAM et al., 2014).

Entre os primatas neotropicais, espécies do gênero *Sapajus* (Cebidae) têm esse destaque pelo uso de ferramentas na natureza como forma de facilitar o acesso aos recursos alimentares (SANTOS et al., 2018). Sabe-se que é comum a ocorrência deste comportamento em grupos de macacos-prego silvestres e em semi-liberdade (especialmente em grupos de *S. libidinosus*), principalmente relacionada à quebra de cocos, utilizando o sistema de "martelo" (para quebra) e "bigorna" (para apoiar), como visto por Fragaszy et al. (2004b) e Falótico (2011).

Os macacos-prego utilizam ferramentas de quebra, como pedras, para consumir uma diversidade de frutos encapsulados (FALÓTICO; OTTONI, 2016). Os alimentos encapsulados são caracterizados por possuírem uma estrutura resistente que recobre o conteúdo comestível. Nos frutos encapsulados com (cápsula loculicida), a deiscência ocorre ao longo da nervura mediana de cada carpelo. A abertura da cápsula ocorre por meio dos seus septos, expondo as sementes por uma fenda (FALÓTICO, 2011). Dentre os frutos encapsulados consumidos por macacos-prego no Cerrado e na Caatinga, estão incluídos os frutos de palmeira *Attalea* spp. e *Astrocaryum* spp. (CHALK et al., 2016) e a castanha de caju *Anacardium* spp. (SIRIANNI; VISALBERGHI, 2013).

Em se tratando do uso de ferramentas em alimentos de origem animal que são protegidos por estruturas rígidas, estão incluídos os mariscos como os moluscos constituídos por conchas e crustáceos formados por exoesqueleto na carapaça e nas pinças (quelípodos). O caranguejo *Ucides cordatus* é um crustáceo consumido com ferramentas de madeira de mangue por macaco-prego nos manguezais do Rio Preguiças (SANTOS, 2010).

No manguezal da Tailândia, os macacos da espécie *Macaca fascicularis aurea* usam ferramentas de pedra para processar os quelípodos, que são as partes do caranguejo mais difíceis para quebrar (GUMERT; MALAIVIJITNOND, 2012).

Há explicações para a existência do uso de ferramentas em macacos-prego, como, por exemplo, a terrestrialidade, pois a quebra de frutos utilizando-se pedras ocorre apenas em ambientes em que os animais têm a oportunidade (ou necessidade) de descer ao chão (VISALBERGHI et al., 2005). Além disso, a capacidade de usar ferramentas por estes animais pode ser explicada pelo fato destes primatas apresentarem flexibilidade comportamental, grande habilidade manual e elevada capacidade cognitiva (FRAGASZY et al., 2004 a).

Há duas principais hipóteses que tentam explicar o uso de ferramentas em primatas, a primeira é conhecida como hipótese da necessidade, que diz que o uso de ferramentas se dá pela necessidade de quebrar os alimentos encapsulados devido à escassez dos principais recursos alimentares (MOURA; LEE, 2004; CUTRIM, 2013). A segunda consiste na hipótese da oportunidade, que sugere que o uso das ferramentas acontece pelo acesso simultâneo a martelos e alimentos encapsulados, e pode ocorrer com maior probabilidade em ambiente com abundância de recursos alimentares (OTTONI; MANNU, 2001; SPAGNOLETTI et al., 2012).

Para Spagnoletti et al. (2012), a frequência do uso das ferramentas em macacos-prego é refletida pela abundância de frutos encapsulados e não pela disponibilidade de outros tipos de frutos e invertebrados, suportando assim a hipótese da oportunidade. Além disso, a tolerância social, característica presente nesses primatas (IZAWA, 1980), pode influenciar o uso de ferramentas. A aprendizagem social pode ser favorecida pela dinâmica social e proximidade entre os indivíduos, uma vez que quanto maior é a proximidade, mais provavelmente um observador poderá aumentar a informação socialmente adquirida com informações obtidas através de suas próprias atividades (COUSSI-KORBEL; FRAGASZY, 1995).

A atividade de quebra de frutos com pedras em uma superfície dura tem sido bem documentada em macacos-prego cativos e semi-livres (FRAGASZY et al., 2004 b). Nos ecossistemas de terra firme, como a Caatinga e o Cerrado, os macacos-prego utilizam ferramentas feitas de artefatos de pedra para quebrar frutos de palmeiras (e.g. FRAGASZY et al., 2010; MANGALAM; FRAGASZY, 2015; FALÓTICO; OTTONI, 2016).

2.2 Uso de Ferramentas em *Sapajus libidinosus* em diferentes ambientes

A espécie *S. libidinosus* ocorre em florestas de terra firme, igapós, na Caatinga, no Cerrado e em Manguezais do Brasil e apresenta dieta onívora (SANTOS et al., 2018). Esses primatas estão distribuídos geograficamente em toda a região Nordeste do Brasil e em algumas localidades fazem o uso de ferramentas, como martelos e bigornas, para a quebra de frutos (OTTONI; IZAR, 2008).

As populações mais estudadas deste primata associado ao uso de ferramentas concentram-se principalmente na Fazenda Boa Vista – FBV (SPAGNOLETTI et al., 2011; MANGALAM; FRAGASZY, 2015) e no Parque Nacional da Serra da Capivara - PNSC (MANNU; OTTONI, 2009; FALÓTICO; OTTONI, 2016), ambos localizados no Estado do Piauí, Nordeste do Brasil. A FBV é um habitat de floresta semiárida localizado na zona de transição entre habitats Cerrado e Caatinga (IZAR et al., 2012: CHALK et al., 2016) e o PNSC compreende a vegetação seca de Caatinga (MANNU; OTTONI, 2009).

No manguezal, às margens do estuário Rio Preguiças, Barreirinhas, Maranhão foram feitos registros de uso de ferramentas por *S. libidinosus* (SANTOS et al., 2018; CUTRIM, 2013). Nas observações, a espécie utilizou ferramentas (martelos) obtidos das madeiras de mangue para facilitar a quebra de mariscos como crustáceos e moluscos. Contudo, em outro fragmento no estuário Rio Novo com 20km de distância, na cidade de Paulino Neves, em *S.*

libidinosus não foi observado o uso de ferramentas para o consumo de caranguejos (SANTOS, 2010).

As informações sobre esse comportamento foram registradas principalmente por observações indiretas, constituídas pelo reconhecimento e caracterização de sítios de quebra com a presença de ferramentas com sinais de desgaste e vestígios de carapaças e/ou conchas dos mariscos (SANTOS, 2010; CUTRIM, 2013) e por meio do barulho de quebra obtido pelos sons produzidos pela batida dos pedaços de madeira utilizados como martelos nas bigornas de madeira (CUTRIM, 2013).

No estudo realizado por Santos, 2010, também foram feitas observações por meio de experimentos com plataformas de alimentação iscadas com caranguejos. Na ocasião, os macacos transportavam os mariscos das plataformas para os sítios de quebra e faziam o consumo usando as mãos e/ou utilizando ferramentas para a atividade de quebras. Os crustáceos constituem o alimento com maior frequência encontrados nos sítios de quebra por ser um recurso maior e de provável maior retorno energético que os outros recursos animais encapsulados como os moluscos (CUTRIM, 2013).

O manguezal expõe condições favoráveis para proteção, alimentação e reprodução para inúmeras espécies de animais, além dos macacos pregos do gênero *Sapajus* (SANTOS; BRIDGEMAN, 2018). Em manguezais maranhenses, nas raízes de *Rhizophora mangle*, um macaco-prego da espécie *Sapajus apella* foi visto abrindo conchas de ostras com outra ostra (FERNANDES,1991).

No manguezal, as condições ecológicas às quais os macacos-prego estão sujeitos são bem diferentes das áreas de Caatinga e Cerrado. O fluxo de maré que inunda periodicamente o manguezal ocasiona a submersão dos mariscos afetando a disponibilidade dos recursos alimentares, podendo influenciar a atividade de quebra nesse ambiente (SANTOS, 2010). Os macacos-prego são arborícolas e passam a maior parte do tempo no estrato arbóreo do manguezal, com altura superior a 5 m (CUTRIM, 2013). Porém, exploram o estrato inferior da floresta de mangue constituído pelo conjunto de raízes aéreas acima do chão (SANTOS, 2010).

2.3 Seleção de Ferramentas por Características Morfológicas dos Alimentos

As características morfológicas dos alimentos e os pesos das ferramentas podem influenciar a maneira como os macacos-prego usam as ferramentas (FRAGASZY et al., 2010; SPAGNOLETTI et al., 2011). Os macacos-prego já habituados com o uso de ferramentas podem selecionar as ferramentas de acordo com o peso que elas apresentam e também conforme a resistência de quebra dos alimentos encapsulados (SPAGNOLETTI et al., 2011). Foi observado por esses autores, por exemplo, que alguns indivíduos do grupo na FBV, usaram os martelos de pedras mais pesados para quebrar frutos de maior resistência do que para os frutos de menor resistência.

Os macacos-prego podem avaliar os custos e benefícios do uso de ferramentas quando podem escolher entre diferentes frutos. Nesses casos, os animais acabam por preferir aqueles que apresentam menor resistência de quebra, e, portanto, mais fáceis de quebrar, o que demanda menos esforço e tempo para o consumo do fruto, e essa preferência é vista também para frutos que possuem maior conteúdo alimentar (FRAGASZY et al., 2010).

Os macacos-prego são capazes de perceber o peso de ferramentas e a distância necessária para transportá-las. Em um experimento com duas pedras de massa igual, todos os indivíduos minimizaram o gasto de transporte, escolhendo a pedra que se encontrava 3 m da bigorna, em vez da pedra que estava a 6 m da bigorna. Em outro experimento, com as pedras de massas diferentes, a 3 e 6 m, os macacos tiveram preferências pela pedra pesada quando estava a 3m e selecionaram a pedra leve a 3m, quando a pesada estava a 6m (MASSARO et al., 2012).

Em estudo na FBV, Fragaszy et al. (2010) observaram que macacos-prego fazem distinção para o peso das pedras que eles usam para quebrar cocos, e selecionam a ferramenta mais pesada quando é dada uma escolha de martelos de pedras com pesos distintos. Além disso, os macacos usam ferramentas mais frequentemente para quebrar frutos menos resistentes a frutos com alta resistência (SPAGNOLETTI et al., 2011).

O uso de ferramentas pode implicar em custos além da energia como, por exemplo, risco de predação devido à facilidade de localização do predador pelo som produzido, risco de lesão física e tempo de manipulação. Assim, se os macacos estiverem atentos a algum ou a todos esses custos, eles devem selecionar os alimentos mais fáceis de quebrar e as pedras mais pesadas, que devem minimizar o número de batidas durante o uso (FRAGASZY et al., 2010). No manguezal pode haver o risco de predação de macacos-prego durante a manipulação de ferramentas, como por exemplo, durante a maré alta. O mangue alagado possibilita maior presença de predadores naturais como sucuris (*Boa constrictor*) e jacarés (*Caiman crocodilus*), podendo interferir no consumo de alimentos com o uso de ferramentas no estrato inferior do manguezal.

Enfim, os estudos com uso de ferramentas e suas formas de seleção relacionadas ao peso estão descritos principalmente para o Cerrado e para análises, como, por exemplo, do transporte de ferramentas (VISALBERGHI et al., 2007; MASSARO et al., 2012); entre diferenças de uso entre classes sexuais (SPAGNOLETTI et al., 2011); das características de bigornas (VISALBERGHI et al., 2007; FRAGASZY et al., 2004 b); dos frutos com tamanhos diferentes (FERREIRA et al., 2010), dos frutos com diferentes graus de resistência (SPAGNOLETTI et al., 2011) e dos frutos de diferentes espécies (MORAES et al., 2014, FALÓTICO; OTTONI, 2016; FALÓTICO et al., 2018). Em áreas costeiras, como o manguezal, há registros de seleção de peso de ferramentas de pedras em *Macaca fascicularis aurea* para a quebra de diversos alimentos, dentre eles caranguejos, porém com raros registros (GUMERT; MALAIVIJITNOND, 2013).

2.4 Uso de Ferramentas nas Diferentes Classes Etárias

Macacos-prego adultos apresentam maior massa corporal que indivíduos jovens (FRAGASZY *et al*. 2010). A massa corporal também pode interferir no transporte de ferramentas pesadas (MASSARO et al., 2012). Na Fazenda Boa Vista, os jovens começam a quebrar pedaços de frutos resistentes entre 2 e 3 anos de idade (FRAGASZY et al., 2013). Entretanto, os jovens usam ferramentas com pouquíssima frequência quando comparado aos adultos (SPAGNOLETTI et al., 2011). Em outro estudo na FBV, foi observado que tanto os jovens como os adultos consomem alimentos que possuem resistência similar e os alimentos quebrados pelos adultos são acessíveis pelos jovens depois do desmame (CHALK et al., 2016). Neste caso, o autor desconsiderou os episódios em que houve uso de ferramentas.

No PNSC, Mannu e Ottoni (2009) observaram que os mais jovens parecem muito interessados em observar o comportamento dos adultos durante o uso de ferramentas, exibindo "gestos de empatia" e aproveitando qualquer oportunidade para manipular os frutos e as pedras. As taxas de sucesso de adultos e subadultos na aquisição de recursos com ferramentas parece ser maior do que em juvenis (FALÓTICO; OTTONI, 2016).

Além da massa corporal dos animais, a experiência dos indivíduos de um grupo para acessar e consumir determinados recursos, é outro fator que pode influenciar diretamente no comportamento alimentar de indivíduos de diferentes classes-etárias. Além disso, o desenvolvimento do aparato mastigatório, em fase de desenvolvimento nos jovens e completamente desenvolvido nos adultos, pode influenciar bastante na dieta dos jovens e isso depende também das propriedades físicas do alimento (GUNST et al., 2008).

Considerando que o peso corporal de um animal adulto, pode variar de 2.5 a 3.7 Kg (FRAGAZSY et al., 2004 a), as pedras utilizadas como martelo, podem pesar entre 1/2 a 1/4 do corpo de um animal adulto. O retorno energético no consumo de frutos de Aceraceae, por exemplo, pode ser maior do que o gasto de energia requerido para utilizar as pedras como ferramentas (ROCHA et al., 1998). O retorno energético no uso de ferramentas pode ser visto como a diferença entre os ganhos energéticos e os custos da utilização de ferramenta (EMÍDIO; FERREIRA, 2012).

O custo total da utilização de uma pedra para a quebra de um fruto aberto inclui a energia em movimentos ascendentes e descendentes com metade da energia gasta durante a elevação, e a outra metade gasta empurrando o martelo contra o alimento encapsulado durante a fase descendente (LIU et al., 2009; EMÍDIO; FERREIRA, 2012). O consumo de caranguejos por *S. libidinosus* pode trazer a esses animais maior energia alimentar. A carne dos crustáceos é apreciada em várias partes do mundo por seres humanos também e apresenta elevado teor de proteínas e outros nutrientes (FISCARELLI, 2004).

3. OBJETIVOS

3.1 Geral

- Avaliar de que modo o uso de ferramentas de quebra é utilizado para explorar caranguejo por macacos-prego em manguezais

3.2 Específicos

- Verificar se o uso de ferramentas é mais frequente nos caranguejos mais pesados.
- Analisar se os tamanhos dos quelípodos influenciam a seleção de ferramentas.
- Verificar se o uso de ferramentas é mais frequente nos adultos do que nos subadultos e jovens.

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CAPÍTULO II

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Tool selection and crab-catch by wild capuchin monkeys (*Sapajus libidinosus*) in the mangroves of Maranhão, Brazil

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Abstract Bearded capuchins use tools to consume a wide variety of foods. The majority of about tool use by bearded capuchins are carried out in cerrado and caatinga environments. In this study, we verified how capuchins of different age groups living in mangroves select tools according to the size of the food resource. This research was conducted in the mangroves of the Preguiças River, Maranhão State, on the north coast of Brazil. Experiments were carried out in the natural environment with the use of five wood-feeding platforms fixed to roots of *Rhizophora mangle*. The experimental sessions were characterized by the provision of crabs of the species *Ucides cordatus* and of tools made of wood. We obtained 285 feeding records from eight individuals who used tools in 33% of the records. The results indicate that there was no correlation between the weights of the crabs and the tool weights (P = 0.21). The use of tools was recorded only in adults and subadults, but not by young individuals. We found a significant difference in tool weight used by the two age groups, where adults used heavier tools than subadults. Our results bring new insights into the ecological and evolutionary context of tool use in *Sapajus libidinosus*, and more specifically the use of wood tools for crabmeat consumption in mangrove forests.

Keywords Tool use • *Ucides cordatus* • Wood tool • *Rhizophora mangle*

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Introduction

The use of tools to obtain food allows the expansion of an individual's diet, providing flexibility when food resources fluctuate, and food cannot be exploited otherwise (Spagnoletti *et al*. 2012). Several factors may explain variation in tool use, as for example, the resource limitation due to seasonal reductions in food abundance (i.e. tool use as a fallback strategy), high abundance of nutritious, encapsulated foods which require tools to access, low dietary richness, availability of anvil and stones sites, increased terrestriality and low predation risk (Barret *et al.* 2018).

Primates that stand out by the usual use of tools are the chimpanzees (*Pan troglodytes*) in West Africa, the long-tailed macaques (*Macaca fascicularis aurea*) in Thailand, and the bearded capuchin monkeys (*Sapajus libidinosus*) in Brazil (Haslam *et al.* 2014). Chimpanzees that use stones to break fruit have been models for the investigation of the human evolution and the use of tools by hominids (Spagnoletti *et al*. 2011). Long-tailed macaques consume shellfish with the help of stone in a coastal environment formed by mangroves associated with sandy beaches and rocky shores (e.g. Gumert and Malaivijitnond, 2012), and bearded capuchins use stone tools to break encapsulated fruits in savanna environments (e.g. Fragaszy *et al.* 2004) and wooden tools to break crabs in mangroves (Cutrim, 2013; Santos *et al*. 2018).

In the wild, the use of tools was observed spontaneously and habitually in wild groups of capuchin monkeys (Fragaszy *et al*. 2004, Moura and Lee 2004, Waga *et al*. 2006, Spagnoletti *et al*. 2011). The use of tools by capuchin monkeys has been studied mainly in two long-term research sites, Fazenda Boa Vista (FBV) and Serra da Capivara National Park (SCNP), separated by 320 km (Falótico *et al*. 2018). These two sites are located in the Northeast of Brazil. The FBV is a transition area between the caatinga and cerrado (open woodland) and the SCNP is an area of caatinga characterized as dry savannah (Olson *et al.* 2001; Oliveira and Marquis 2002; Izar *et al.* 2012). In these areas, the monkeys use stone tools to accomplish different tasks: whereas in FBV they are used to open hard palm fruits (Arecaceae), cashew nuts (*Anacardium* spp.) and manioc (*Manihot* spp.) (Spagnoletti *et al.* 2011), in the SCNP, the stone tools are used to open cashew nuts (*Anacardium* spp.), manioc (*Manihot* spp.), mango (*Mangifer*a *indica*), cacti (Cactaceae), and Brazilian copal (*Hymenaea* spp.) (Falótico *et al.* 2018). In addition, these monkeys use stone to dig for tubers in the soil, use rods (bits of tree branches) to access food or water in cracks, holes or insect nests (Moura and Lee 2004; Mannu and Ottoni 2009).

In the mangroves of Maranhão State, during foraging when the tide is low, the capuchin monkeys use two diverse strategies to hunt crabs: they wait for the crabs to come out of the burrow to catch them or place one of the arms inside the crabs' burrows and grab them. After the capture, the monkeys transport the crab to an anvil and consume them with the use of tools. The anvils are generally roots of *Rhizophora* spp. and trunks of fallen trees and the tools are pieces of tree branches that are available on the ground (Cutrim, 2013; Santos *et al*. 2018).

Studies on tool use in capuchin monkeys have mainly focused on the degree of hardness and resistance of the different food items (e.g. Fragaszy *et al.* 2010; Spagnoletti *et al.* 2011). The efficiency in opening a food with the use of tools varies according to the strength or "degree of hardness to break" of the encapsulated food items. Thus, capuchins monkeys that are already accustomed to using tools can select them by their weight in relation to the weight and type of food (Spagnoletti *et al.* 2011). Capuchins generally prefer fruits that have lower breaking strength and are easier to break, which requires less effort and time during at cracking (Fragaszy *et al.* 2010a). The size and weight of the tool also influence the energy expenditure during feeding (Luncz *et al.* 2016). The capuchins prefer heavy than light stones tools, including when the difference in weight of the stones is a few hundred grams (Fragaszy *et al.* 2010a)

Tool use skills may be related to the age of individuals and can result in the selection of tools and encapsulated foods. Adults have greater body mass than young monkeys and food breakage activity is possibly more expensive for smaller individuals and those less skilled in the use of tools (Fragaszy *et al.* 2010a). Heavier individuals are more efficient at breaking down highly resistant fruits than slender individuals (Spagnoletti *et al.* 2011). Thus, limitations related to cognitive developmental abilities or physical limitations (smaller size and lower strength) may contribute to differences in tool use proficiency among age groups (Chalk *et al.* 2016).

In the areas of caatinga and cerrado, the tools used by monkeys are hammer stone to break fruit nuts. However, in the mangrove forests the tools used to break crab (animal origin food) are wood pieces. Thus, in this study we aim to assess weather capuchin monkeys select wood tools that have different weights to break crabs that also have different weight and size. Additionally, we tested whether the capuchins select specific tools according to the size of the chelipeds of the crabs. Moreover, we verified whether the age class choose different tools.

Our first hypothesis is that (a) the heavier crabs are most often consumed with tool use. Thus, we predicted the weight is a variable that correlates positively with the growth and development of the crab and the greater crabs have exoskeleton with greater hardness, which would imply the need for the use of tools. The second hypothesis proposes that (b) the use of tools is more frequent in adults than in other age groups. So, we predict that adults have greater strength, greater ability and, therefore, greater experience for the breaking activity. This study brings new insights into the ecological and evolutionary context of the use of tools by *Sapajus libidinosus*.

Methods

Study Site

We conducted the study in the mangroves of Preguiças River, on the north coast of Brazil, in the State of Maranhão (2° 37'21.7 "S, 42 ° 41'18.5" W). In the north/ northeast margin of the river, the mangroves are limited by moving dunes that fill with sand the mangrove and the river. Thus, the sand in the area causes several natural fragments of mangrove of different sizes (Santos *et al.* 2018). One of these fragments called Morro do Boi (Fig.1) that has 33 hectares (personal communication, Stuart Hamilton) is inhabited by several groups of capuchin monkeys. The monkeys living on the river Preguiças do not have contact with the populations of cerrado and caatinga (Santos and Bridgeman, 2018).

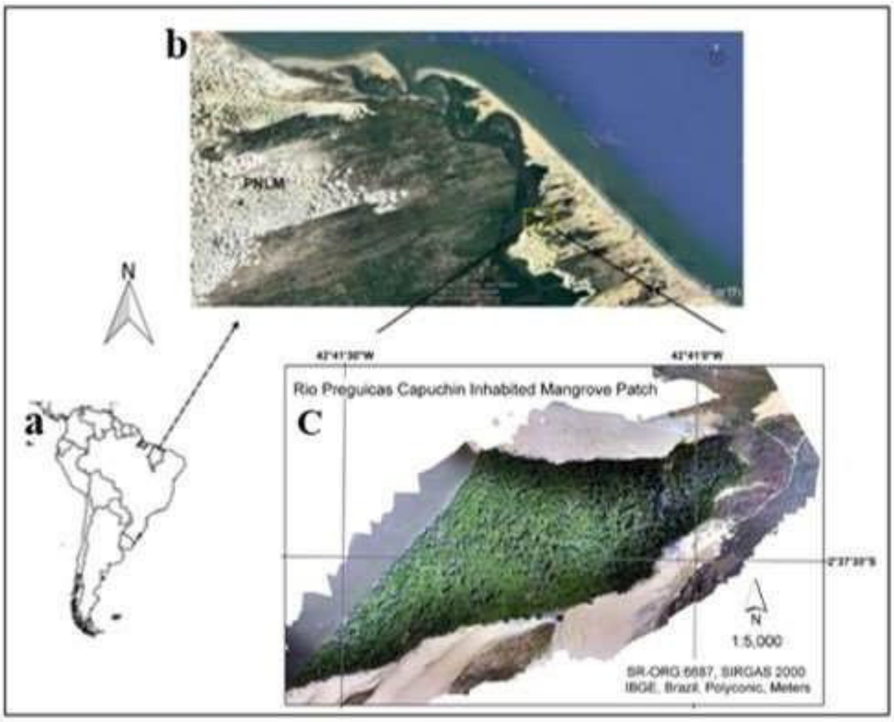

Fig. 1 Study site. **a** South America. **b** Preguiças River Estuary, on the north/ northwest side is the Lençóis Maranhenses National Park. **c** Mangrove fragment of Morro do Boi. Credit: Stuart Hamilton.

Subjects

The study group is composed of approximately 60 wild individuals of *Sapajus libidinosus* (Santos and Bridgeman, 2018). In our study, 16 animals participated in the experimental sessions (Table 1). For all individuals, the age in months was not known, so the subjects were categorized into three age groups according to their morphological characteristics (size and appearance) and adult females were identified according to the reproductive stage (Fragaszy *et al*. 2010a, Spagnoletti *et al*. 2011). Juveniles capuchin monkeys have a smaller body size and lack of tufts, the subadults show the beginning of tufts formation and the darkening of the head. Adults have a well-developed tuft and a more robust body than the others (Fig. 2).

Table 1 Different sex-age classes of *Sapajus libidinosus* who participated in the experimental sessions in the mangrove Morro do Boi, in Barreirinhas, Maranhão.

Name of Individual	Age	Sex
Claudinho	Adult	Male
Zeca	Adult	Male
Zorro	Adult	Male
Barbudo	Adult	Male
Zangada	Adult	Female
Gracinha	Adult	Female
Maya	Subadult	Female
Gabriel	Subadult	Male
Precioso	Subadult	Male
Daniel	Juvenile	Male
Dingo	Juvenile	Male
Júnior	Juvenile	Female
Pitomba	Juvenile	Female
Manny	Juvenile	Male
Arisco	Juvenile	Male
Kipper	Infant	Not identified

Fig. 2 *Sapajus libidinosus* in mangrove. **a** Juvenile male. **b** Adult male.

Data Collection

We put platforms on roots of *Rhizophora mangle* at a height of 1m from the ground. Each platform consisted of a $1m^2$ wooden pallet. In the feeding platforms we placed adult-living specimens of mangrove crabs *Ucides cordatus* (Linnaeus, 1763) collected in the region, being a species abundantly consumed by capuchin monkeys with the use of tools in our study area (Santos *et al.* 2018).

The habituation of the animals to the feeding platforms and to the presence the researchers, as well as the individual identification of the animals, were performed prior to the behavioral data collection. In the months of February and March 2017, two initial pilot tests were carried out for a total of 12 days. Three feeding platforms were provisioned with crabs and bananas for successive times, in order to habituate the animals to the experimental area (adapted from Santos, 2010; Garber *et al.* 2012). We carried more pilot tests from April to August for a total of 41 days of observation. The experimental sessions in this stage were performed only with the provision of one crab for each of the four platforms simultaneously instead of three platforms. Besides, we provide wood artificial tools of different weights and sizes. During these pilot tests (53 days in total) the experiments were conducted both in the morning (6:00-11:30 a.m.) and/or afternoon (2:00-5:30 p.m.) and methodological adjustments were made to the numbers of tools, platforms and tool weights.

From the end of August 2017 to January 2018 we conducted 84 experimental sessions during 39 field days using five platforms. In each experimental session, each platform (Fig.3a) was simultaneously provisioned with a crab (Fig. 3b) and three breaking tools of different weights (Fig. 3c).

Fig. 3 Experiment. **a** Feeding platform; **b** Crab tied on the platform; **c** Tools with your ID number.

To reduce the influence of the social hierarchy in the access to the platforms, these were arranged with a minimum distance of 11 meters, according to the spatial configuration of *Rhizophora mangle* trees (Fig. 4). In addition, the area of the experiment was kept clean at 15m radius by removing all mangrove wood that could be used as a tool by animals.

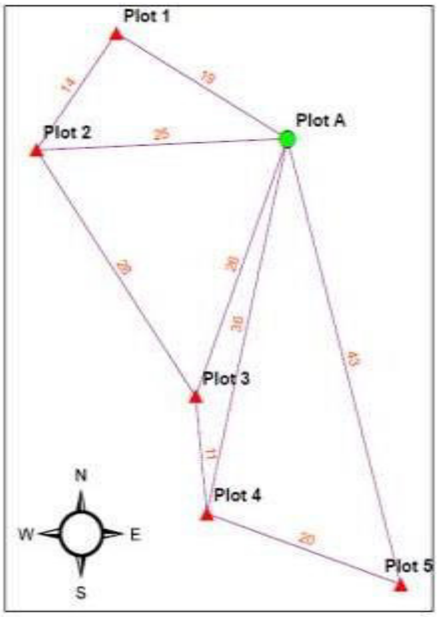

Fig 4. Location and distances (m) of the platforms. Plots 1, 2, 3, 4 and 5 represent the five platforms and plot A represents the starting point of observation.

The experimental sessions were carried out in the morning (from 6:15 a.m.) and in the afternoon (starting at 2:30 p.m.). The number of sessions ranged from one to four per day, which was set according to weather and tide conditions. On average, two sessions per day were performed. The minimum time interval from one session to another was one hour.

The selection of the crabs for each platform was performed randomly. The first crab taken from inside the storage cage (Tomawalk cages) was the first to be weighed, marked and placed on the first platform, and so on. The crabs were weighed with pesola® medium-line spring scale (accuracy of 20g) and the length measures of the chelipeds (claws) with millimeter tape (supplementary material, Table 1).

We made the marking and differentiation of the crabs with TNT (Nonwoven Fabric) tapes of standardized colors and tied to the chelipeds. Identification of the crabs us to differentiated when the animals accessed and transported crabs between feeding platforms. Thus, each platform received the crab with the standard color: platform 1 (blue), platform 2 (green), platform 3 (yellow), platform 4 (red) and platform 5 (orange).

To simulate the natural condition in which the crabs are caught by the capuchin monkeys, the crabs were covered with a layer of the mud soil removed from the site. They were then tied lightly to the platform with crochet hooks wrapped around the cephalothorax to allow removal of the crab by the monkey.

We make 15 wooden tools of the trumpet-tree, *Tabebuia* spp. (Bignoniacea), with weights between 40 - 600 g and 40 g weight intervals, standard circumference of 10 cm and length of 8.30 - 79.00 cm. The variation of the weights followed Santos (2010) and Cutrim (2013), who recorded the use of mangrove tools with weights ranging from 25-1598 g. The 40 g interval between the tools and the maximum weight of 600 g was an adaptation acquired during the pilot tests and also followed Santos (2010). In the pilot test, we observed that the wood artificial tools that had higher weights corresponding to 600 g and circumference equal to 16 cm were rarely used and handled with difficulties by capuchin monkeys.

The tools were previously numbered to enable their identification during the records (Table 2) and, were distributed randomly between the platforms always organized from lowest to highest according to raffle.

Table 2 Artificial tool metrics

Nº	Tool weight (g)	Tool lenght (cm)
1	40	8.30
2	80	13.00
3	120	20.00
4	160	20.40
5	200	26.60
6	240	29.90
7	280	34.00
8	320	42.50
9	360	47.50
10	400	49.50
11	440	51.00
12	480	53.50
13	520	57.50
14	560	70.50
15	600	79.00

We used animal focal sampling to record feeding behaviors (Altmann, 1974). The session started when at least one animal reached the platform and accessed the crab and finished when the feeding bouts ended. The beginning of each session was signaled by the sound of a whistle in order to increase the probability of access to the platforms by the different animals dispersed in the area. The observations were recorded using a Sony Dsc Hx1 Semiprofissional® camera, 4 cameras with a remote device (three camera traps (Tigrinus and one GoPro Hero 4®), which were fixed close to the platforms (supplementary material).

Video Data Analysis

During each feeding bouts, we verified whether the same individual: (1) accessed more than one crab, (2) used a single tool to break more than one crab, and (3) used more than one tool to break the same crab (secondary and tertiary tool use). In addition, we counted the sequence of individuals who accessed the same crab, which was classified as "second accesses".

For each experimental session, we recorded which individuals accessed the crabs on the platforms, the age group (infant, juvenile, subadult or adult), the ID tools used in the breaking process, and the crab structures that were broken and consumed by the animals. Finally, we describe details of feeding behavior of the capuchin monkeys used to eat each structure of the crab.

Statistical Analysis

For the analysis of weight of the crabs associated to the weight of the tools, we performed the tests, first, with all obtained weights and then we categorize the weights of the crabs in three classes (smaller, medium and larger). Thus, the 15 weights were organized as group 1- smaller crabs (80-90-100-110-120 g), group 2 – medium crabs (130-140-150-160-170 g) and group 3 – larger crabs (180-190-200-210-220 g).

To verify that heavier crabs are most often consumed with the use of tools, we used the Mann-Whitney test. To analyze if the weight of the crabs is related to the lenght of the chelipeds, if the weight of the crabs is related to the weight of the tools, and if the lenght of cheliped is related to the weight of the tools, we used the Spearman correlation test. To verify if there are differences in the weight classes of crabs consumed with tools, we performed the Kruskal-Wallis test. To test whether there were significant statistical differences between the use of tools and the different age groups, the Kruskal-Wallis test was used. The statistical significance for all tests was evaluated at the level of $\alpha = 0.05$. For statistical analysis, we use Software R version 3.4.2 (R Core Team, 2016).

Data availability

The datasets analyzed during the current study are available at https://moar.salisbury.edu

Ethical Note

The research followed protocols approved by the Committee of Ethics in the Use of Animals of the Federal University of Maranhão, Brazil (Record No. 23115.009218 / 2016-11). We obtained permission to collect crustaceans from the State Office of Environment and Natural Resources of the State of Maranhão, Brazil (Authorization Number 23/2016).

Results

Frequency of tool use in the feeding bouts

Experimental sessions (*N* = 84) totaled 2,901 minutes of filming over 39 days. The tools were used by eight individuals (Table 3). For two individuals of the group, it was not possible to identify the crabs ID consumed with tools. The episodes with tool use occurred in 32.6% (*N* = 93) of the 285 feeding bouts (in average 3.4 episodes per session). Of the 420 crabs in the 84 experimental sessions, we observe 256 crabs consumption, which contributed to the complete feeding bouts. That is, individuals, crabs, and manipulated tools were identified.

Table 3 Frequency of participants.

Name of individual	Age	Sex	Nº of episodes with tool use	Nº of episodes of participation in the sessions	Relative frequency of tool use by participant episodes
Claudinho	Adult	Male	8	80	10.00
Zeca	Adult	Male	1	1	100.00
Zorro	Adult	Male	36	60	21.00
Gracinha	Adult	Female	1	1	100.00
Gabriel	Subadult	Male	40	100	40.00
Precioso	Subadult	Male	7	8	85.71
Daniel	Juvenile	Male	0	30	0
Maya	Subadult	Female	0	1	0
Júnior	Juvenile	Male	0	1	0
Manny	Juvenile	Male	0	1	0
Arisco	Juvenile	Male	0	1	0
Barbudo*	Adulta	Male	1	3	0
Zangada*	Adult	Female	2	4	0
Dingo**	Juvenile	Male	0	4	0
Pitomba**	Juvenile	Female	0	3	0
Kipper**	Infant	Not identified	0	2	0

*Monkeys that used tools, but it was not possible to identify the tool or the crab.

** Monkeys that ate the rest of the crabs left by other individuals.

In these observations there were 16 episodes in which the same crab was accessed by more than one monkey (second access), and in 13 episodes the same monkey used different tools to break the same crab, consisting of the (secondary or tertiary use of tools).

For 164 remaining crabs available on the platforms, 14 were not accessed by any monkeys and 150 were accessed by individual/s who fed giving their backs to the researchers, in the mangrove canopy, behind roots, branches, and trunks, or left the experimental area.

Weights of crabs consumed with and without tools

We recorded 17 different weights for the crabs provided during the feeding records (N = 256). Of these 256, there was no use of tools for the minimum and maximum weight, 70 g (N = 2) and 240 g (N = 6) respectively. Tool use was more frequent for crabs of 140 g (N = 21) (Fig. 5). For feeding bouts, mean weights of crabs consumed without tools were 142.45 g ± SD = 39.35 g (N = 192) and with tool use was 146.45 g ± SD = 34.88 g (N = 93). The median of the weights for the two types of consumption is equal to 140 g.

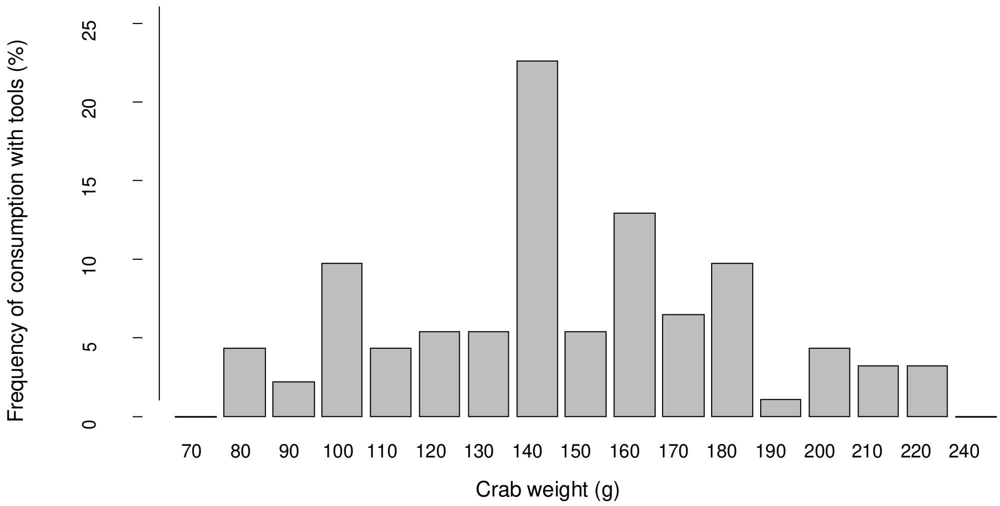

Fig. 5 Frequency of use of tools according to the weight gradient found in crabs.

There were no differences between the weight of the crabs consumed with tools and without tools (Wilcoxon Mann-Whitney: $U = 8169$, $P = 0.24$, $N_{\text{consumption with use}} = 93$, $N_{\text{consumption without use}} = 192$), including second access episodes (N= 16) and episodes of secondary and tertiary uses for the same tool (N = 13). In addition, tool use did not differ even when considering the three weight classes of crabs (Kruskal-Wallis: $H = 1.04$, df = 2, P = 0.59, N = 93) (Fig 6).

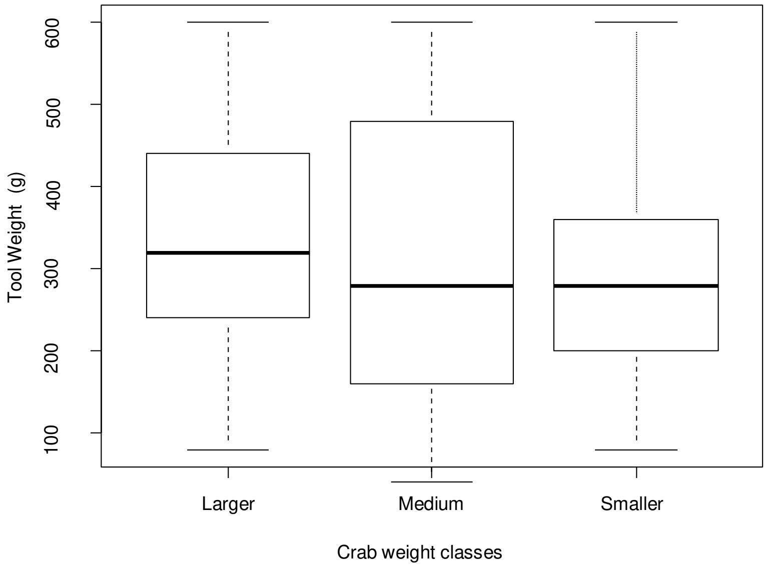

Fig. 6 Weight of the tools associated with the three weight classes of the crabs: smaller (80-120g), medium (130-170g) and larger (180-220g).

All 15 tools were used for cracking crabs. The weights that presented the highest frequencies of consumption per crab were of tools 9 and 7, respectively (Fig. 7).

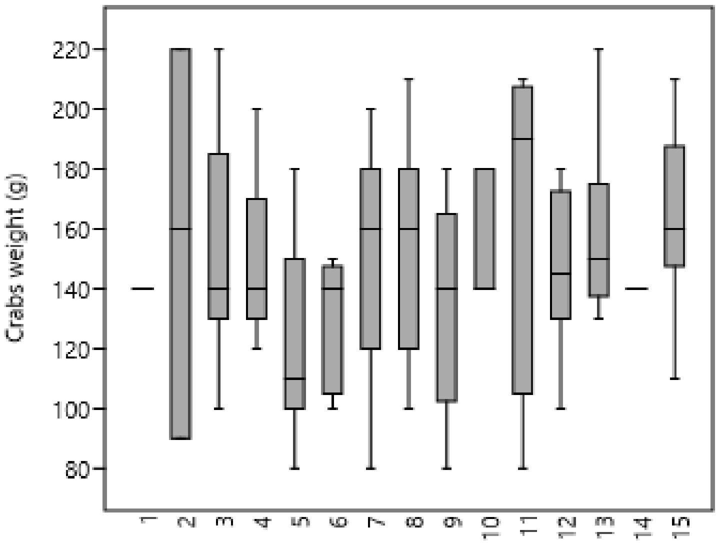

Fig. 7 Median weights of crabs per tool (1-15).

Structures of the crabs consumed

To access the meat of the crab, the animals used tools to break down the different structures of the exoskeleton of the crabs: only chelipeds, 61% (*N* = 57) (Fig. 8); only pereopods 3% (*N* = 3); only abdomen 2% (*N* = 2), and episodes where two structures were simultaneously broken: chelipeds / pereopods 23% ($N = 21$) and chelipeds / abdomen 1% ($N = 1$). In 10% ($N = 9$) of the episodes, we were not able to identify the structure consumed with tool because the crabs was out of sight due to the animal position. The feeding behavior observed in capuchins monkey was described separately for each structure, including, cephalothorax, pereopods and cheliped (see Table 4).

Fig. 8 Consumption of crab meat using tools by Gabriel, a subadult (*Sapajus libidinosus*) in mangrove in Preguiças River, State of Maranhão, Brazil (indicated by the arrow). **a** Cheliped positioned to be broken with the tool (yellow arrow). **b** Gabriel moving tool 5 to break the cheliped. Anvil (blue arrow) is a *Rhizophora mangle* stem projection (called aerial root) located close to platform (green arrow).

Table 4 Feeding behavior of *Sapajus libidinosus* during crab consumption in the Preguiças River mangrove, Maranhão, Brazil.

Structure consumed	Cracking behavior without using tool	Feeding behavior
Cephalothorax (Carapace)	With one or both hands, the capuchin holds the crab in the dorsal back and hits the abdomen of the crab in the anvil. The beats disarticulate the appendages and lead it to partial or total immobility of the locomotor limbs. With the hands or teeth, the subject separates the cephalothorax from the abdomen, exposing the internal contents.	From the carapace, the animal remove the meat with one of the hands and taken it to the mouth and/or taken the carapace with meat directly to the mouth. The meat on the abdomen is removed by hand and brought to the mouth and/or taken directly to the mouth.
Pereopods (walking legs)	After separating a pereopod from crab's body, the subject disarticulates it at different points of articulation with both hands, with or without the aid of beats on the anvil. After it, capuchin breaks the pereopods with the teeth, and/or with the hands, through the beat on an anvil, and/or after the structure is positioned on an anvil, the crabs suffer blows with one hand. The distal portion containing the nail is discarded.	The meat's pereopod is removed with the fingers and brought to the mouth, and/or the pereopod is taken directly into the mouth to eat the meat". So, only soft content is eaten.
Cheliped (claws)	After separating one of the chelipeds from the crab's body, the capuchin disarticulates the cheliped with both hands in one or more parts, with or without the aid of beats on the anvil (here is called disarticulation beats). After it, the subject breaks each part with the teeth and/or beating on it in the anvil with the left or right hand, but never holding with both at the same time.	The meat is removed with the hands and brought to the mouth, and/or brought to the mouth still inside the cheliped. The capuchin licks the meat that remains on the anvil and in the different parts of the crabs.

Behavior with tool use
After placing a crab or a crab's structure on an anvil, the animal holds the tool with both hands, lifts the tool and strikes the structure until it cracks, partially or totally cracks. Capuchin have the same feeding behavior as describe above for each structure consumed.

The part of the crab most consumed with tools was the cheliped (74% of records), followed by pereopods (23% of records), and abdomen (3% of records). The right chelipeds had an average length of 10.31 ± SD = 2.10 cm (*N* = 52) and the left ones of 11.30 ± SD = 2.07 cm (*N* = 52). There was a positive correlation between the weight of the crabs consumed with tools with the lengths of the rights cheliped (Spearman: rs = 0.324, *P* = 0.009, *N* = 52) and with the length of the lefts cheliped (rs = 0.678, *P* <0.0001, *N* = 52). There was not a significant correlation between tool weight and cheliped lenght (right chelipeds: rs = 0.07, *P* = 0.62, *N* = 52 and chelipeds on the left side: rs = 0.22, *P* = 0.11, *N* = 52).

Tool use in different age class of capuchin monkeys

Adults compose 50% (*N* =144) of the feeding bouts, subadults 38% (*N* = 108), and juveniles 12% (*N* = 33). In the episodes using tools, the adult's monkeys represent 49.5% (*N* = 46), and subadults 50.5% (*N* = 47). However, we did not observe use of tools for the juvenile individuals. We found significant differences between tool weights used by subadults and adults (Mann-Whitney test: *U* = 1501, *P* = 0.001), with the latter using heavier tools with the median equal to 360 g and the median for subadults equal to 240 g.

In 128 feeding bouts (45% of total) monkeys accessed two or more crabs. In episodes with use of tools (*N* = 93) we observed the use of the same tool (*N* = 9) for the breaking of two crabs, and in one session, a single tool for the breaking of three crabs, totalizing 21 crabs with the minimum weight of 80 g and the maximum weight of 200 g. The largest weight range between two crabs in these cases was equivalent to 100 g and the lowest was equal to zero, that is, the same tool was used to break two crabs with equal weights. In addition, in 11 episodes, a single crab was broken by a second tool and in two episodes in which a single crab was broken by three different tools. In five episodes, the first tool was replaced by another tool of lesser weight, and in seven episodes, the second tool presented greater weight than the first one. In the latter case, the second tool was replaced by a third heavier tool and in another episode, the second tool was replaced by a lighter tool.

The episodes characterized by a second individual accessing a crab previously abandoned in the same experimental session by another subject totaled 5% with 4 episodes for juveniles, 7 for subadults and 5 for adults. In 56% (N = 9) of the second access episodes, tool use occurred.

Discussion

Our findings may indicate that Preguiças river mangrove monkeys may be selective during the feeding of crab with tools. However, contrary to our first hypothesis, the monkeys did not use tools according to the weight of the crab. We expected bearded capuchins to use tools more often on heavier crabs. Thus, the use of tools in mangroves seems to occur in an optional manner, since in 67% of the episodes, the consumption was carried out without the use of artificial tools, using only the hands to beat the crab on the wooden anvils. There are records of the use of natural tools (fallen trunks and roots of *Rhizophora mangle)* in the mangrove that also indicate that the use of tools by capuchin monkeys is not a necessary condition to consume the crabs (Santos *et al.* 2018).

Our results demonstrate that tools with average weights represented the bulk of eating episodes (53%). In addition, they suggest a wide variation in choosing these tools for medium weights crabs. However, in an experimental study with pairs of tool choices, capuchin monkeys in the caatinga selected heavier tools and less resistant fruits such as tucum (*Astrocaryum campestre*) supposedly by reducing the effort and time required to break more resistant fruits such as piaçava (*Orbignya* spp.) (Fragaszy *et al.* 2010b).

In the experiment conducted by Fragaszy et al. (2010b), the preference was evaluated for two types of fruits with different hardness: tucum and piaçava. In our study, the use of tools is attributed to a food that presents biometric variations that can cause the use or not of the tools. Our hypothesis suggested that the tools are selected to break the heavier crabs. According to Luncz et al. (2016), the monkeys made adjustments in their tool selection based on the different maturation stages of the cashew fruits (*Anacardium* spp.) when using different stone weights to break fresh or dried nuts. This may suggest a tool selection adjustment within the range of weights of the crabs according to the stage of development since an older crab will have a larger size, larger weight and probably a higher degree of resistance. Thus, the different stages of development of the crab can lead to the use of tools of different weights. Probably the size of the adult crab does not change significantly, but the hardness of the parts does.

In the caatinga, it was observed that the weight of the stone tools present in the breaking sites varied according to the type of fruit cracked at the breaking sites (Ferreira *et al.* 2010). The average weights of the tools for *Attalea* spp. in the FBV was 1,096 g (Visalberghi *et al*. 2007, and in the caatinga was 1.414 g (Ferreira *et al*. 2010). In the mangrove, the average weight of the wood tools for cracking crab were 515 ± 100 g, and 452 g (Santos, 2010; Cutrim, 2013).

More specifically, heavier tools were associated to larger and heavier crab structures, and not the whole animal weight. We verified that the breaking activity is done separately in the different structures of crab, with tool use occurring most frequently in the breaking of chelipeds for meat consumption. This structure have greater breaking resistance than the other structures. The chelipeds make up approximately 40% of the total wet weight in the male crabs (Pinheiro *et al.* 2015) and should provide a higher energy return compared to that of other parts of the crab body.

Chelipeds were also the most frequently consumed part of the crabs open with the help of tools in macaques in Thailand. In this case, the tools used to extract the meat of mollusks and crustaceans were composed of stones and shells. In Thailand the study area is composed of 66% rocky shore, 29% mangrove and 5% sandy beach. The macaques used stones as tools in the rocky shore and mangrove intertidal regions. In contrast to Thailand the mangroves of the Preguiças river do not have any rocks, so the capuchins monkeys use wood as tools instead (Gumert and Malaivijitnond, 2012).

The use of tools in mangrove was restricted to adults and subadults. Although in the caatinga, youngsters, despite less frequently and having fewer successes, manipulate the tools for fruit breakage (Spagnoletti *et al.* 2011). In feeding bouts, the juveniles ate whole crabs and/or also just the structures of the crabs left by other individuals of the group. In all episodes, the juvenile Daniel did not try to use the tool, as opposed to Junior who tried to use a tool but without success. These two individuals were almost reaching the subadult phase, and the juveniles Arisco and Manny have recently left the infancy stage. As in FBV (Eshchar *et al.* 2016), mangrove monkey infants interact with potential tools and food items years before they begin using the tools successfully. Accordingly, several years are needed for young monkeys to become efficient tool users (Resende *et al.* 2014). In our study, the individual named Manny took the tools from the platforms and used it to pound on different surfaces but never use it on food (supplementary material).

In the caatinga of northeastern Brazil, juveniles seemed more interested in observing the behavior of adults during the use of tools instead of taking advantage of any opportunity to manipulate food and tools (Mannu and Ottoni 2009), similarly to what we observed. This may be explained by evidence that competencies in cognitively demanding tasks may develop relatively late in the juvenile period (Chalk-Wilayto *et al.* 2016).

Since the use of tools in the mangrove may be optional, adult monkeys may be more selective about which crabs may to using tools. In relation to the mandatory use of tools for fruits, it was observed by Luncz *et al.* (2016) that although fresh cashew nuts are on average larger than the dried ones, the tools are not necessary to open the soft external mesocarp of chestnuts cashews, and thus the capuchin monkeys choose to use their hands and teeth instead of tools to eat the food.

Regarding sexual difference in our study, only two females participated in the experiments but only one used tool. For the unique record of participation of the subadult Maya, the use of tools was not observed. However, for the incomplete episodes, we recorded tool use for two other adults, one male and one female, but it was not possible to relate the use to the weight of the consumed crabs. In this study, females did not have "priority" access to platform resources, and consumption of crabs or parts of them occurred in a secondary way, as did other individuals in the group. The sexual dimorphism in body size between males and females can determine differences in efficiency in tool use (Spagnoletti *et al.* 2011). However, the body weight of male capuchin monkeys predicts greater efficiency in the use of tools, since subadults, as well as adult females, have a smaller size and body weight than adults (Fragaszy *et al.* 2010a).

In the episodes in which a secondary access occurred the subjects were mostly Gabriel and Precioso. Most often, the first capuchin who accessed the platforms were individuals most habituated with the researchers. This is because before starting the experiments, these subjects were frequently already in the experimental area. Gabriel, a subadult, and Claudinho, an adult, were the two individuals with the highest participation in experiments with 100 and 80 episodes, respectively. Even when controlling for subject identity we still have significance for some results. Gabriel was the first to be habituated to the platforms and researchers, which may have influenced his greater participation of the feeding bouts.

Besides the variable (weight) of the crab interfere in the use or non-use of tools, we can mention an odd case of an individual of the group, the subadult Precioso, who in the 85% of the episodes used tools. The high frequency of use by him can be attributed to a deficiency in the right hand (middle fingers and index finger were inflexible) that he probably acquired in some accident or fighting with other individuals.

In episodes where a single crab was consumed with more than one tool, we can infer that the subject probably made tests on his choices. This was observed in two situations: first, after the subject picked up a tool and left it without using it, then the animal selected another tool to perform the beats; second, after the subject performed beats with the first tool, he also selected another tool to continue breaking the crab. In another study on tool selection, the capuchin monkey have always used the stone they first chose and never modified their initial choice after the first beating (Visalberghi *et al.* 2009).

There are many environmental differences in the caatinga and cerrado. However, it is unlikely that these are responsible for all the observed behavioral variation, because these population differences may constitute the outcome of distinct social traditions (Mannu and Ottoni 2009). The coastal region of Thailand and the mangroves of the Preguiças River are also different environment, and shelter species of different primates who use different tools.

The behaviors observed in Preguiças mangrove monkeys suggest that although the use of tools seems to be optional, monkeys tend to prefer to use tools more often for medium-sized crabs. Although we did not find a positive correlation between tool and crab weights, and they don’t select crabs according to tool weights, we observed that the median weights of crabs consumed with the most commonly used tools were higher than the medians of the tools with smaller and medium weights, corresponding to 160 g. The medians for lighter tools were equal to 140 g. Thus, we infer that monkeys tend to use heavier tools in larger crabs, and this is also linked to the more frequent use of tools in the chelipeds that are the toughest parts of the crab's body. In addition, in relation to age group, our results indicated that adult individuals tend to use heavier tools than subadults, evidencing that individuals with higher body weight as adults present greater strength and abilities in fracture activity than individuals of smaller body size. This finding may indicate that the monkeys of the mangrove select tools of different weights according to their capacity of use.

This new scenario for the use of tools by *Sapajus libidinosus* in mangrove-living groups opens doors to other comparative analyzes of the use of tools. In addition, to increasing the tool kit set by this species, such as stones and rods, this study provides a new insight into a feeding behavior based on the capture of a mangrove prey. This raises our questions about the ecological events that instigated the use of tools by capuchin to consume crabs in the mangrove. Thus, future investigations directed to the resistance of the chelipeds in relation to the other parts of the body of the crabs are necessary, as well as, an energy efficiency analysis will respond if the use of tools in these structures occurs according to the weights and sizes of the crabs. Instead, monkeys in using tools appear to increase the efficiency of consuming crabs and/or expand their diet (Santos *et al.* 2018).

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CONSIDERAÇÕES FINAIS

Este trabalho propôs investigar o uso de ferramentas em macacos-prego que vivem nos manguezais do Maranhão. Assim, verificamos se os animais selecionam ferramentas de madeira de mangue para quebrar caranguejos mais pesados, e se a escolha das ferramentas está associada aos tamanhos dos quelípodos (pinças) do caranguejo. Além disso, averiguamos se os macacos adultos usam ferramentas mais frequentemente que subadultos e jovens. Nossos resultados parecem não corroborar a hipótese de que as ferramentas são usadas mais frequentemente em caranguejos mais pesados. Entretanto, observamos que as ferramentas foram usadas especialmente nos quelípodos e não sobre o caranguejo inteiro. O quelípede foi a estrutura mais consumida com ferramentas. Observamos que os indivíduos adultos usaram ferramentas mais pesadas do que indivíduos subadultos, corroborando a hipótese de que os adultos podem apresentar maior força, e por serem mais experientes, são mais habilidosos durante a atividade de quebra. Porém, nos indivíduos jovens não observamos o uso de ferramentas. Os resultados deste trabalho expandem o conhecimento sobre uso de ferramentas em macacos-prego que até então são mais conhecidos por usarem ferramentas de pedras em ambientes de terra firme como o cerrado e a caatinga para quebrar frutos de palmeira. Nossas descobertas sugerem a continuação de novos estudos complementares nos manguezais do rio Preguiças, pois estes resultados preliminares apresentam indícios que de que os macacos-prego possam ser seletivos durante o uso de ferramentas para o consumo de carne, visto que, observamos que o uso de ferramentas para caranguejos no manguezal foi facultativo.