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An ignored role of *sartenejas* to mitigate water shortage hazards for tropical forest vertebrates

Water availability is a key limiting resource for vertebrates (Hayward and Hayward 2012). Even in tropical ecosystems supporting lush vegetation, water exists in forms not easily exploited by the local fauna (Krügel and Richter 1995; Ferrari and Hilário 2012). For example, tropical seasonal forests growing on karst landscapes in the Yucatan Peninsula of Mexico lack flowing rivers or extensive water bodies on the surface (García-Gil et al. 2002). However, it supports an extremely rich and abundant terrestrial vertebrate fauna (Calmé et al. 2015; Reyna-Hurtado et al. 2015). The capacity of this fauna to withstand the harsh environmental conditions imposed by water scarcity, particularly during the dry season, has traditionally been associated with natural waterholes, locally known as "*aguadas*" (O'Farrill et al. 2014). These *aguadas* form when rainfall accumulates in topographic depressions under sparse canopy cover (Torrecano-Valle and Folan 2015). There are approximately one *aguada* per 10.5 km^2 in the region. Although their size may range from less than a few square meters to several hectares, most of them occupy less than a half hectare (Reyna-Hurtado et al. 2012; O'Farrill et al. 2014). The majority of the *aguadas* dry out during the dry season that occurs between November and April (O'Farrill et al. 2014). The likelihood of the *aguadas* to dry out is determined, to a large extent, by their size and depth, which also affect their thermal and chemical stratification and primary productivity (Hodell et al. 2005).

While conducting field surveys to monitor wildlife in the 128,390-ha Bala'an K'aax Protected Area in the central region of the Yucatan Peninsula, Mexico (Appendix S2: Fig. S1), we set up camera-traps in nearby *aguadas* as well as in the vicinity of water accumulated in small crevices opened in the rocky floor. These crevices of small water deposits are known locally as *sartenejas* (Millspaugh 1896; Appendix S2: Fig. S2). Unexpectedly, we recorded a highly diverse faunal ensemble using water in the *sartenejas*. These *sartenejas* occurred beneath full canopy cover. There is not an estimate of the density of the *sartenejas*. Their estimated volume, calculated based on their length, width, six depth measurements, and the application of the half-ellipsoid formula, ranged between 11 and 79 L (SD $\pm$ 28; *personal observation*). The ecological

Fig. 1. Birds using water inside *sartenejas*. Top-left, a group of ocellated turkey drinking water; top-right, a great curassow mate using *sarteneja* water; bottom-left, a roadside hawk taking a bath into a *sarteneja*; bottom-right, a crested guan drinking water.

importance of *sartenejas* is completely unexplored. In fact, the scientific literature does not mention the importance that *sartenejas* have for wildlife. There is only one brief account of their use by white-lipped peccary herds (Reyna-Hurtado et al. 2012). Thus, our findings could change the notion of *aguadas* as constituting the primary source of water for wildlife in the Yucatan Peninsula, and help to generate new insights regarding those elements of the landscape that might be affecting habitat connectivity.

We set up twelve camera-traps in six *sartenejas* and six *aguadas*. Camera-traps were set at least 1 km apart, and were programmed to take one photo and a 30 s video every time they were activated. We identified the relative importance of *sartenejas* vs. *aguadas* as a source of water for medium-large terrestrial mammals and birds (heavier than 100 g). After reviewing 1021 camera-trap days (350 in *sartenejas* and 671 in *aguadas*) we documented the occurrence of 20 medium-large mammal species and 17 medium-large bird species. Remarkably, 30 of these species (16 mammals and 14 birds) occurred in the *sartenejas* whereas only 20 (15 mammals and five birds) were recorded at the *aguadas*. Species making use of the *sartenejas* included some at a high risk of extinction, both locally and globally (Appendix S2: Table S1), such as: tayra (*Eira barbara*), ocelot (*Leopardus pardalis*), Yucatan brown brocket deer (*Mazama pandora*), jaguar (*Panthera onca*), great curassow (*Crax rubra*), eastern thicket tinamou (*Crypturellus cinnamomeus*), ocellated turkey (*Melagris ocellata*), scaled pigeon (*Patagioenas speciosa*), crested guan (*Penelope purpurascens*), and great tinamou (*Tinamus major*) (Fig. 1). Some of these threatened species were only recorded in the *sartenejas* (Appendix S2: Table S1). Fauna had a clear differential use of *aguadas* and *sartenejas*: 17 of the recorded species in the *sartenejas* (five mammals and 12 birds) were not recorded at the *aguadas* (Bray-Curtis dissimilarity index: full data set of animal records = 0.528, data set of mammal records = 0.45, data set of bird records = 0.744). Moreover, animal species shared by the two water sources were more frequent in the *sartenejas* (Fig. 2). There is some chance that due to the fact cameras set in the *aguadas* were not able to monitor their entire surface, we were missing some animal visits but we do not have any evidence indicating this is having a major impact on our comparisons.

Some vertebrate species visited *sartenejas* briefly (ca. 1 min) while others stayed longer, such as jaguars, which spent an average of 4.5 min at each visit. We clearly documented water use for 23 (12 mammals and 11 birds) of the 30 recorded species at the *sartenejas* (Appendix S2: Table S1). The most common species using water from *sartenejas* were the grey fox (*Urocyon cinereoargenteus*), spotted paca (*Cuniculus paca*), and white-nosed coati (*Nasua narica*) but, species like the jaguar (Video S1), cougar (*Puma concolor*, Video S2), ocelot, and nine-banded armadillo (*Dasypus novemcinctus*) were also frequently recorded.

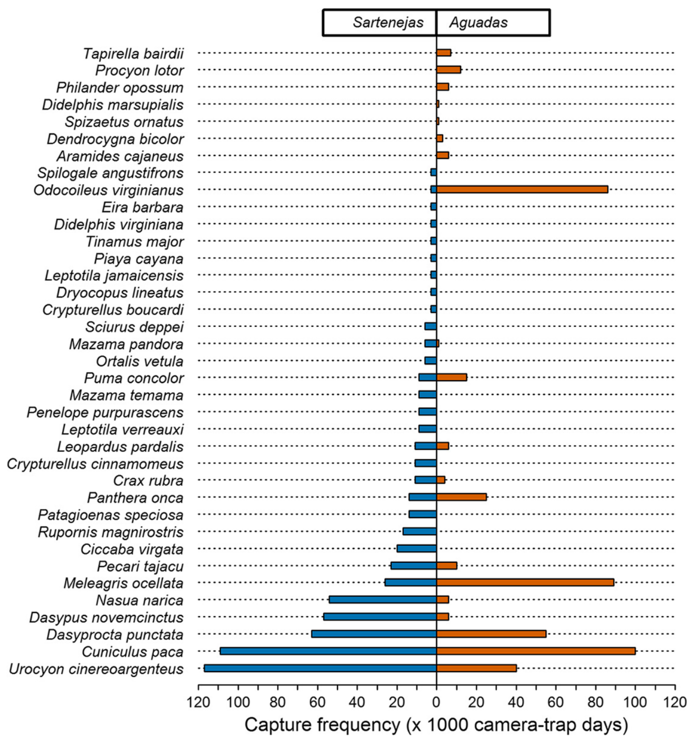

FIG. 2. Recorded species at *sartenejas* and *aguadas*. Capture frequency was derived from the total events of each species divided by sampling effort; we considered as independent events those records of the same species occurring with at least an hour of difference.

We were able to distinguish two main behaviors regarding the fauna's water use in the *sartenejas* (Appendix S2: Table S1). Twenty-three species (12 mammals and 11 birds) drank water from the *sartenejas* while seven species (four mammals and three birds) bathed in them. The most frequently recorded species bathing in the *sartenejas* were the nine-banded armadillo (Video S3), followed by the collared peccary (*Pecari tajacu*, Video S4), and the mottled owl (*Ciccaba virgata*).

Our observations reveal that *sartenejas* are a potential key resource for the local fauna both as a supply of drinkable water and as a probable tool for regulating body temperature by bathing. Remarkably, the *sartenejas* seem to provide a service to a somewhat disjunct set of fauna that do not frequent the *aguadas*. The distinct species composition between *sartenejas* and *aguadas* suggests that these two sources of water support two different faunal communities, perhaps because of the differences in canopy cover above them. More research is needed to generate a comprehensive view of the role *sartenejas* play to support wildlife populations in the Yucatan Peninsula.

Given the global climate change, it is urgent to know the ecological role of different vital resources for wildlife, such as water, in order to have better tools to mitigate its effects on biodiversity. In this sense, understanding water dynamics in tropical ecosystems is an essential topic in conservation biology (O'Farrill et al. 2014; Paredes et al. 2017). Our findings are of particular relevance due to the growing concern regarding the expected impact of climate change on water availability in the Yucatan Peninsula. Models suggest that temperature will increase and precipitation will be reduced in this region in the near future (O'Farrill et al. 2014). Pronounced dry seasons in the Yucatan Peninsula have already caused some *aguadas* to shrink or even to dry out (*personal observation*). If this trend persists, many animals may die from dehydration, especially those with large body sizes such as the tapir, white-lipped peccary, and jaguars (Knight 1995; Gandiwa et al. 2016). Even at milder levels of water scarcity could lead to greater negative intra and interspecific interactions among the fauna, and to increase metabolic costs (as animals face the need to move farther to find water supplies). Moreover, if animal incursions to human populated areas become more frequent, chances of human-fauna conflicts will likely increase (Hoare 1999). *Sartenejas* might play a key role to mitigate these negative impacts functioning as stepping stones to maintain landscape connectivity in the region by providing water to animals moving among major forest tracts in the Yucatan Peninsula (e.g., Sian Ka'an and Calakmul protected areas). Among those questions which need to be addressed are: (1) How are *sartenejas* distributed and what is its density throughout the forests in the Yucatan Peninsula? (2) How does water supply vary in the *sartenejas* along the year? (3) What relative benefits does the fauna obtain from *sartenejas* in comparison to *aguadas*? And (4) what are the direct and indirect impacts of human activities on the *sartenejas*' water supply? Addressing these questions will help to increase our understanding of the ecological relevance of *sartenejas* for wildlife in the Yucatan Peninsula, and their vulnerability to anthropogenic impacts. Moreover, research on these topics could provide the basis for designing sound management strategies to mitigate human impact on this resource, therefore helping to increase chance of persistence of medium and large vertebrates in this region.

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