Revisiting Camu-camu (*Myrciaria dubia*): Twenty-seven Years of Fruit Collection and Flooding at an Oxbow Lake in Peruvian Amazonia[1]

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Revisiting Camu-camu (*Myrciaria dubia*): Twenty-seven Years of Fruit Collection and Flooding at an Oxbow Lake in Peruvian Amazonia Camu-camu (*Myrciaria dubia* HBK McVaugh; Myrtaceae) is an important riparian species in the floodplain forests of Peruvian Amazonia, and its fruits have been harvested commercially for over 30 years. We examined the population impacts of intensive fruit collection on this species by remeasuring a 1,000 m^2 inventory transect that was established in 1984 in a dense stand of *M. dubia* along an oxbow lake. We found that regeneration rates had declined notably since the original survey, and that the number of *M. dubia* individuals had dropped from 693 to 161 genets. While this dramatic shift in population structure would appear to be caused by excessive fruit collection, the same decline in regeneration was noted for *Eugenia inundata* DC, an associated species of similar growth form and phenology that is not harvested. The life cycles of both species are closely tied to the rise and fall of the river. In addition to annual fruit collection, we suggest that the extreme hydrological events that have occurred in the Amazon Basin over the last few decades, as well as the successional development of the ox-box lake study site that has been slowly filling up with sediment, also play a role in the observed reduction in *M. dubia* numbers.

Revisitando camu-camu (*Myrciaria dubia*): Veinte y siete años de la recolección de frutos y la inundación en una cocha en la Amazonía peruana Camu-camu (*Myrciaria dubia* HBK McVaugh; Myrtaceae) es una especie importante en los bosques inundables de la de la Amazonía peruana, y sus frutas han sido cosechados comercialmente por más de 30 años. Examinamos el impacto de la cosecha intensiva de frutas en una población de esta especie por la re- medición de un transecto de inventario de 1,000 m^2 que fue establecido en 1984 en un área densa de *M. dubia* al lado de una cocha meandro. Encontramos que las tasas de de regeneración había disminuido notablemente desde la encuesta original, y que el número de individuos de M. dubia había caído de 693 a 161 ginetas. Aunque este cambio dramático en la estructura de la población parece estar causada por la excesiva recolección de frutas, la misma disminución de la regeneración se observó por *Eugenia inundata* DC, una especie asociada con forma similar de crecimiento y de fenología pero que no es cosechada. Los ciclos de vida de ambas especies están estrechamente ligados a la subida y bajada del río. Además de la colecta anual de frutas, sugerimos que los fenómenos hidrológicos extremos que se han ocurrido en la cuenca del Amazonas en los últimos decenios, así como el desarrollo sucesional de la cocha de estudio que se ha llenanda lentamente con sedimentos, también fueron responibles por parte de la reducción observada en los números de *M. dubia*.

Key Words: *Myrciaria dubia*, camu-camu, *Eugenia inundata*, non-timber forest product, wild harvest, oxbow lake, ethnobotany.

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Introduction

Although non-timber forest products (NTFPs) have been harvested on a subsistence basis by local communities for thousands of years, the growing commercialization and dramatic increases in harvest volume from many wild populations have led to concerns about overexploitation (Peres et al. 2003; SCBD 2001; Ticktin and Shackleton 2011). A recent review concluded that NTFP harvest appears to be both ecologically and economically sustainable in over 60% of studies globally and in over 80% of studies conducted in Latin America (Stanley et al. 2012). It is important to note, however, that few of these studies have actually quantified the long-term effects of NTFP harvest on a wild plant population. According to a review by Ticktin (2004), only about 10% of NTFP studies have monitored populations for more than three years, and over two-thirds of this research was conducted in two years or less.

Camu-camu (*Myrciaria dubia* HBK McVaugh) has been exploited from the flooded forests of Peruvian Amazonia for several decades, but, as with many NTFPs, there is little research on the long-term effects of commercial fruit collection. The species may be somewhat more resistant to the effects of harvesting because of the atypically high density of the populations that it forms (Peters et al. 1989), yet the persistent market demand for the fruit and the continual harvest of wild stands is worrisome (Penn 2004). To address this concern, the present study examines the effect of 27 years of fruit collection on a wild population of camu-camu in Peruvian Amazonia by resampling an inventory transect first measured in 1984.

Species Description and Use

Myrciaria dubia (Myrtaceae) is a shrub or small tree native to western Amazonia and a common component of riparian vegetation along the Napo, Nanay, Ucayali, Marañon, and Tigre rivers in Peruvian Amazonia (McVaugh 1963). Dense stands of *M. dubia* ("camu-camales") form along the banks of oxbow lakes and rivers in the region, and these associations provide a nursery habitat and an important food source for many fish species, including the commercially valuable tambaqui (*Colossoma macropomum*) (Araujo-Lima and Goulding 1997).

Camu-camu fruit has long been harvested for local use in juices, ice creams, liqueurs, and other products. Commercial interest in the species began to grow both nationally and internationally when the fruit was discovered to contain between 2.7–2.8 g of ascorbic acid per 100 g of pulp (Ferreyra 1971), one of the highest concentrations of vitamin C found in any plant. Since 1994, at least 500 mt of camu-camu pulp/year have been exported from the cities of Iquitos and Pucallpa, most of this material collected from wild populations (Penn 2004). In an attempt to increase supplies of the fruit in more convenient locations, the government of Peru launched the Programa Nacional de Camu Camu (PNCC) in 1996 to promote the domestication of *M. dubia*. Many of the PNCC plantings, however, were only marginally successful, and a significant quantity of camu-camu fruit is still harvested from wild populations (Penn 2006).

Methods

The study site was located near the village of Jenaro Herrera in a dense stand of *M. dubia* growing along the northern bank of Sahua Cocha, an 80 ha oxbow lake off the Ucayali River in the Department of Loreto, Peru (Fig. 1). The riparian vegetation around the lake is usually flooded for six to seven months each year. The original inventory on the site was conducted during low water levels in September 1984 using a series of ten contiguous 10 x 10 m plots (Peters & Hammond 1990). The height and basal diameter of all stems of all species were measured, and *M. dubia* stems were also classified as ramet or genet.

The 2011 transect was laid out in the same location along the oxbow lake (Fig. 1c, d) with the aid of the research assistant who had worked on the original survey. Water levels along the bank of the lake, however, were still ankle to waist deep at the time of this survey, and, as a result, all stems of all species over 1.0 m tall were identified and measured for diameter at a height of 1.0 m, rather than at the base of the plant. The basal diameter of a subsample of *M. dubia* plants was measured after water levels had dropped to determine the relationship between basal diameter and diameter at 1.0 m. Each stem was identified as genet or ramet depending on whether a connection between stems could be found at the base of the plant.

The density and size-class structure of *Eugenia inundata* DC (Myrtaceae) were recorded in both the 1984 and 2011 inventories. This species is a common associate of *M. dubia* in the floodplain

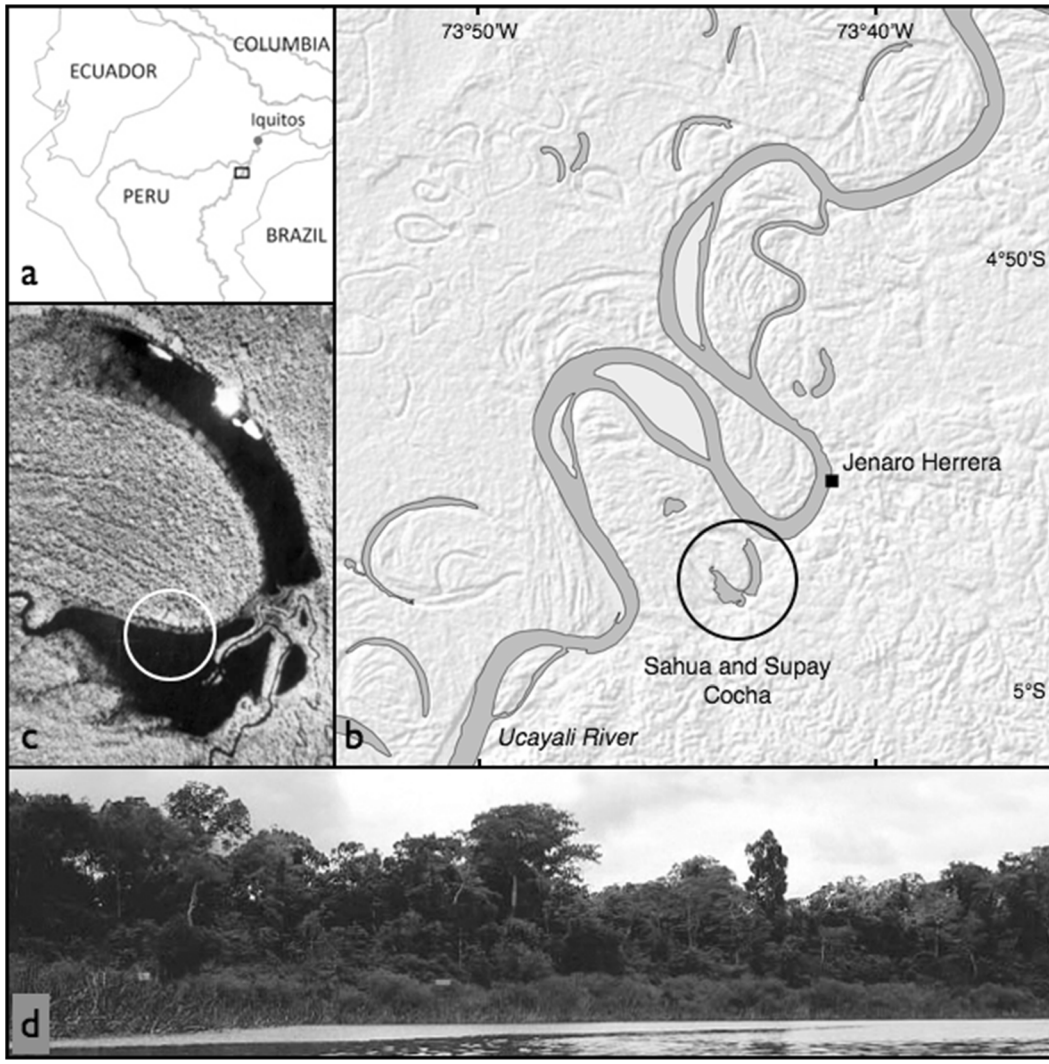

Fig. 1. Study site at Sahua Cocha in the Department of Loreto, Peru. **a**. geographic location of site, **b**: location of Sahua and Supay Cocha near town of Jenaro Herrera on the Ucayali River, **c**: aerial photo showing study site location and riparian vegetation along the northern bank of Sahua Cocha, and **d**: *Myrciaria dubia* population in 1984 during the initial inventory; transect was laid out between the two signs shown above the canopy.

forests of Peruvian Amazonia, is a member of the same botanical family, and exhibits a similar habit and growth phenology. The important difference is that the fruits of *E. inundata* are not harvested, and, as a result, the species offers a useful control for assessing the ecological impact of fruit collection.

We used the R statistical computing program (R Development Core Team 2010) for data analysis. To enable comparisons between the stem diameters measured at 1.0 m in 2012 and the basal diameters of original data set, we did linear regressions using data from 41 *M. dubia* stems and 11 *E. inundata* stems measured for both basal and 1.0 m high diameters. The 1.0 cm minimum diameter at 1.0 m high corresponded with a basal diameter of 1.6 cm for *M. dubia* and 1.5 cm for *E. inundata*, so all stems with basal diameter below these values were excluded from the 1984 dataset for comparisons.

Results

The density of *M. dubia* in the transect at Sahua Cocha decreased from 693 genets greater

than 1.6 cm basal diameter in 1984 to 161 genets in 2011 (Table 1); the density of *E. inundata* genets greater than 1.5 cm basal diameter decreased from 185 to 126 during this period. The number and density of associated species recorded in the inventory transect also declined. The mean number of ramets per genet, in contrast, increased for both *M. dubia* and *E. inundata* over the measurement period. This resulted in a small increase in total density of *M. dubia* ramets in the transect from 933 ramets in 1984 to 1052 ramets in 2011, and a doubling of the ramet density of *E. inundata* in the transect from 244 ramets in 1984 to 509 ramets in 2011.

We found significant linear relationships between the basal diameter and diameter at 1.0 m for both *M. dubia* (r^2 = 0.88, p <0.001) and *E. inundata* (Regression, r^2 = 0.99, p <0.001), enabling us to compare the basal area and the size-class distributions of these two species in 2011 to the 1984 dataset. In 1984, the size-class distributions for both *M. dubia* and *E. inundata* exhibited negative exponential curves. By 2011, the size-class distributions for both species shifted to a more bell-shaped curve, with few individuals in either the smallest or largest size-classes and the majority of stems in the middle size-classes (Fig. 2).

Because of the increase in the number of ramets/genet and the shift in size-class distribution toward larger individuals, the total basal area of both *M. dubia* and *E. inundata* increased in the transect from 1984 to 2011 (Table 1). The combined basal area of associated species declined notably from 730 cm^2 to 198 cm^2 (Table 1).

Discussion

There has been a sharp drop in the density of *M. dubia* at Sahua Cocha since 1984, particularly in the small size-classes. While the negative exponential distribution found in 1984 is commonly associated with successful regeneration (Leak 1965; Peters 1996), the bell-shaped distribution recorded in 2011 suggests a disruption in regeneration dynamics such that new seedlings are not replacing the older cohorts as they grow into larger size-classes. The *M. dubia* stems in the 3.0–5.0 cm size-classes represent a successful regeneration event at some time in the past, and, depending on the rate of diameter growth exhibited by the species, may even be the cohort of seedlings that was counted in the original survey. One likely cause of this decline in regeneration is the intensive harvest of camu-camu fruit from Sahua Cocha population. At the time of the original survey in 1984, collectors annually shipped 45.3 mt of camu-camu fruit from Jenaro Herrera to Iquitos (Peters, unpublished data). Intensive fruit extraction has continued since this time, with particularly large harvests from 1997–2001 when companies sent boats directly into the lake to purchase fruit, and in 2007, when both fruit yield and demand were atypically high and fruit exports totaled almost USD 5 million (Pinedo et al. 2010).

Commercial fruit harvesting, however, has nothing to do with the reduction in seedlings exhibited by the *Eugenia inundata* population. What other factors might be inhibiting the regeneration of riparian plants along the floodplain? The life cycles of *M. dubia* and *E. inundata* are intimately linked to the Amazon flood pulse, which is divided into a low water period (the terrestrial phase) and a high water period (the aquatic phase) (Junk et al. 1989). A longer terrestrial phase clearly gives riparian plants such as *M. dubia* and *E. inundata* a longer growing season, while collectors report that high flood levels in the aquatic phase trigger larger fruit sets.

Table 1. DENSITY AND BASAL AREA PER 1,000 m^2 OF *MYRCIARIA DUBIA*, *EUGENIA INUNDATA*, AND ASSOCIATED SPECIES IN THE ORIGINAL 1984 SURVEY AND THE 2011 SURVEY. ALL CALCULATIONS INCLUDE ONLY INDIVIDUALS WITH BASAL DIAMETER >1.6 cm FOR *M. DUBIA* AND >1.5 FOR *E. INUNDATA* (CORRESPONDING TO THE 1.0 cm DIAMETER AT 1.0 m HIGH MINIMUM MEASURED IN 2011). THE ASSOCIATED SPECIES DENSITIES AND BASAL AREAS ARE BASED ON 12 RECORDED SPECIES IN 1984 AND 8 RECORDED SPECIES IN 2011.

	Myrciaria dubia		*Eugenia inundata*		Associated species	
	1984	2011	1984	2011	1984	2011
Genets/1,000 m^2	693	161	185	126	66	21
Ramets/1,000 m^2	933	1052	244	529	-	-
Mean ramets/genet	2.2	6.6	1.3	4.2	-	-
Basal area (cm^2)/1,000 m^2	7,898.3	19,063.3	2,311.5	2,580.9	730.9	198.0

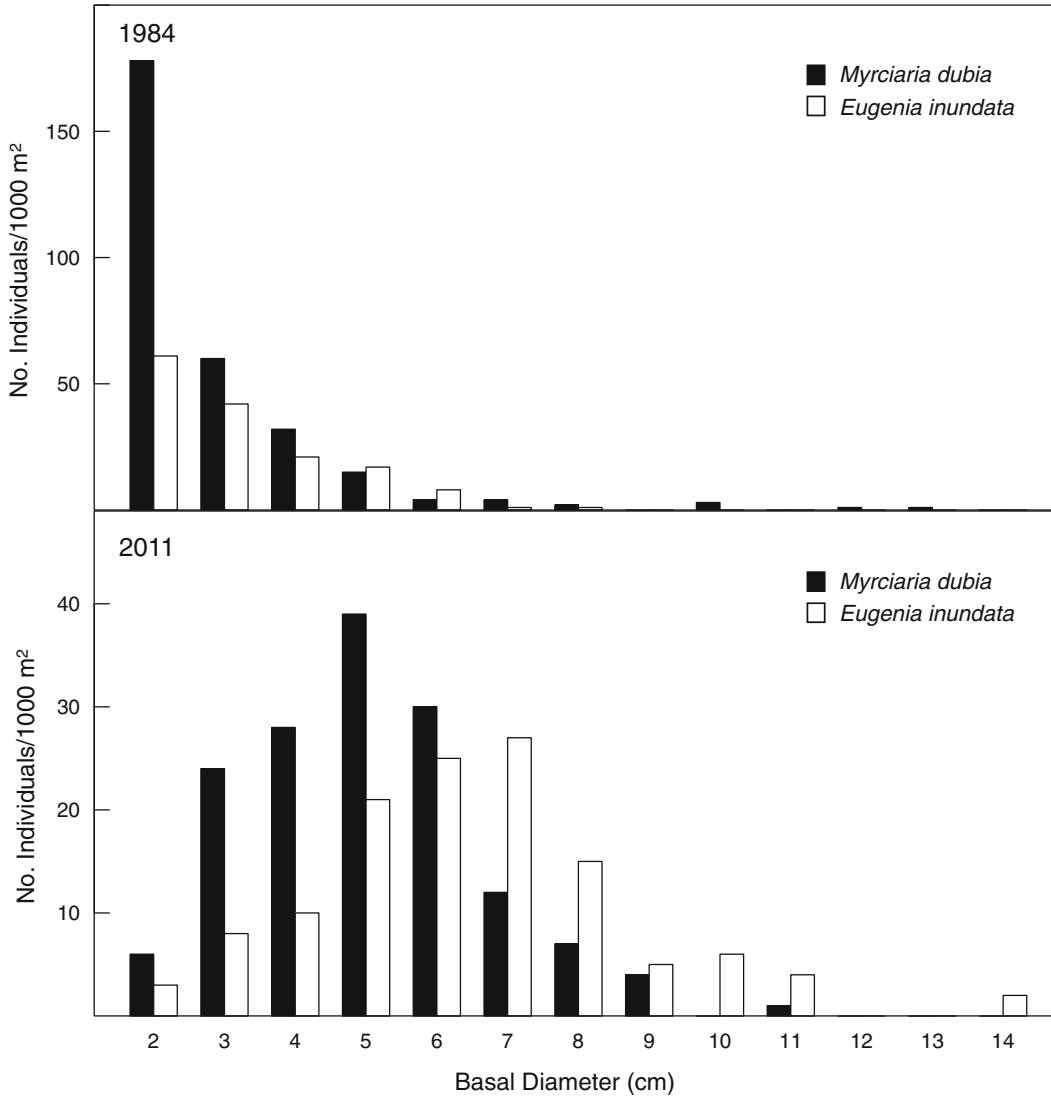

Fig. 2. Size-class distributions for *Myrciaria dubia* and *Eugenia inundata* in the inventory transect in the 1984 (top) and the 2011 (bottom) surveys. Size-classes are in 1.0 cm intervals of basal diameter for the largest stem of each genet. Stems smaller than 2.0 cm basal diameter are not included, as stems smaller than 1.6 cm and 1.5 cm for *M. dubia* and *E. inundata*, respectively, were not measured in 2011, and thus the 1.0 cm class would be underestimated in the figure.

The exploitation of camu-camu fruit likely exacerbates any abiotic stresses, thus contributing to the much greater decrease in regeneration of *M. dubia* compared to that of the unharvested *E. inundata.* The increase in density of ramets of both species is also an indicator of disturbance and environmental stress, and is likely a response to drought or rising water levels in the lake (Bellingham and Sparrow 2000).

Since the late 1980s, there has been an increase in the frequency of extreme hydrological events in the Amazon Basin, linked by many authors to an increase in climate variability (e.g., Espinoza et al. 2009; Marengo et al. 2008, 2012). Severe droughts were observed in 1997, 2005, and 2010, and extreme flooding events were recorded in 1989 and 1999. The flood of 2009 was ranked as one of the largest of the last 107 years

(Davidson et al. 2012; Marengo et al. 2012). The transition from extreme drought in September 2010 to record high floods in the summer of 2011 was the highest increase in the discharge rate of the river since 1984 (Espinoza et al. 2012). *Myrciaria dubia* and *E. inundata* are well adapted to the unpredictability of life along the floodplain. They are, however, both terrestrial plants that need time out of water to flower, fruit, and establish a new seedling cohort. The erratic hydrology of the Amazon River over the last two decades has undoubtedly disrupted the regeneration rates of these species to some extent. Unfortunately there are no other studies examining the status or regeneration of wild populations elsewhere in the region to determine whether these declines are widespread outside of the Sahua Cocha.

The shift in size-class distributions of *M. dubia* and *E. inundata* may also be tied to the inevitable successional development of the oxbow lake. Oxbow lakes are formed when a wide meander is cut off from the main stem of a river. Many of these lakes, including Sahua Cocha, remain connected to the river through tie channels, which transfer water and suspended sediment and act as the dominant mechanism for lake infilling (Rowland et al. 2005). Many of the flooded forests in Amazonia are composed of old floodplain sites, including a heterogeneous mosaic of abandoned river channels, oxbow lakes, and sedimentary beds of different ages (Salo et al. 1986). Although there were no *Eugenia* individuals smaller than 2.0 cm recorded in 2011, it appeared that seedlings and saplings of this species had started to colonize new sediments that extend into the lake outside of the transect. This spatial shift is part of the normal successional development of the oxbow lake as it fills up with sediment and is reclaimed by tree species from the surrounding flooded forests. The decrease in the diversity and basal area of associate species are additional indications of the successional change occurring at Sahua Cocha.

The changes in demography in the *M. dubia* population may not yet affect fruit production, as the increase in density of ramets and basal area should lead to high fruit yields. Ramets begin producing fruit at 2.0 cm basal diameter, so the small increase in number of *M. dubia* ramets in the transect may maintain similar yield levels to those measured in 1984 (Peters and Hammond 1990). According to interviews with local fruit harvesters and members of a community organization created to manage the camu-camu harvest (the Comité Agrario de Bosque Local "Román Sánchez Lozano"), fruit production over the past decade has been highly variable. Fruit is harvested from canoes during the flood season before the shrubs are completely submerged, and although there are signs of damaged branches, cutting or breaking branches to access fruit is not the norm for harvesting. Fruit sets are reported to be particularly high following years of high flood levels, and particularly low following years of drought. The combination of inconsistent fruit production in the stand with fluctuations in price has led many harvesters to view wild camu-camu as a somewhat unreliable resource. However, the timing of harvest in the months of November–January can provide important extra income during the holiday season, and many of the people interviewed expressed hope that a more regular source of commercial demand would create incentive for stronger management of the lake's resources.

Conclusions

Despite a dramatic decrease in regeneration, the *M. dubia* population at Sahua Cocha has managed to maintain itself on the site. The species has actually increased its basal area, and has provisionally compensated for the lack of seedlings by increasing the rate of sprouting, i.e., the number ramets/genet. While the number of different genetic individuals producing seeds has dropped considerably, the total number of fruit-producing stems in the population, as well as the total output of seeds, is still quite high. This finding is somewhat surprising given 27 years of intensive, uncontrolled fruit harvests.

There is no question that fruit collection has had an impact of the regeneration dynamics and population structure of the *M. dubia* at Sahua Cocha, probably accounting for the much greater decrease in *M. dubia* genets compared to the decrease in unharvested *E. inundata*. Other factors, however, are also at work here. The declining densities of *E. inundata* and other associated species around the lake are strong indications that local abiotic conditions are changing. The oxbow lake is filling up, new species are moving in, and it is only a matter of time before the lake—together with the camu-camu that grows there—will be gone. The extreme flooding that has occurred in recent years

will undoubtedly lead to the formation of new oxbow lakes, with new riparian habitats to colonize. If there is a source of seeds, and the fish species to disperse them, *Myriciaria dubia* will start a new population. The fruit, the collector, the oxbow lake, and the river are all part of a context in the floodplains of Peruvian Amazonia. Our study is a useful reminder that contexts change and that explanations are not always as facile as they seem.

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