Assessing the sustainability of yellow anaconda (Eunectes notaeus) harvest in northeastern Argentina

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Abstract

Sustainable wildlife management is required to guarantee source species viability; however, it is practiced rarely in the tropics. The yellow anaconda (Eunectes notaeus) has a long history of being harvested for its leather. Since 2002 its harvest has operated under a management program in northeastern Argentina, which relies on adaptive management through limiting the minimum anaconda length, number of hunters and restricting the hunting season. We investigated the effects of the anaconda harvest on its biological parameters based on 2002-2016 data. Here we show that the levels of species exploitation are sustainable. The gradual reduction in the annual hunting effort, due to a decrease in number of hunters and hunting season duration, reduced the total number of anacondas harvested. Conversely, captures per unit effort increased across the study time-period. There was no variation in the mean length of anacondas harvested, or in largest anaconda sizes. Though more females than males were caught, the sex ratio did not vary significantly. We also found that a decrease in mean temperature positively influenced anaconda harvest and the captures of giant individuals. Because sustainable use is a powerful tool for conservation, those discoveries are highly applicable to other species and regions.

Introduction

Reptile skin has long been considered a major fashion product due its strength and diversity of patterns[1]. Additionally, reptile flesh, eggs[2,3] and other subproducts[4] have nutritional and medicinal value to traditional human communities[5–7]. Commercial hunting of Neotropical reptiles dates from the beginning of the 18th century, starting as a source of oil[8]. After centuries of exploitation, the fashion industry became a notable driver of wild reptile hunting in the 1920s. This practice initially occurred in Southeast Asia, before quickly expanding to Africa and South America in the next decade[9]. Currently, the snake families Pythonidae and Boidae dominate the global trade in reptile skin[10], due to their large sizes. In South America, snakes of the genus *Eunectes,* popularly known as anacondas, and *Boa* are the most commonly exploited for this international trade[9].

Despite being a historical practice, harvesting reptiles is prohibited in several countries, while management alternatives are seldom proposed[3,11]. However, the very use of such wild sources of meat for subsistence, often means that traditional communities become marginalized when such activities are prohibited. This can have severe consequences in remote localities, where such practices are often economically irreplaceable[12]. While it is true that uncontrolled commercial harvest of reptiles has been considered one of the main threats to their conservation[13], increasing the extinction risk of species[14] due over exploitation[15], range reduction or abundance[16], the use of management plans can help to ensure economic viability of conservation initiatives reducing its costs[17,18], promoting the recovery of biodiversity[3]. Moreover, management plans focused on the sustainable use of wild resources have great potential for ensuring social and environmental quality[19,20]. Thus, the implementation of responsible management plans should be a priority in any viable conservation agenda.

To construct and execute wildlife management plans is challenging, as there is often an absence of technical or scientific criteria, well-trained personnel, studies of the supply chain, marketing strategies, specific parameters for each taxon[19], and inadequate remuneration for hunter communities[21]. In some cases, as for the Central American river turtle *Dermatemys mawii*, the laws and regulations for the management of the species are simply ignored by locals[22]. But in most cases, the sustainable use of Neotropical reptiles has been considered viable, as is the case of the river turtles *Podocnemis expansa* and *P. unifilis*[3,23,24], caiman species (*Melanosuchus niger, Caiman crocodilus*[19], *C. yacare*[25], and *C. latirostris*[26,27]), lizards (*Salvator merianae* and *S. rufescens*[28]), and snakes (*Boa constrictor*[9], yellow anaconda *Eunectes notaeus*[29,30]). Functional management plans for these species benefit local communities via the sustainable use that results from their implementation.

Traditional communities in northeastern Argentina historically hunt yellow anacondas—locally known as *boa curiyú*—for their skin[29]. Between 1980 and 1999, some 320,000 individuals were harvested[31], but the harvest decreased abruptly when trade was effectively banned in 1999, affecting the subsistence of local residents[29]. In 2002, a management program for the species—hereafter *Programa Curiyú*—was developed and remains in operation to the present day[31].

Because management plans must ensure the continuous availability of the exploited resource[32,33], selected biological parameters must drive management strategies, and this was done for the yellow anaconda in Argentina[30]. During a pilot period (2002-2004), the managers established that accredited hunters should be restricted to: 1) hunt during the annual hunting season (currently, a three to four months period during the local winter), and 2) only capture individuals longer than 200 cm snout-vent length (SVL), corresponding to a skin of 230 cm SVL[29,31], however, a small number of undersized animals has been tolerated. After skins have been extracted and dried by hunters, they are sent to a local buyer, where the *Programa Curiyú* team collects and systematizes harvest data. Since it is not possible to confidently predict the response of yellow anaconda population to the harvest, the program is done using an adaptive management framework[34], which allows for periodic changes in the management parameters, such as hunting effort, hunting season duration, and minimum size of individuals. Such variables have been occasionally redefined as field data were produced and analyzed[30,35].

Given that the essence of biological monitoring lies in data comparison over time[36], in this work we conducted a historical analysis of the *Programa Curiyú* database. Making the assumption the harvest would be sustainable over time, we hypothesize that we will not find significant declines in: 1) total number of anacondas harvested each year; 2) mean skin SVL; 3) mean SVL of giant skins, which correspond to the 5% of largest individuals captured each year; 4) proportion of skin SVL > 230 cm; and V) capture rates. The amount of analyzed data also permitted us to assume that a decline of at least 5% on analyzed parameters listed above has sufficient statistical power to indicate overharvest[36,37]. Furthermore, because the harvest is dependent on climatic conditions, due to the poikilothermic requirement of anacondas for thermoregulatory behavior, we analyzed the influence of mean air temperature and water level on hunting productivity. By testing sustainability with parameters, we can help identify management weaknesses and strengths for future improvement, help create new parameters, and identify marginal or suboptimal harvest levels. All of these results can help improve conservation policies for the Earth's largest snakes.

Methods

Management Program.

The first concern in the implementation of an anaconda management program is the gathering of biological data, due to the cryptic nature of snakes[11]. Traditionally, data on population size and structure are first obtained, either by direct counting or by using abundance indexes, so that hunting rates can be defined[11,19,23–25]. However, this traditional approach was considered unrealistic for managing yellow anacondas[11], the *Programa Curiyú* performed a pilot study of regional anaconda biology to define which parameters were important to guide the program under the adopted adaptive management approach[29,34].

Adaptive management is a strategy commonly used in wildlife harvesting[36]. Its main goal is to provide a decision-making scheme that can be remodeled as new information becomes available[38], as such it resembles an experiment capable of learning from its own results[39]. From a practical perspective, *Programa Curiyú* controls the harvest by limiting hunting effort (number of hunters and hunting season duration). As a result, there is no direct control over the number of anacondas harvested, and data on the managed population size is inferred from capture rates[29]. Previous studies, via estimates of yellow anaconda reproductive biology, established a minimum skin snout-vent length (SVL) of 2.30 m[30].

Study area.

Programa Curiyú occurs in La Estrella marsh (24°08'S, 60°35'W), a seasonally flooded area in Formosa Province, northeastern Argentina, in the La Plata river basin and in the Chaco vegetative domain. The marsh arose as a result of the natural sedimentation of the Pilcomayo river, which, around 1960, led to the natural damming of its course, causing overflow and creating a marshland about 3,000 km^2 [40]. The dominant landscape is characterized by macrophytes and by epiphytic vegetation covering dead hardwood trunks—locally known as *champas*—with an emergent layer formed by caranda palms (*Copernicia alba*, Arecaceae)[40].

In this subtropical region, the climate is characterized by extreme seasonal fluctuations between flood (Jan-May) and dry (Oct-Dec) periods. The marsh follows a flooding pattern related to the Andean rainfall, so that the main water influx from the Pilcomayo river occurs from December to February, with approximately one month required for the marsh to fill (like a wave of flooding coming from the west to the east). Once established, stable levels of flooding may last several months. Around April/May the water progressively drains out, with minimum water levels or total drought occurring from October to January. The area is subject to atmospheric cold fronts, when temperatures can suddenly drop several degrees for a period of a few days. During 1961-1990, the maximum monthly average temperature (33.4

°C) was recorded in January during summer (Dec-Mar), and the minimum (12.1 °C) was recorded in July during winter (Jun-Sep) (33 °C)[41].

Study species.

Yellow anacondas (*Eunectes notaeus* Cope, 1863) are non-venomous semiaquatic Boidae snakes that remain active throughout the year[30]. During summer at La Estrella (Dec-March), they hide among moist aquatic vegetation, making them difficult to detect. During the winter, however, and especially after cold fronts, they can easily be found while basking in the sun on the *champas*[30]. Yellow anacondas exhibit fast growth and remarkable sexual dimorphism—females are 20% longer and twice as heavy as males[30]. Reproductive activity begins in the spring, with parturition occurring in early autumn, in April [30].

Yellow anacondas are generalist predators that both ambush and actively hunt for prey[42,43]. They feed on invertebrates, fishes, reptiles, mammals, birds, eggs, and eventually carrion[30,42–45]. Currently, the species is being assessed by the International Union for Conservation of Nature (IUCN) and—as all members of the Boidae family—it is listed in the Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Data Collection and Analysis.

We obtained data on yellow anaconda hunting activities from the technical reports issued annually by the *Fundación Biodiversidad*, located in the Ciudad Autónoma de Buenos Aires, Argentina; this institution created, and currently supervises, *Programa Curiyú*. Additional data and specific clarifications were obtained directly from the management program coordinators. We emphasize that no anacondas were killed solely for the purpose of the current study. We used data available for the period from 2002-2016. However, a remarkable climatic event took place in 2013, when a severe drought affected the flooding regime at La Estrella[35,46], as a consequence, there was no anaconda hunting activity. Consequently, 2013 was excluded from all analyzes.

A wide variety of parameters were obtained for the 14 years of harvest. Because overharvesting can reduce target resource availability[36,37], we analyzed the total number of anacondas harvested each year, as well as captures in the most productive month (July, the month with the highest number of captures of the hunting season). Because overharvesting can change the sex ratio and the average body size of harvested populations[47,48], we also analyzed the sex ratio, mean skin SVL, mean length of giant skins (*i.e.*, top 5% of the longest skins from each year), and proportion of skins > 230 cm. The length of harvested snakes was defined in the pilot period in 2002 and 2003, however, the only available data for individual skin SVL was for 2004-2016 period. Because skins are usually stretched by the hunters to dry them out, we obtained the true skin SVL according to the following equation (1)[49]:

Equation 1.

$$\text{SkinSVL} = \frac{\text{raw skin SLV} + \text{raw skin width} \ * 10}{2}$$

Furthermore, we estimated the SVL of living snakes according to the following equation (2)[31]:

Equation 2.

$$\text{LiveSVL} = 11.71 \ + \ 0.66 \ * \ \text{raw skin length} \ + \ 1.59 \ * \ \text{raw skin width}$$

We also analyzed the number of accredited hunters active during the hunting season, total days of harvest, and capture rate (captures per unit effort; CPUE), determined by the equation (3):

Equation 3.

$$\text{CPUE} \ = \ \frac{\text{c}}{\text{n} * \text{d}}$$

Where: c = total number of anacondas harvested in year *x*; n = number of accredited hunters in year *x*; d = hunting season duration (days) in year *x*[49]. We calculated the CPUE of the most productive month (July) as well as outside the most productive month, for which the number of accredited hunters remained constant. However, the nominal effort is not homogeneous across the whole hunting season: not all hunters begin their activities when the legal start the season is announced, while towards the end of the season falling water levels can make it disproportionality difficult to hunt within the marsh. As a result, we focused on the effects on different capture rates.

Additionally, we analyzed environmental variables, such as mean hunting season temperature (ºC) and maximum water level in the marsh. Air temperature data was collected by the *Progama Curiyú* every two hours, from 2003 to 2016, using data loggers in a sunshield Davis station located in Fortín Soledad—a small city on the southeastern edge of La Estrella marsh. Water level records were taken by the local police department between 2002-2016 using a measuring gauge located on the edge of Fortín Soledad. This means that the water level recording begins once the water arrives at the edge of the city and reaches 0.4 m approximately in the measuring gauge. However, *Programa Curiyú* estimates that this is equivalent to 1.1 m in the deepest part of the marsh. Because there are no continuous records of the water level throughout the year due seasonal ebbing, we used the peak water level as a proxy for water volume. During the two driest years, 2005 and 2013, flooding extent was so minimal that the water never reached the measuring gauges at Fortín Soledad, therefore there were no water level records for these years.

We performed generalized linear models (GLMs) using R software v.3.5.1[50] and, for all analyses, used a significance level of 5%. To analyze trends in captures, number of hunters, and hunting days across the years, we used Poisson distributions at first, but when overdispersion[51] was observed we used a negative binomial distribution[52] as a corrective, using the MASS package[53]. We modelled proportion of captures in the most productive month from each year, proportion of skins with SVL > 230 cm, and sex ratio separately using binomial distributions for each, and used the function *glm.binomial.disp* from 'dispmod' package[54] to account for overdispersion. To analyse trends in mean skin SVL and CPUE, we used log Gaussian and Gaussian distributions respectively; a Shapiro-Wilk test was used to assay for normality[55]. Finally, we analyzed the effect of mean temperature during the hunting season and maximum water level on the following harvest parameters: number of captures, skin SVL and sex ratio. For these we used negative binomial, log Gaussian and binomial accounting with overdispersion, respectively. To understand the effect of different temperatures in July and in the rest of the hunting season on capture rates, we modelled the relation between CPUEs and the mean temperatures using the Gaussian distribution.

Results

A total of 54,950 yellow anacondas were harvested for their skins during the 15-year existence of *Programa Curiyú*. The total number of harvested anacondas decreased during the studied time period (GLM -0.07, range: -0.12 to -0.02, $P < 0.05$, deviance: 36.2%), as well as the captures in the most productive month, July (GLM -0.05, range: -0.09 to -0.01, $P < 0.05$, deviance: 30.3%; Fig. 1). On average, 50.9 ± 8.8% of the anacondas were captured during the most productive month. However, the proportion of captures in July increased across the years (GLM 0.05, range: 0.01 to 0.08, $P < 0.05$, deviance: 35.9%; Fig. 1). In general, more females than males were captured every year (1⌧: 4.7 ± 2.2⌧), but the proportion of captured females was not constant across the study period. It increased at the start of the *Programa Curiyú*, reaching a peak in 2010 (when nearly 10 females were captured for every male), then decreased in more recent years (GLM χ^2: 0.21, range: 0.03 to 0.39, $P < 0.05$, χ^2: -0.01, range: -0.02 to 0.002, $P < 0.05$, deviance: 35.5%; Fig. 2).

Considering sizes of captured individuals, 2015 had the lowest mean skin SVL (244.21 cm), and 2009 the highest (263.76 cm; Table 1), although the general mean SVL showed no significant variation across the study period (GLM -0.002, range: -0.005 to 0.00004, $P > 0.05$, deviance: 23.6%). On the other hand, the mean length of giant skins slightly decreased across time (GLM -0.004, range: -0.01 to -0.001, $P < 0.05$, deviance: 35.6%). In 2016, however, there was an increase in the mean SVL of the 5% longest skins, which returned to original values (Table 1). Moreover, the proportion of skins > 230 cm (88.78 ± 7.16%; Table 1) showed no significant variation over the years (GLM -0.06, range: -0.15 to 0.02, $P > 0.05$, deviance: 15.8%). The median estimated size of hunted individuals when alive was 219.6 cm (208.3 - 237.8), and we estimated that the smallest harvested anaconda measured 193.72 cm SVL when alive, captured in 2014, while the longest was 410.71 cm SVL, captured in 2009 (see Supplementary Fig. S1). However, it is important to keep in mind that these values are merely indicative, since they are based on an average stretching value of 15%[29], and that they do not consider the variation in skin stretching, which may reach up to 30% compared to a live specimen (TW, pers. obs.).

Table 1. Biological attributes of yellow anaconda skins harvested under the *Programa Curiyú* from 2002-2016. Mean skin width and snout-vent length (cm), number and % of skins with snout-vent length > 230 cm, mean snout-vent length (cm) of giant skins (corresponding to the 5% longest skins).

Year	Mean skin width (cm)	Mean skin SVL (cm)	Number (%) of skins with SVL>230	Mean 5% longest skin SVL (cm)
2002	24.64	253.07	5688 (89)	NA
2003	20.01	254.83	5733 (89)	NA
2004	24.06	256.32	4325 (98)	345.42
2005	26.18	258.82	3961 (91)	341.99
2006	26.23	261.1	2344 (94)	339.47
2007	25.91	258.8	4794 (92)	344.07
2008	25.96	257.59	2952 (88)	344.46
2009	26.99	263.76	5257 (97)	349.00
2010	25.86	255.94	3714 (91)	338.88
2011	25.51	251.6	3657 (82)	335.82
2012	24.97	247.2	1542 (71)	340.57
2014	25.48	251.05	613 (88)	329.90
2015	24.58	244.21	1637 (78)	314.06
2016	26.01	255.15	3185 (95)	341.32

We recorded a decrease in the number of hunters (GLM -0.13, range: -0.17 to -0.1, $P < 0.05$, deviance: 80.2%), as well as in the number of harvesting days (GLM -0.05, range: -0.09 to -0.02, $P < 0.05$, deviance: 44.5%), during the 15 years of *Programa Curiyú* data analysed (Fig. 3). In general, the CPUE during the most productive month (July) was greater than during the rest of the hunting season combined, particularly in more recent years (2010-2016), and with exception of 2008 (Fig. 4). The CPUE increased at the start of *Programa Curiyú*, then stabilized between 2012 and 2016 (GLM_{annual} χ: 0.07, range: 0.03 to 0.11, $P < 0.05$, χ2: -0.03, range: -0.01 to 0.001, $P < 0.05$, deviance: 67.9%; $GLM_{annual\ except\ July}$ χ: 0.08, range: 0.03 to 0.12, $P < 0.05$, χ2: -0.003, range: -0.01 to 0.001, $P < 0.05$, deviance: 54.6%), except for the CPUE during the most productive month, which continued to increase over the years (GLM_{July} 0.03, range: 0.02 to 0.04, $P < 0.05$, deviance: 75.7%; Fig. 4).

Mean temperature during the annual hunting season (April-October) varied between 19.3 and 22.3ºC. In the years with higher mean temperatures the number of total captures decreased (GLM -0.44, range: -0.74

to -0.13, $P < 0.05$, deviance: 36.3%), causing also a decrease in the captures in July (GLM -0.38, range: -0.56 to -0.11, $P < 0.05$, deviance: 39.1%; Fig. 5), with the mean SVL of giant skins also reduced (GLM -0.02, range: -0.03 to -0.003, $P < 0.05$, deviance: 35.1%; Fig. 6). Additionally, the mean temperature during July was significantly lower than the rest of the hunting season (Fig. 7). The increase in capture rate (CPUE) in the most productive month was significantly influenced by the lower temperatures (GLM -0.04, range: -0.06 to -0.02, $P < 0.05$, deviance: 34.8%; Fig. 7). On the other hand, while maximum measured water level varied from 0.5 to 1.9 m, it did not have any effect on recorded yellow anaconda harvesting parameters.

Discussion

While wildlife management has been perceived as key missing tool for sustainable use of Neotropical resources[56,57], few studies have been published on the subject to date[3,58]. In this study, we have shown that: (1) the total number of harvested snakes, the number of hunters, and the hunting season duration decreased since the implementation of *Programa Curiyú* in 2002; (2) capture per unit of effort has increased; (3) the number of captures in the most productive month (July) has decreased over time, while the proportion of captures occurring in this month (relative to the total number of anacondas harvested each year) has increased; (4) mean skin length from captured anacondas has not varied significantly, even though more females are being hunted than males. The management framework has therefore proven its usefulness and applicability in a low-cost context, with a hard-to-sample species, leading to its sustainable exploitation.

Most snakes have secretive habits and to estimate their population parameters requires expensive and time-consuming field work, therefore, data obtained from management programs represent a viable source of inference allowing us to identify safe levels of exploitation[36,37,49]. Over time, decrease in total number of harvested individuals, changes in length and sex ratio[36,37,47], or increase in hunting effort, are appropriate indicators of overexploitation. A study analyzing the management of reticulated pythons (*Malayopython reticulatus*) in Indonesia argues that, for large constricting snakes, the minimum sample required for statistically viable detection of population changes would be 551 individuals, an unlikely feat for most field studies. Additionally, the authors suggest that an annual decline of 5% over approximately 5,000 individuals or declines greater than 10% over smaller samples of about 1,000 individuals, may indicate overexploitation[37]. In this study—by means of a sample of 54,950 individuals—we conclude that the yellow anaconda harvest is sustainable, since there were no significant declines on analysed parameters.

Previous studies suggest that yellow anacondas are resistant to intense exploitation[29,30], as are pythons (*Malayopython reticulatus*) in Indonesia[37] and tegu lizards (*Salvator* spp.) in Argentina[59]. Several aspects of their biology contribute to the ability of some reptile species to resist such harvesting pressures, including[60]: 1) high reproductive rate, 2) wide geographic distribution, 3) strong population inter-connectivity, 4) existence of areas with no hunting, 5) exploitation of disturbed habitats, and 6) low impact hunting techniques (visual search and manual capture). Individual yellow anacondas grow rapidly, have early maturation—attained at the age of 2.5 years—and a relatively high reproductive rate (an average of 24, offspring, though up to 40 has been recorded[30]), allowing rapid recruitment of new individuals in a short period of time. In addition, juvenile mortality is lower in anacondas than in most other snake species since they are aquatic, very cryptic and aggressive, and are born with a well-developed SVL (40-59 cm) and weight (61-135 g)[30]. The species range occupies some 42 million hectares, extending from latitudes of 15°S to 30°S[30,45,61–63], and encompassing four countries, which makes it unlikely that harvesting in La Estrella could cause total extinction of the species, even if unsustainable. Despite Argentine populations of yellow anacondas show significant genetic structure for mitochondrial genes, males are the principal agents of gene dispersal[64]. By inhabiting large river courses (La Plata basin is the fifth largest on Earth), these animals are part of an extensive and continuous ecological system that connects the Brazilian Pantanal wetlands to the Argentine Chaco; as a result, their high motility results in populations being genetically structuring as part of a metapopulation[30,65].

Additionally, the environmental history of La Estrella marsh, and the conditions of the habitat favor the safe hunting of the anacondas in this part of northeastern Argentina. Covering some 3,000 km², this area represents only 0.70% of the species distribution. Access for hunters to different parts of the marsh is affected by a number of factors, including variable water depth, dense floating vegetation, muddy soils, and fallen trunks[40]. Therefore, when searching for snakes the hunters paddle their canoes across the marsh using a series of regular navigational routes that are concentrated around the villages. Consequently, large portions of the habitat used by anacondas at La Estrella are not accessed, and this likely create a source-sink dynamic[30]. Finally, the rudimentary technique used to hunt snakes (visual search and manual capture) is unlikely to be robust enough to have a significant impact on the local anaconda population.

When the capture effort is constant annual harvest reduction is an appropriate parameter to show overharvesting is occurring in a population. Despite an observed decrease in annual captures, this is related to the reduction in hunting effort, and not to a decline in the availability of anacondas in the marsh. There was a significant reduction in the number of accredited hunters, as well in the hunting season duration, between 2002-2016 (Fig. 3), which contrasts with the trending increase in CPUE (Fig. 4). Within the *Programa Curiyú* there are two types of hunters: the ones that hunt for extra financial income, and the ones whose sole income comes from hunting. The reduction in the hunting effort was mainly due to the abandonment of the activity by people who were not exclusively dedicated to anaconda hunting[46]. Hunters are a key component in the production chain and their compromise to hunt can be decisive for the success of the management program. Furthermore, understanding that is critical for the correct interpretation of our data, both to prevent inappropriate or unnecessary management interventions and to prevent population declines of the target species. In the current study, the increase in CPUE when hunting effort declined suggests strongly that the abundance of anacondas remains constant in La Estrella.

For snakes in general, long-term analysis of the sex ratio of a population is key to understanding the effects of harvesting programs[36]. Females represent a critical limiting factor for the persistence of populations, therefore, to ensure long-term availability of a species, hunting programs focused on non-reproductive males would, in overall, be more appropriate than those focused on reproductive females[37]. So far, during the *Programa Curiyú,* more females than males have been hunted. However, snakes of the genus *Eunectes* copulate in aggregations where one female is inseminated by several males, thus, a reduction in the number of males has a positive effect in the number of infertile eggs in females[11]. Moreover, males have higher dispersion compared to females and as a result are more susceptible to natural predation[11]. Consequently, male harvest may have unexpected effects and unintended consequences on the reproductive biology of the species.

During the historical period of unrestricted anaconda hunting, before the creation of the *Programa Curiyú*, specimens above 135 cm of SVL were harvested[29,49], indicating that large numbers of young non-reproductive males and females were captured. With the establishment of the *Programa Curiyú,* an increase in the minimum skin size to 230 cm of SVL was implemented, corresponding to a live specimen of about 200 cm of SVL. The increase in the minimum size restriction resulted in a reduction of production volume by 50-60%, but ensured the protection of a large number of immature and young females[49]. At first, this rule may seem detrimental to the profitability of hunters and the program, however, larger skins are wider and have bigger scales, which represents a greater monetary value of the resource in the market[49].

Although a tend was observed in the analysis of the size of giant skins for a reduction in size over time, we must emphasize that this is an artifact of the data from 2014 and 2015, when the largest hunted individuals were not as big as in the preceding years (see Supplementary Information), with 2016 measurements returning to previous mean values. This may be an effect of the severe drought in 2013. Giant individuals are more likely to die from overheating because they cannot find suitable places to maintain adequate body temperatures, and may face mobility issues when attempting to leave drying mud pools and head towards shading vegetation[11]. Thus, we argue that there is no tendency to reduction in giant skin sizes, as this is likely a byproduct of the impact of drought on the giant-sized individuals in the local anaconda population.

Environmental factors are thus key determinators of the survival of this species, as well as for the successful development of *Programa Curiyú*[35,62]. As a consequence of the 2013 drought, the hunting was prohibited during this particular year, with a subsequent decline in *Programa Curiyú* productivity, the abandonment of this activity by hunters who sought alternative sources of employment, and a reduction of income of those hunters who remained accredited to the program[35,46,66].

The *Programa Curiyú* had solid empirical evidence that cold fronts improve success when hunting for yellow anaconda. However, there was no scientific evidence showing the relationship between air temperature and captures until now. Thermoregulation is fundamental for survival of ectotherms[67], and reptiles can use behavioral and physiological mechanisms[68,69], body mass[70], and habitat selection[71] to regulate body temperature. Yellow anacondas show different body temperatures in terrestrial and aquatic environments[72], with body temperature in terrestrial habitats reaching 3-4 °C higher than in water[72]. Thus, under natural conditions, yellow anacondas can improve heat absorption by getting out of the water and basking on vegetation, but, when doing so, they also become more exposed to being harvested. Knowing that lower temperatures favor the hunt, new strategies can be developed, such as concentrating efforts during colder periods.

Overall, our data corroborate the hypothesis that exploitation of yellow anaconda in northeastern Argentina is sustainable. We conclude, therefore, that the parameters chosen by the *Programa Curiyú* for hunting restriction are successful in ensuring the demographic viability of the species. The regulation and supervision of management practices by competent institutions and authorities is capable of bringing not only monetary and social benefits to traditional communities, but also to the exploited species by monitoring and conserving its population viability and habitat. Moreover, wildlife management plans represent a great opportunity for scientific exploration of many biological aspects of otherwise difficult-to-survey species, such as the yellow anaconda. Finally, the program exemplifies the use of powerful and cheap tools for sustainable wildlife development, which can be developed for other anaconda populations, as well as for other species and regions.

Declarations

Author contributions

B. F. C., C. S., I. Q., and E. B. P. de M. conceived and designed the experiments, and wrote the paper. T. W., M. B., J. D., and P. A. M. provided data, revised, and made improvements to the paper.

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Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information is available for this paper

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Figures

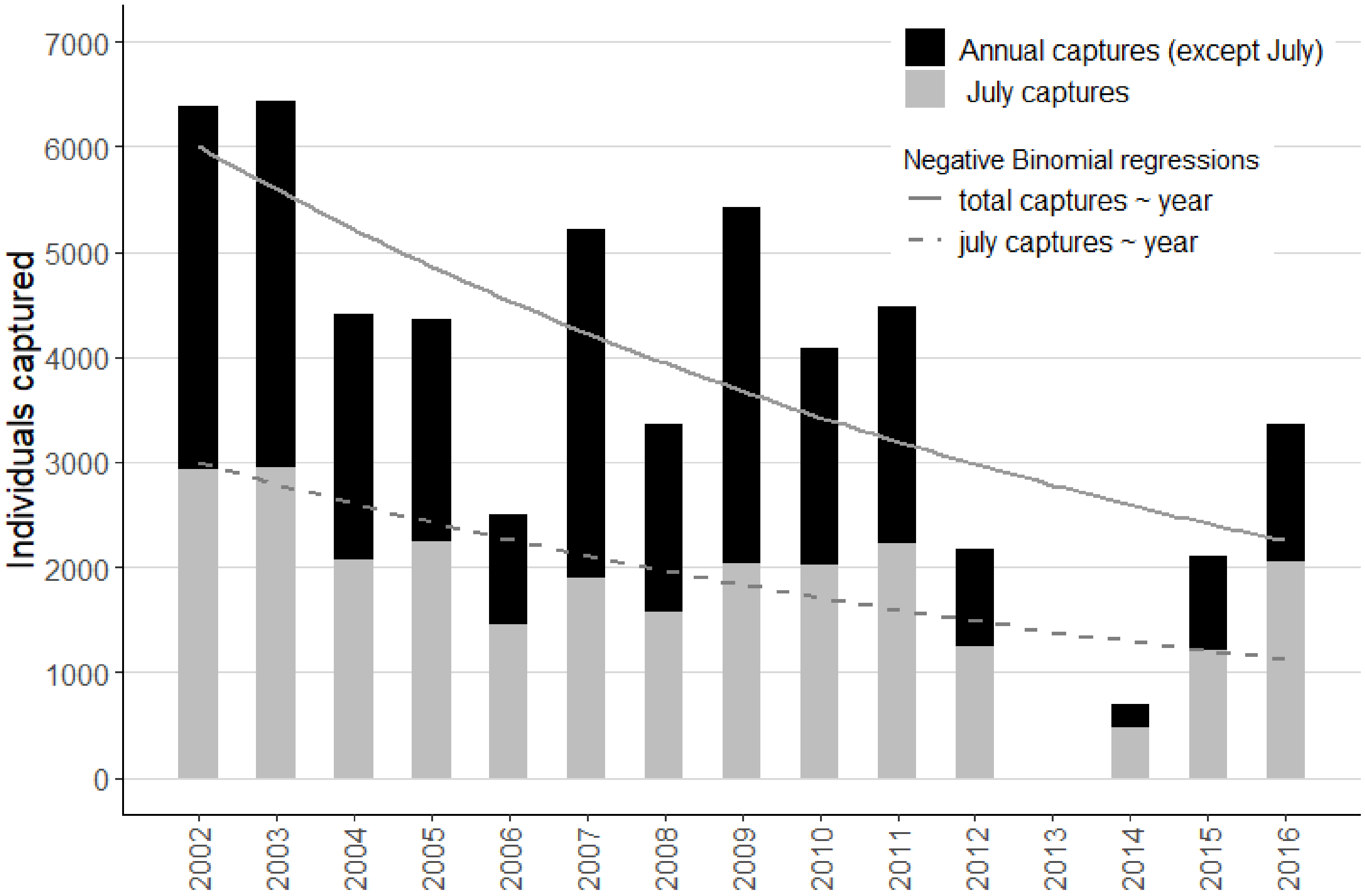

Figure 1

Numbers of yellow anaconda (Eunectes notaeus) harvested by the Programa Curiyú between 2002-2016 in northeastern Argentina. Captures in the most productive month (in gray) and outside the most productive month (in black) are shown, as well as the negative binomial regression for captures in July [captures/year = exp(106.8 -0.05*years)] and for total captures [captures/year = exp(148.69 -0.07*years)].

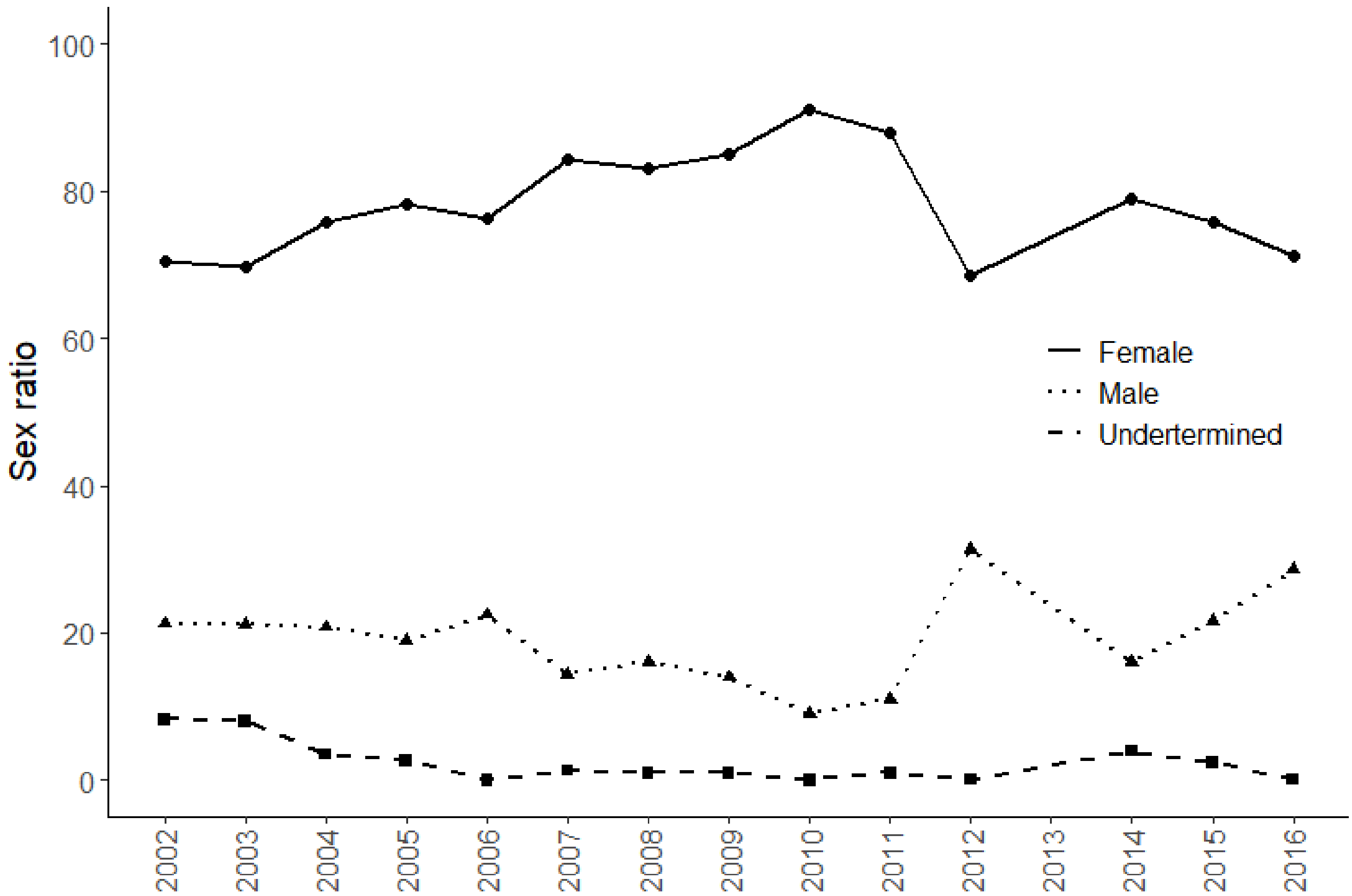

Figure 2

Sex ratio of yellow anacondas harvested by the Programa Curiyú in 2002-2016 in northeastern Argentina.

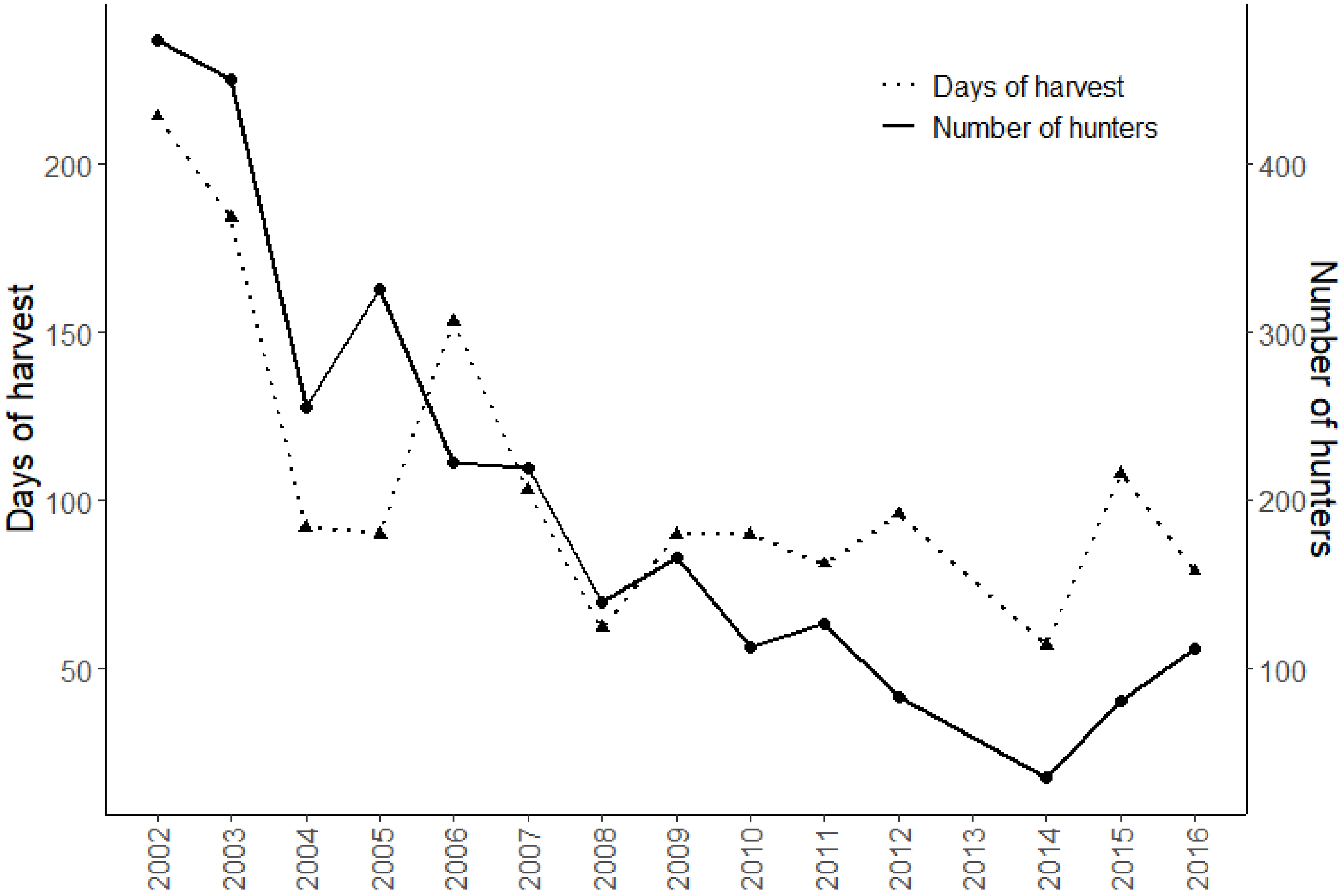

Figure 3

Hunting effort for yellow anaconda (Eunectes notaeus) in northeastern Argentina between 2002-2016. Nominal effort (number of hunters) and number if harvesting days are shown.

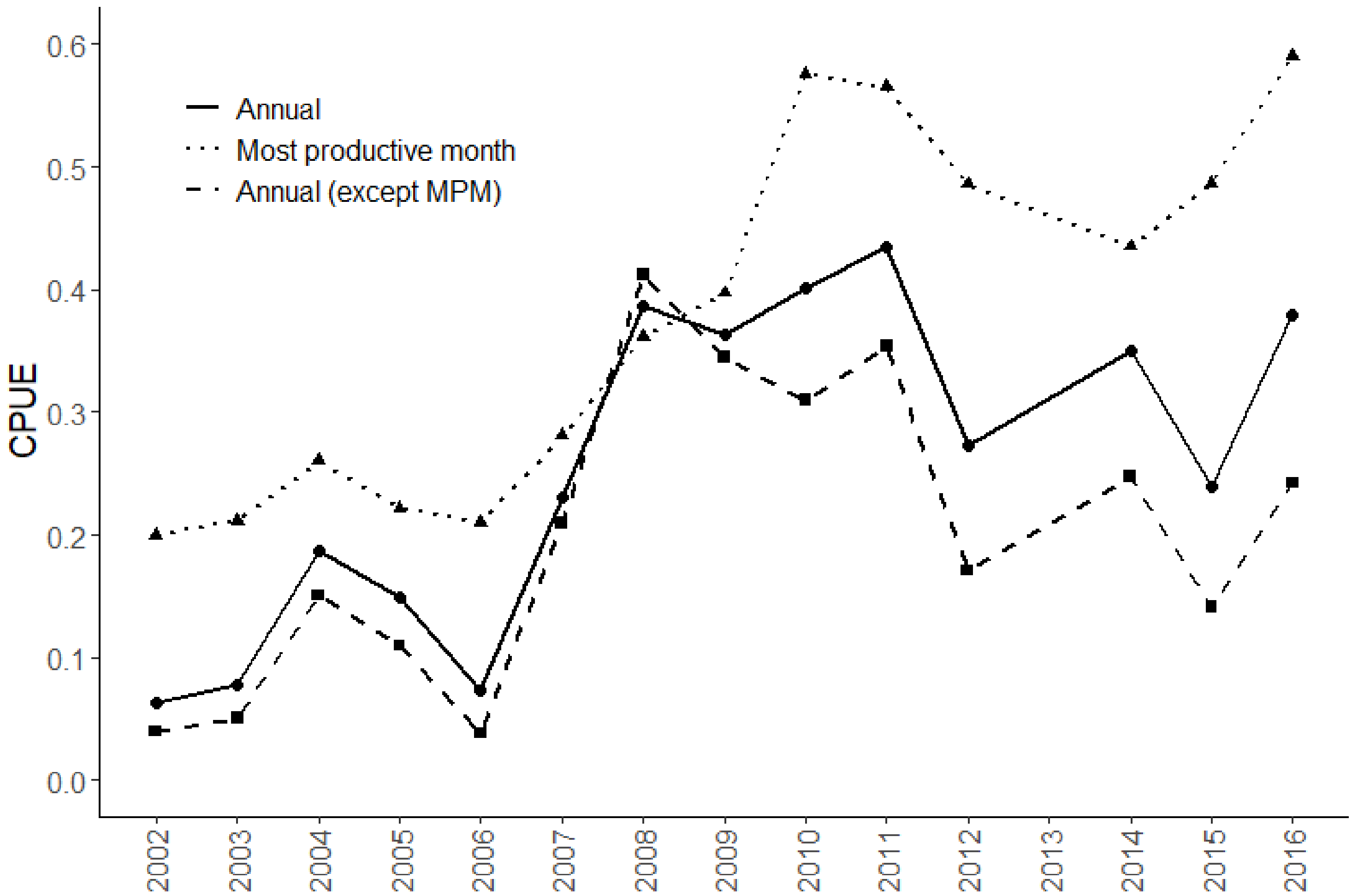

Figure 4

Capture rates for yellow anaconda (Eunectes notaeus) harvested in northeastern Argentina between 2002-2016. Capture rates for the whole year, for the most productive month (July), and outside the most productive month are shown.

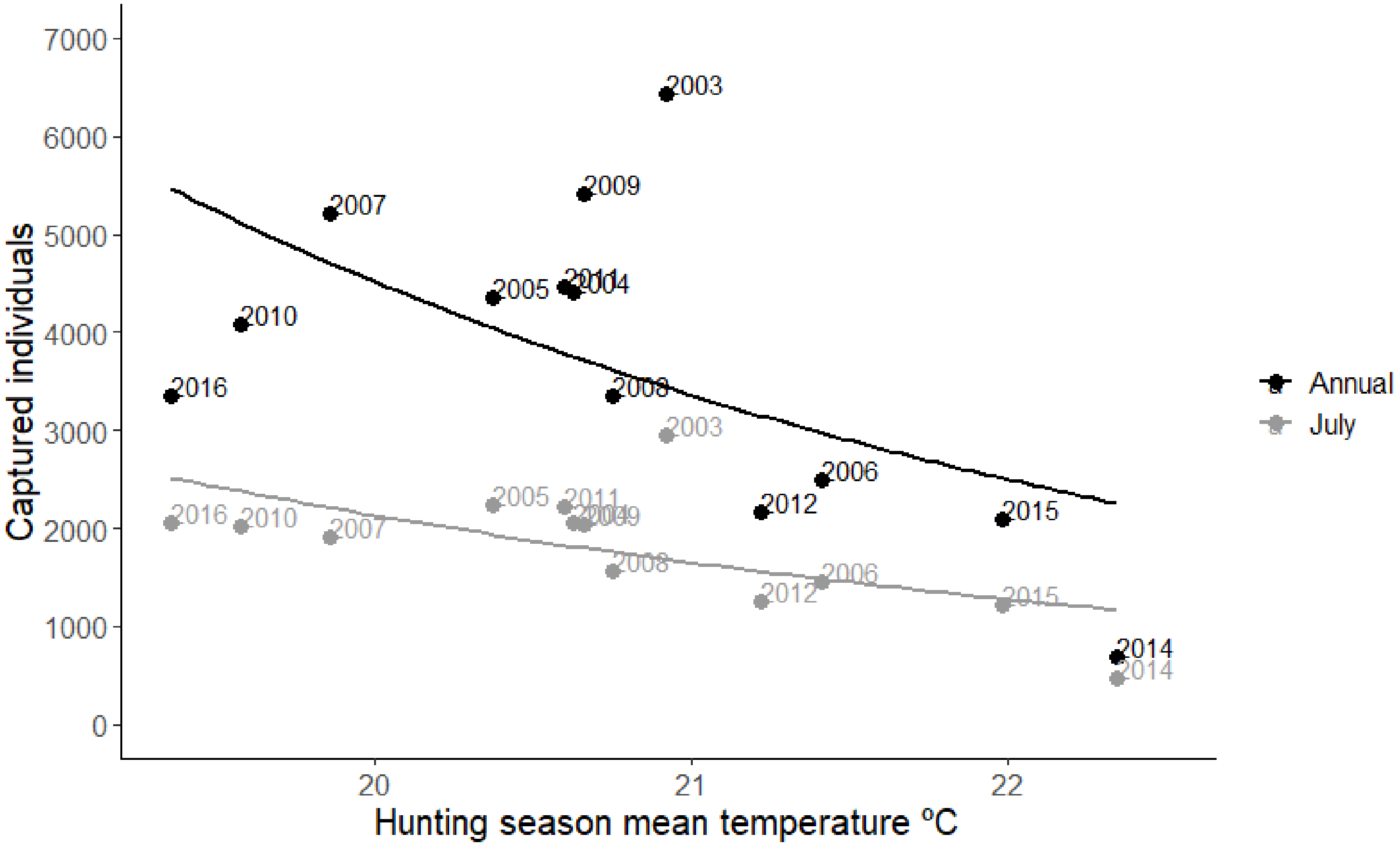

Figure 5

Relation between number of captured individuals and mean hunting season temperature (ºC). The negative binomial regression for total captures (in black: captures/year = exp(17.24 -0.44*mean hunting season TºC)) and for captures in the most productive month (in grey: captures/year = exp(14.46 -0.34*mean hunting season TºC)) are shown.

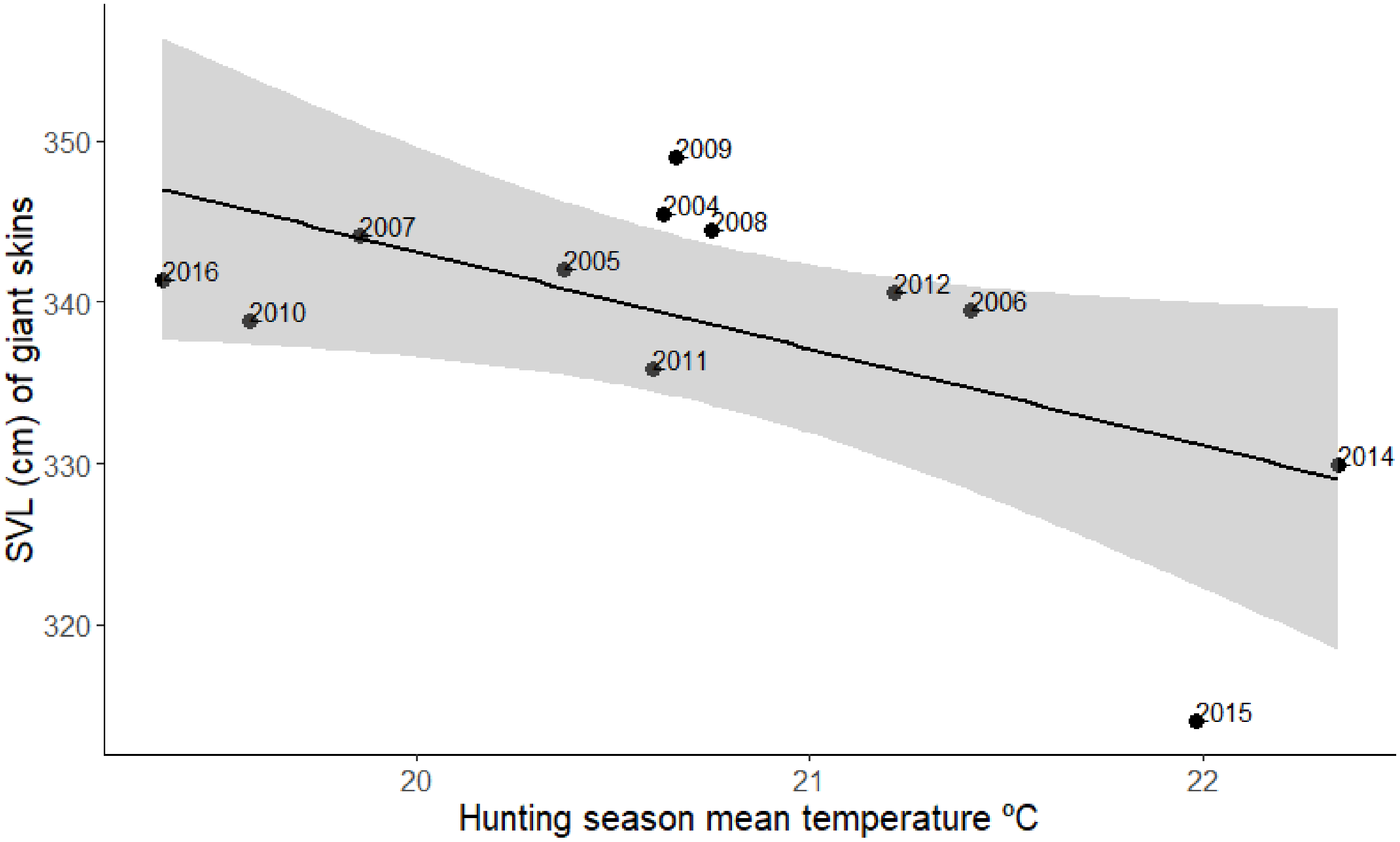

Figure 6

Relation between the mean SVL (cm) of giant skins and mean hunting season temperature (ºC). The Gaussian regression for SVL of giant skins [log (mean SVL of giant skins) = 6.20 -0.02*mean hunting season TºC] is shown.

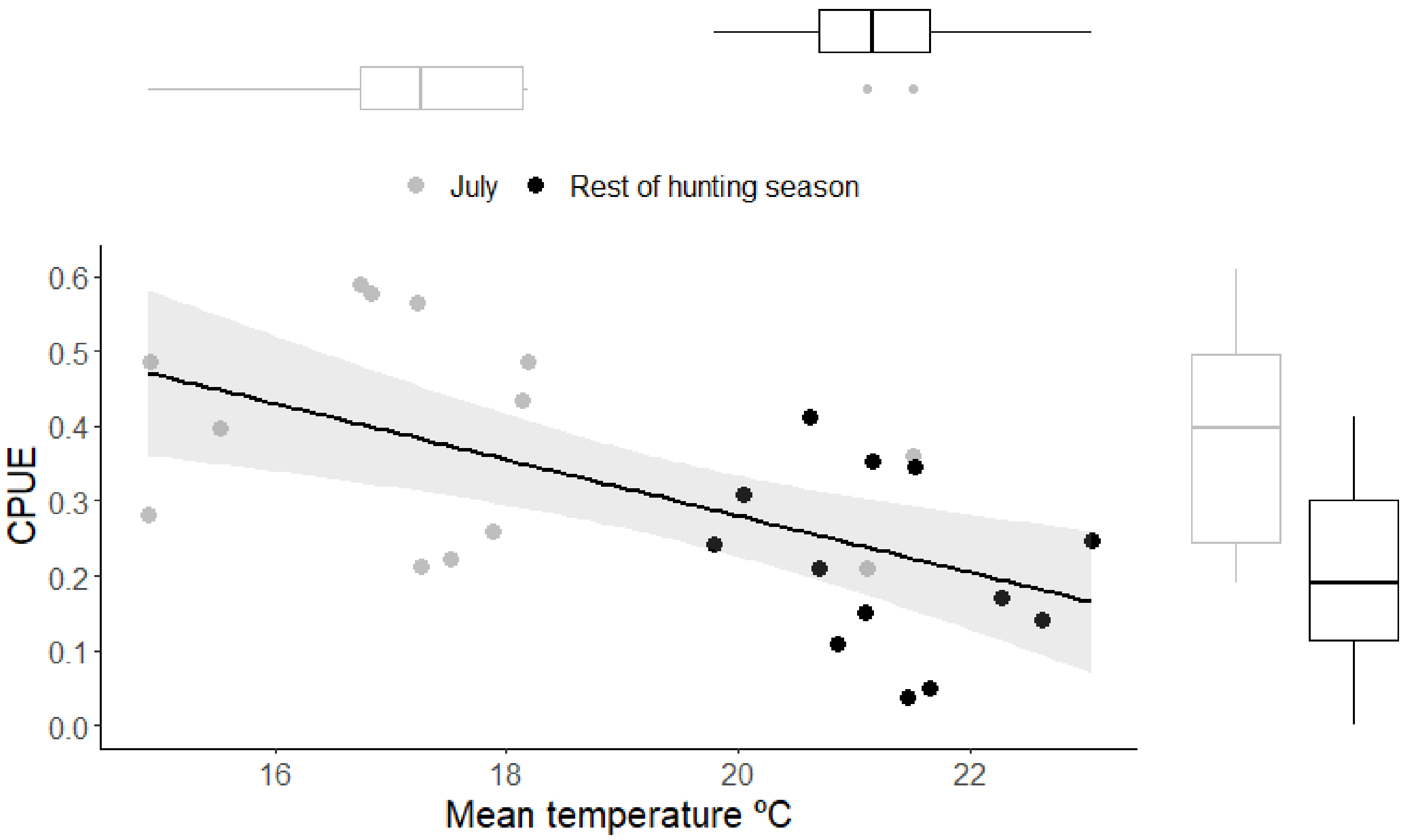

Figure 7

Capture rate (CPUE) in relation to mean temperature (ºC) for the most productive month (July) and outside the most productive month. The Gaussian regression for capture taxa (CPUE = 1.03 -0.04*mean TºC) is shown.

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