

# Harvest quotas, free markets and the sustainable trade in pythons

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## Abstract

Assessing the sustainability of the harvest of animals can be done by obtaining data from processing facilities and establishing that vital attributes of the harvested animals (e.g., size, age structure, sex ratio) do not change over time. This model works if the traders operate in a free market without any regulations on what can be harvested, processed or exported, and when harvest methods and harvest areas do not change between assessment periods. Several studies assessed the harvest effects on blood pythons (*Python brongersmai*) in North Sumatra, Indonesia seemingly under a free market scenario, with some concluding that trade was sustainable and the others hinting at an overharvest. Indonesia has established harvest and export quotas and, internationally, trade in blood pythons is regulated through CITES, and the blood python trade clearly does not operate in a free market. Data suggest that the three (or four) slaughterhouses included in these studies processed ~27,000 blood pythons a year against a quota of 18,000. There is a risk that data from traders alone purporting to show that harvest is sustainable will lead to an increase of quotas or an abandonment of quotas altogether. There is no conclusive data to support that the harvest of blood pythons in North Sumatra is sustainable but there is sufficient evidence to suggest that a substantial part of this trade is illegal. Likewise, at a global level there are clear indications of misdeclared, under-reported and illegal trade involving 10,000 s of blood pythons. While important biological information can be obtained from harvested animals, to assess whether harvest is sustainable there is no substitute for monitoring wild populations. After decades of international trade in blood pythons from Indonesia, during which at least half a million blood pythons were exported, it is all the more urgent that systematic monitoring of wild populations commences.

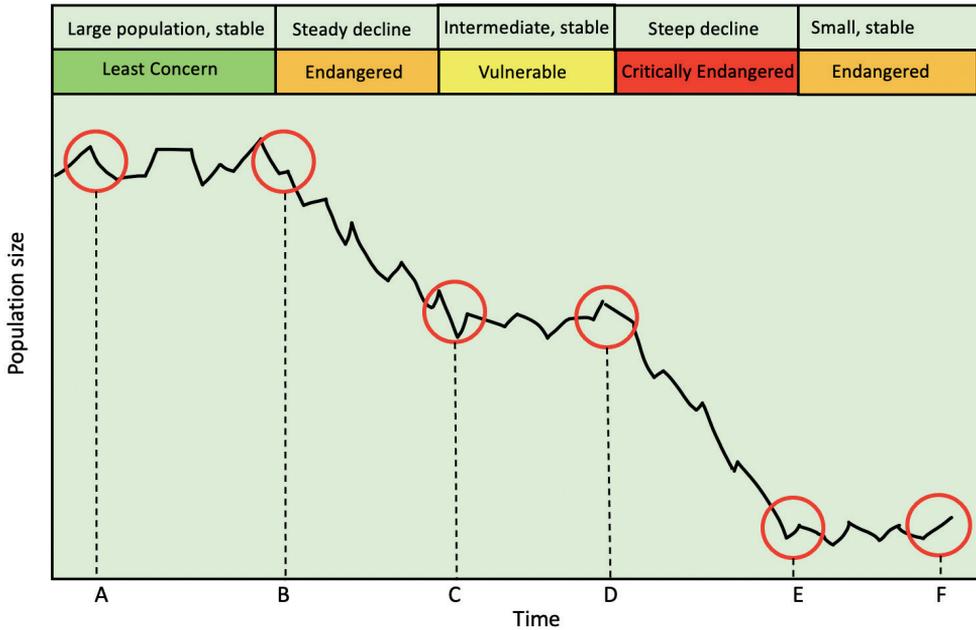
**Keywords**

CITES, conservation, Indonesia, *Python brongersmai*, reptiles, short-tailed python, sustainable management, trade regulations, wildlife trade

**Introduction**

Several studies have addressed the unsustainable exploitation of reptiles (Gibbons et al. 2000; Schlaepfer et al. 2005; Auliya et al. 2016; Marshall et al. 2020; Janssen 2021; Cox et al. 2022) and according to some the intentional harvest of them is one largest threat to the survival of many reptile species, especially crocodiles and turtles (Böhm et al. 2013; Cox et al. 2022). Reptiles represent one of the most species-rich vertebrate class in international trade (Nijman 2010; Scheffers et al. 2019). Species extinction processes that are causally linked to harvest and trade remain relatively undocumented. However, it is evident that those species that are long-lived with long generation times, those with low fecundity, those that are rare, or those that have a very restricted geographic range or small population size, are particularly vulnerable to over-collection (Reznick et al. 2002; Auliya et al. 2016). As noted by Challender et al. (2021) understanding the impact of trade-driven harvest on wild populations requires data on critical population parameters, including intertemporal harvest rates and their influence on density. Using trade data subjectively to determine that trade is detrimental as a shortcut for these in-depth analyses can be problematic (Challender et al. 2021).

In natural resource management the concept of sustainability is central as it would allow to maintain a long-term yield. From an economic perspective obtaining the largest harvest while maintaining the harvested population at a given size indefinitely (or at least long term) is preferable. This is known as the maximum sustainable yield (Tsikliras and Froese 2019); it remains a very useful concept as it provides an invaluable reference point as an ideal against which current practice can be compared (Sutherland 2001). In theory, with population growth following a sigmoid curve, the greatest growth rate occurs at intermediate population sizes. When harvest is sustainable it should not exceed the maximum sustainable yield under any carrying capacity, and it should not lead to a decrease in population size. But sustainability and maximum sustainable yields are not dependent on population size, and we can sustainably harvest at different population sizes. Fig. 1 shows this for three different population sizes – this can represent the trajectory of a single population, for instance water monitors (*Varanus salvator*) on the Thai-Malay Peninsula, that experiences a series of population declines, but at three different intervals (with large, intermediate and small population sizes) the harvest is sustainable. The sections between A and B, C and D and E and F can also represent three different populations, for instance tokay geckos (*Gekko gecko*) on the islands of Borneo (743,330 km<sup>2</sup>), Sumatra (473,481 km<sup>2</sup>) and Java (128,297 km<sup>2</sup>), that have different population sizes with different likelihoods of extinction.



**Figure 1.** Conceptual framework of the relationship between population size, sustainable harvest and global conservation status. The harvest that took place between A and B, C and D, and E and F, could be considered sustainable, whereas it is unsustainable between B and C and D and E. The global threat assessment based on two of the IUCN threat level criteria (population size and declining populations) are not tightly linked to harvest sustainability (modified after Yamaguchi 2014).

As with all assessments over time the definition of the parameters needs to be the same in both assessments. If a population is initially defined as the number of mature individuals, then it cannot be changed to the total number of individuals later on. Likewise, the area under consideration cannot become increasingly larger over time. From Fig. 1 it is also clear that sustainability and conservation status are not synonymous – on the one end a species can be correctly assessed ‘Least Concern’ (one of the IUCN Red List categories) and harvested unsustainably and, on the other end, an ‘Endangered’ species can be harvested sustainably. It is, however, important to note that harvest quotas are normally set at the species level without taking into account genetic diversity (e.g., Auliya et al. 2002; Murray-Dickson et al. 2017), behavioural variants, or possible cryptic diversity (e.g., Rawlings and Donnellan 2003), and that a lack of checks of what is actually traded may provide opportunities for laundering species under incorrect names (including those of look-alike species). This brings us to legality of trade. There is no one-on-one relationship between sustainability of a harvest and its legality. A species can be harvested sustainably in the absence of a permit to do so, or a species can be legally harvested to extinction (Table 1).

Several studies reported on the sustainability of the harvest and trade in blood pythons *Python brongersmai* in Indonesia based on visits to the same processing fa-

**Table 1.** Relationships between the legality of harvest and trade and its sustainability, with examples from reptiles in Indonesia, based on harvest quotas allocated for 2021 (Anonymous 2021) and seizure data from Shepherd et al. (2020). Only one of these four scenarios, legal and sustainable, is desirable.

	Legal	Illegal
<b>Sustainable</b>	Harvest of 750 tokay geckos ( <i>Gekko gecko</i> ) from Sulawesi and 250 from Bali	Harvest of 250 tokay geckos from the province of Central Kalimantan
<b>Unsustainable</b>	Harvest of 1,992,750 tokay geckos from Java	Harvest of 10,000 s pig-nosed turtles ( <i>Carettocheilus insculpta</i> ) from Papua

cilities and covering the same geographic harvest area (Shine et al. 1999; Semiadi and Sidik 2011; Siregar 2012; Sianturi 2016; Sianturi et al. 2018; Natusch et al. 2020). Shine et al. (1999) concluded that with the data they had available to them it was not possible to assess sustainability. Semiadi and Sidik (2011) noted a 25–50% decline in the number of blood pythons (and to a lesser degree Sumatran pythons (*P. curtus*)) arriving at facilities over a ten-year period. Siregar (2012) suggested that there was no decline in sizes of blood python that were caught but 7/9 harvesters questioned indicated that fewer were caught over time. Sianturi (2018) and Sianturi et al. (2018) concluded that trade was sustainable and Natusch et al. (2020) hinted at an overharvest.

Auliya (2006) indicated that much more research is required to reliably assess the species' long-term sustainability of the harvest and trade in blood pythons, and he noted that the relatively stable export quotas of recent years indirectly conceal trade dynamics. In the Red List assessment, it was noted that in Indonesia, when the legal harvest quota was reached before the end of the year, harvesting continued and skins were stockpiled and smuggled out of the country (Grismer and Chan-Ard 2012). Stockpiling, whereby skins from harvested animals remain with traders over longer periods of time, circumvents the ability to monitor annual harvests and allows for the harvest to occur above and beyond agreed quotas without this being noticed in trade statistics. It remains uncertain whether this additional off-take contributes to a severe decline of local blood python populations (Grismer and Chan-Ard 2012). According to Saputra, the former chair of IRATA, the Indonesian Reptile and Amphibian Trade Association, another significant problem was the smuggling of skins, especially from Sumatra to Singapore, using old permits still available in Singapore (Erdelen et al. 1997).

Sutherland (2001) gave a series of pointers for assessing the sustainability of wildlife harvests. He recognised that it is usually easier (and often cheaper) to measure changes in the numbers exploited (and presumably other relevant biological characteristics such as size) but noted that this measure combines changes in population size and changes in exploitation methodology. He warned that these changes in methodology may be subtle. This includes harvesters having created new paths through a forest, or improved access to transport or a better exchange of information (e.g., mobile phones) within the harvest and trade chain (including harvesters, middlemen, transporters, processors, and exporters). Harvesters also learn and over time get better at finding

their species of interest. If the number of animals removed per day or their size distribution has remained constant over time this can be because the population is indeed being exploited sustainably. It is also possible that population is decreasing but this is compensated for by increased efficiency in harvesting or locating animals, or by expansion of the harvest area. Finally, the population could be increasing, but because of regulations on what can be harvested or traded the number of animals that enter the trade chain remain constant. Sutherland (2001) furthermore noted that if illicit exploitation is taking place, then this will be excluded from the estimates of exploitation.

Using publicly available information I here establish if there is sufficient data to assess whether blood pythons are indeed exploited sustainably. Specifically, I assess the following:

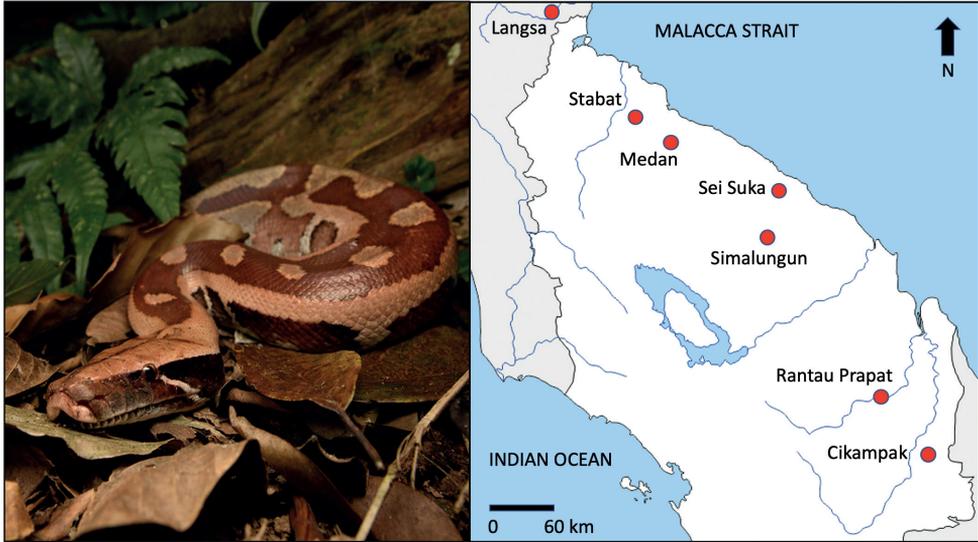
1. Is there a sufficient time between the first and the second assessment period, and if so (a.) do methods of harvest remain the same (or largely similar) between the two assessment periods; (b.) has access to harvest areas changed over the assessment period; (c.) has the harvest area remained the same; (d.) has the regulatory landscape remained the same
2. Is there evidence for illicit trade in blood pythons and if so (a.) does this happen at the national or provincial level; (b.) does this happen at the international level.

## Methods

### Study species

The blood python is found in eastern Sumatra and Bangka, and smaller offshore islands of Indonesia and the Thai-Malay Peninsula (with one record in Vietnam near the Cambodian border: Barker et al. 2018). The species' exact range within Sumatra, e.g., to what extent it occurs in the western, northern and southern parts of the island, is unclear (Auliya 2006; Grismer and Chan-Ard 2012). Blood pythons can grow up to ~250 cm with a mass of 15 kg (females can grow larger than males) and are found in a wide range of habitats, including agroforests and palm oil plantations (Abel 1998; Keogh et al. 2001; Grismer and Chan-Ard 2012; Siregar 2012). Most biological data we have of the species is derived from processing facilities or slaughterhouses (examining the animals that are brought in prior to or after slaughter) (Fig. 2). Indonesia is the main supplier of blood python skins and live blood pythons in international trade.

Blood pythons are not included on Indonesia's protected species list, but their harvest and trade, both domestically and internationally, is regulated by a quota system (Anonymous 2008, 2011, 2016, 2020, 2021). The harvest for domestic trade typically constitutes 10% of what is allowed to be exported. The export of blood pythons is regulated through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), where the species is included on Appendix II (regulating all international commercial trade). The species is listed as Least Concern on the IUCN Red List of Threatened Species (Grismer and Chan-Ard 2012).



**Figure 2.** Left: Blood python (*Python brongersmai*) in Kaeng Krachan National Park, Thailand Right: Map of the province of North Sumatra, Indonesia, indicating the locations of slaughterhouses that were visited by various researchers to assess sustainability of the harvest and trade in blood pythons. Photo by Tontan Travel (CC-BY-SA2.0).

## Data acquisition and analysis

Based on detailed observations in Indonesia between the mid-1990s to present, and through active participation in quota setting meetings, collaboration with NGOs and government bodies, and visits to numerous reptile traders, slaughterhouses, and processing facilities throughout western Indonesia, I gained an insight into the regulatory landscape of the reptile trade in Indonesia. In addition, for 12 years I was a member of the Dutch CITES Scientific Authority, with the Netherlands being one of Indonesia's main wildlife trading partners (Janssen and Blanken 2016), providing me opportunities to observe the international trade in pythons and python skins.

The facilities where pythons are killed and skinned, have their gall bladders and meat removed, and where skins are cleaned, pegged to dry, and processed, are called slaughterhouses (rumah pemotongan or rumah potong in Indonesian) by most of the researchers (e.g., Shine and Harlow 1998, 1999; Shine et al. 1999; Keogh et al. 2001; Auliya et al. 2002; Natusch and Lyons 2014; Sianturi 2018; Sianturi et al. 2018). They were also referred to as skinning premises (Shine and Harlow 1999) or skinneries (Auliya et al. 2002) but in recent years some researchers now refer to them as processing facilities (e.g., Natusch et al. 2016, 2019a, 2019b, 2020). I refer to them as slaughterhouses, acknowledging that just like slaughterhouses for the meat production the activities in these slaughterhouses are not restricted to just the killing of the animals.

To assess if any illicit trade in blood pythons occurred within Indonesia, I first focussed on the annual harvest quotas for the province of North Sumatra in 2015 and

compare them with data collected at various slaughterhouses (Table 2). Sianturi et al. (2018) and Natusch et al. (2020) both visited python slaughterhouses in two cities, i.e., Rantau Prapat (both), Cikampak (Natusch et al. 2020) and Stabat (Sianturi 2018) (Fig. 2). Natusch et al. (2020) report on two periods, i.e., August 1996–June 1997 and November 2014–September 2015, and Sianturi et al. (2018) report on one period, October–December 2015 (Sianturi 2016). Both Natusch et al. (2020) and Sianturi (2016) reported on the number of blood pythons that were brought into these slaughterhouses on the days they were present, and these were considered by them to be representative for the remainder of the year. In an earlier study, Natusch et al. (2018) report on the number of blood pythons brought into three slaughterhouses in North Sumatra combined, i.e., Rantau Prapat and Cikampak, as in Natusch et al. (2020), as well as Simalungan. Subtracting the number that were brought into Rantau Prapat and Cikampak, as reported in Natusch et al. (2020), should give the number for Simalungan. However, the observation days (24), the number of blood pythons (1,019 or 1,020) and mean number of blood pythons arriving per day for the facilities combined (42.5), are the same for Natusch et al. (2018) and Natusch et al. (2020), suggesting that the 2020 study sampled three facilities rather than two.

Secondly, for comparison, I focussed on the province of South Sumatra. Natusch et al. (2018) report on three one day visits in 2015 to one slaughterhouse in Palembang. This facility was also included in the study by Shine et al. (1999).

In calculating the number of blood pythons that were processed in these slaughterhouses in 2015 I conservatively assumed that they are operational six days a week (from experience it is more likely that they receive snakes every day). I obtained harvest quota and export quota data from the website of the Indonesian Ministry of Forestry for the period 2008 to 2022.

The time between the first and the second assessment period in the blood python studies was taken from the data presented in Sianturi et al. (2016) and Natusch et al. (2020). The same sources, in addition to Shine et al. (1999), Siregar (2012) and Sianturi (2016) were used to assess whether the methods of harvest and the harvest areas have remained the same between the two assessment periods. Additional information on the sustainability of the blood python harvest was taken from Semiadi and Sidik (2011). Semiadi and Sidik (2011) visited 10 slaughterhouses throughout North Sumatra (and

**Table 2.** Overview of visits to slaughterhouses to assess the sustainability of the harvest and trade in blood pythons (*Python brongersmai*) in the province of North Sumatra, Indonesia. See Fig. 2 for locations.

Year (total days)	Snakes	Rantau Prapat	Cikampak	Sei Suka	Medan	Stabat	Simalungan	References
1996–1997 ( $\geq 43$ )	2,063	22 days	13 days	$\geq 4$ days	$\geq 4$ days			Shine et al. 1999; Natusch et al. 2020
2007–2008 (<31)	260	not specified			not specified			Semiadi and Sidik 2011
2010 (<90)	not specified	not specified			not specified			Siregar 2012
2014–2015 (24)	1,020	8 days	16 days					Natusch et al. 2020
2014–2015 (24)	1,020	not specified	not specified				not specified	Natusch et al. 2018
2015 ( $\geq 6$ )	541	not specified				not specified		Santiuri 2016; Santiuri et al. 2018

one facility in Langsa just across the border in Aceh), including one or more that were included in the studies mentioned above. They obtained records of the number pythons arriving per month in 2007–2008 and compared them with records from 1998–2000.

To assess any illegal international trade, in January 2022 I obtained data on the trade in blood pythons from the CITES trade database for the period 2004 to 2020. This covers the trade in live blood pythons, skins and leather products. Data from 2021 was not yet available and prior to 2004 Indonesia did not recognise *Python brongersmai* as a species different from *P. curtus* (Keogh et al. 2001). I used data as reported by exporters.

Prices were normally quoted in Indonesian Rupiah; I corrected these for inflation to December 2021 and then converted them to US dollars.

## Results

### Assessing sustainability in the harvest of blood pythons

In order to assess whether or not harvest is sustainable one needs at least two temporary separated assessment points. Semiadi and Sidik (2011) compared records of the number of blood pythons (and to a lesser degree short-tailed pythons) arriving at slaughterhouses in North Sumatra from 1998–2000 with those from 2007–2008 and concluded there had been a 25 to 50% decline. Siregar (2012) based his assessment on information provided by harvesters who were asked to assess if any current trade had changed compared to three years ago (i.e., comparing 2010 with 2007). While the size of the blood pythons reportedly had remained the same, seven out of nine harvesters indicated that fewer blood pythons were harvested and two stated it had remained the same. Siregar (2012) concluded that there was a decrease in catches per area, but this was compensated by an increase of the number of harvest areas. Sianturi et al. (2018) only visited the slaughterhouses over a relatively short period (October–December 2015) thus precluding assessing whether or not harvest was indeed sustainable. The observation that an equal number of males and females are brought into a facility does not provide support that harvest occurs in a random and non-selective manner. Likewise, the observation that 272 female blood pythons were present in two slaughterhouses during three visits does not support the conclusion made by Sianturi et al. (2018) that blood pythons are still abundant in the wild. Natusch et al. (2020) did assess two time periods, but the length of time between the two (up to 20 years), with no data from the intervening period, makes it likely that changes other than just changes in the population of blood pythons have occurred.

### Harvest methods, access and harvest areas

There is clear evidence from North Sumatra that over the last decades there have been marked changes in the way blood pythons are harvested, from opportunistic capture to, at least in part, targeted collection. Likewise, the harvest area has changed as well.

Siregar (2012) found that over a relatively short time period (2007 to 2010) there had been a decrease in the number of blood pythons that could be harvested in any particular area, but this was compensated for by an increase in the area where the species was harvested. Shine et al. (1999: 251) wrote that in 1995–1996 “.. most of the blood pythons came from oil palm plantations near the slaughterhouses, and were often brought in (as single snakes or in small numbers) by the people that had caught them. These snakes had been captured serendipitously, usually in palm oil plantations.” Natusch et al. (2020), working with the same slaughterhouse operators, stated that “... > 80% of pythons were captured from oil palm plantations immediately surrounding the processing facilities (< 50 km) ...” and “... evidence indicated that local people also targeted this species using a flashlight at night, and could actively identify and capture snakes from shelter sites”. Concerning the change in collecting area, Natusch et al. (2020) commented that this “changed little between surveys” but this seems to be at odds with the data provided.

In addition, there have been significant changes in infrastructure in Sumatra with the percentage of road sections that were > 80% paved increasing from 56% in 1995 to 71% in 2005 (Rothenberg 2013), and this has increased in the years since. Hence, in the mid-1990s in North Sumatra, to travel 50 km, over even 40 or 30 km, could be quite an undertaking. “Surrounding the processing facilities (< 50 km)” does not equate with “near the slaughterhouses”, and it would not be profitable to travel tens of kilometres to deliver single or small numbers of blood pythons. It is also worth rephrasing Natusch et al. (2020)’s statement – up to 20% of blood pythons that arrived at the two processing facilities were harvested more than 50 km from these facilities– as this does not give the suggestion of a local harvest and a local trade. The later conclusion is supported by data from 2008 when it was reported that the harvest of blood pythons, Sumatran pythons and reticulated pythons was carried out at distances between 2 to 90 km (and up to 120 km) from the slaughterhouses (Semiadi and Sidik 2011). Erdelen et al. (1997) furthermore indicated that the catchment area of reptile dealers in Rantau Prapat reached as far as Sibolga on the western coast of North Sumatra, at a straight-line distance of 130 km, and to Labuan Bilik on the east coast, a distance of 70 km.

Semiadi and Sidik (2011) noted that it was challenging to gain insight into the state of the python populations in North Sumatra based on information from harvesters and traders, as the change in the number of blood pythons that are brought into slaughterhouses was influenced by more than their status in the wild. They list the complexity of the harvesters-middlemen-exporter network, with individuals moving up and down the network, moving to other networks and establishing their own network. They furthermore note that at times when the price of palm oil was low (e.g., 1999–2000; 2004), many oil palm workers switched to catching wild animals, including blood pythons. Semiadi and Sidik’s (2011) point of reference is a ten-year period (1998–2008) and covers a significant part of the province of North Sumatra, and thus may not be directly comparable to the experiences of individual slaughterhouse owners, but it does give the impression that much has changed in terms of how blood pythons are, and were, harvested.

## Changes in regulation over time

The economic and regulatory landscape of the blood python trade has changed considerably over the last two decades, making it difficult to disentangle whether any change that Natusch et al. (2020) observed between periods is due to changes in the populations of the snakes or due to changes in the decisions consumers, traders and / or harvesters had to make.

Indonesia has an annual quota system in place for the harvest of both CITES listed and non-CITES listed species (Table 3). Exploited species have restrictions on the number of individuals that can be harvested from a specific area (typically a province) and on the number of individuals that can be exported (Amir et al. 1998; Siswomartono 1998; Nijman et al. 2012). Government-approved traders in the reptile skin trade have to be members of IRATA and are allocated part of the quota (expressed as a number of individual snakes) and they cannot trade above and beyond these quotas. If in a given year a trader does not meet its allocated quota it is not allowed to carry the remainder over to the next year. The trade in blood pythons from Indonesia is predominately for international trade. This is regulated through CITES, which oversees a limit on the number of python skins that can be exported (Kasterine et al. 2012). When exports exceed agreed numbers, sanctions can be put in place through CITES. This happened in 2004 when CITES's Scientific Review Group formed a negative opinion on the import of blood pythons from Indonesia and temporarily suspended international trade, and later that year permitted trade subject to the use of species-specific quotas (Kasterine et al. 2012). In recent years it is no longer permitted to harvest gravid female blood pythons (Anonymous 2020), but in the past there was no restriction on this.

**Table 3.** Harvest quotas for blood pythons in Indonesia (number of individuals for the live pet trade / number of individuals for the skin trade) for four selected years; export quotas are 90% of the harvest quotas. Bangka-Belitung was established as its own province in 2000; up to 2020 its quota was included in South Sumatra.

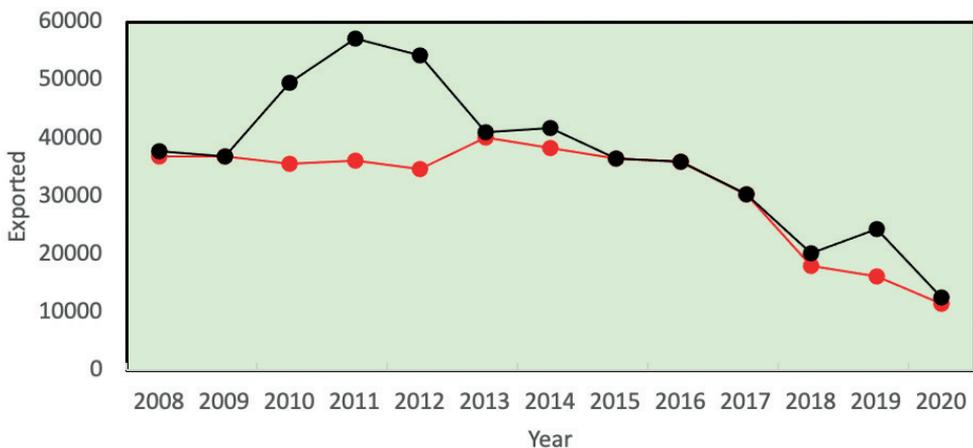
Province	2008	2015	2020	2021
Aceh	0 / 2,850	0 / 10,000	0 / 10,000	600 / 7,100
North Sumatra	1,500 / 21,090	1,500 / 17,840	1,500 / 18,000	1,500 / 20,000
Riau	0 / 4800	300 / 4,900	0 / 4,900	0 / 4,900
West Sumatra	0 / 0	0 / 0	0 / 0	0 / 0
Jambi	0 / 4,000	0 / 4000	0 / 4,000	0 / 4,000
Bengkulu	0 / 0	0 / 0	0 / 0	0 / 0
South Sumatra	250 / 4,300	300 / 4,300	300 / 4,300	700 / 5,000
Bangka-Belitung	-	-	-	0 / 0
Lampung	750 / 4,000	0 / 0	0 / 0	0 / 0
<b>Total</b>	38,740	43,140	43,000	43,800

## Quotas, unregulated and illegal trade

There is considerable evidence of unregulated and illegal trade in blood pythons and that they are harvested in numbers that are above the set quotas. Erdelen et al. (1997)

noted that during their visits to the slaughterhouses of North Sumatra (including those in Rantau Prapat), it could not be determined whether harvesters who delivered their catches were turned away because of the implementation of the quota system. They inferred that the catches that were above the quotas were transferred to other provinces, and an unquantifiable or difficult-to-quantify proportion of this entered the illegal international trade. The province of North Sumatra, where Shine et al. (1999), Semiadi and Sidik (2011), Siregar (2012), Sianturi et al. (2018) and Natusch et al. (2020) conducted their studies, is allocated the largest proportion of Indonesia's blood python quota, and typically, approximately 18,000 individuals are allowed to be harvested each year (Table 3). For the slaughterhouses in Rantau Prapat and Cikampak, Natusch et al. (2020) indicate that 27.0 and 50.2 blood pythons / day are received; Sianturi (2016) suggests this number to be 10 blood pythons / day for Stabat. Combined, the three slaughterhouses receive 87.2 blood pythons/ day; assuming they are operational six days a week this amounts to more than 27,000 blood pythons each year, or around 9,000 over their allocated quota. In order to remain within the quota, on average, these facilities have to be closed for three days of the week, every week. Even if these were the only three slaughterhouses in North Sumatra, the number of snakes processed would be an overharvest of the agreed quotas, similar to that seen for a range of other reptile species (Nijman et al. 2012). However, there are other slaughterhouses that operate in the province (Shine et al. 1999; Semiadi and Sidik 2011; Natusch et al. 2018) (Fig. 2) and Siregar (2012) reported that seven exporters were active in North Sumatra.

Natusch et al. (2018) during three one day visits in 2015 recorded an average of 52 blood pythons per visit in a slaughterhouse in Palembang, South Sumatra. The harvest quota for 2015 for South Sumatra was 4,300; for the facility to remain within its quota it has to be operational, or receive blood pythons, just three times every two weeks.



**Figure 3.** Export of wild-caught blood python skins as reported by exporting range countries (red: Indonesia; black: Indonesia, Singapore, Malaysia, Thailand, Myanmar). Indonesia did not report any export for 2013 or 2014 and for these years data from importing countries was used. In 2009–2012 and 2019–2020 Singapore reported the re-export of large numbers of blood python skins from Indonesia, markedly above what was reported by Indonesia as being exported to Singapore, and this surplus has been added to the total.

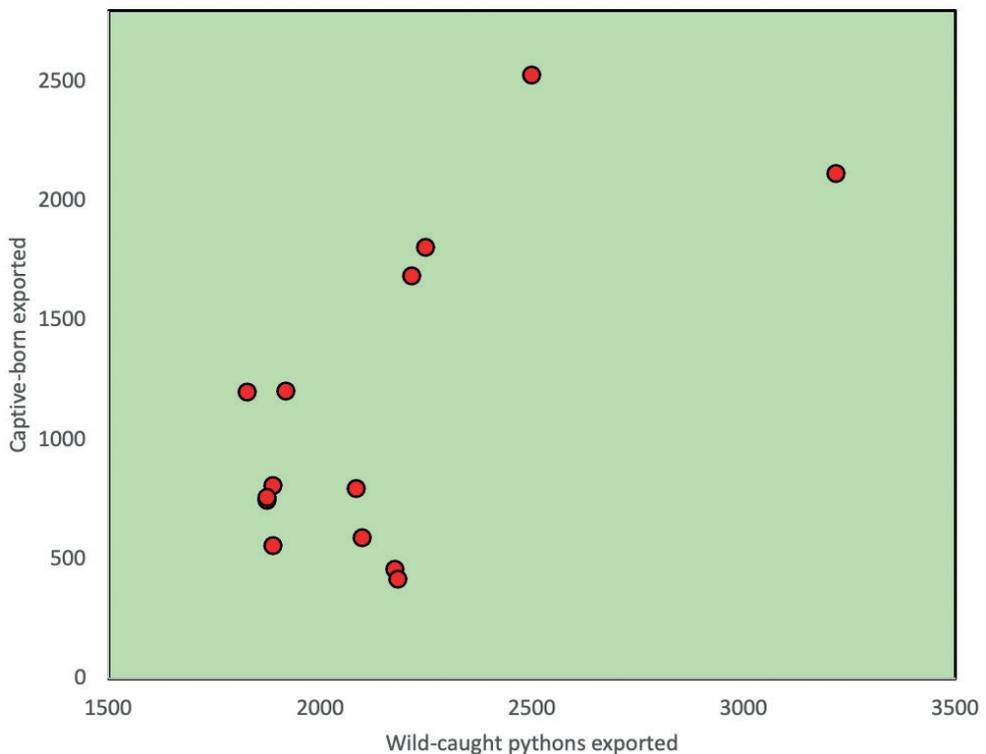
The overall trend of the export of whole skins from wild-caught blood pythons over the last thirteen years is downwards (Pearson's  $r = -0.753$ ,  $P = 0.003$ ) (Fig. 3). This downward trend is not reflected in the setting of Indonesian quotas (Table 3). Singapore emerges as a major re-exporter (i.e., a country that imports blood python skins from Indonesia and other countries and then exports them to other countries); in many years the number of blood python skins Singapore re-exports from Indonesia is substantially above what Indonesia reports as being exported to Singapore. More curious, and potentially of concern, is the re-export of blood python skins by Singapore that they declare as being imported from Lao PDR. For every year between 2009 and 2013 Singapore reported the import of blood pythons from Lao PDR, for a total of 57,500 individuals. Singapore also reported the re-export of 57,980 blood python skins (and 13 small leather products) originating from Lao PDR to the rest of the world. Lao PDR does not report the export of any blood python skins to Singapore (or any other country for that matter) other than 30,000 blood python 'chips' in 2009. The blood python skins are reported as being derived from captive-bred snakes, viz. second-generation offspring of above (CITES source code 'C'). Lao PDR is not a blood python range country and dating back to at least 2003 no country ever reported the export of live blood pythons (or fertilised eggs) to Lao PDR. Moreover, other than the imports and re-exports from Lao PDR, the 1.13 million blood python skins that were exported or re-exported between 2003 and 2020 are all labelled as wild-caught (source code 'W'). Thus, if the data that Singapore reported to the CITES Secretariat are correct then Lao PDR is the only country in the world that exported such large numbers of commercially captive-bred blood pythons for the skin trade, and did so for a short five-year period only, from stock that never was reported as being exported to Lao PDR. Perhaps a more parsimonious explanation is that blood python skins imported and re-exported by Singapore did not come from Lao PDR, were not from captive-bred snakes, but instead were wild-caught individuals imported very likely sourced in Indonesia (as the main trader in blood python skins) or, less likely, West Malaysia.

The CITES trade database also gives some additional information on the legality of the trade in blood pythons. Various countries, including Singapore and Italy, report the international trade of 14,144 blood python skins that were at one point traded without proper permits (CITES source code 'I'), all but seven of these skins, i.e., 99.9%, originated from Indonesia. The 14,137 illegally traded blood python skins that were intercepted, represent 3.0% of the total trade in blood python skins that was reported by Indonesia over this period. Accepting that only a proportion of the illegally exported blood python skins would be intercepted and then traded internationally, this suggests a significant illegal trade in the species.

There are some peculiarities in the export of live blood pythons from Indonesia over the last 17 years (Fig. 3). Just like the trade in skins, their harvest is subject to a quota system, and a large proportion of this (60–70%) is allocated to the province of North Sumatra (Table 3). Typically, for all of Indonesia, each year between 1,890 and 2,250 live blood pythons can be exported for the pet trade, and indeed Indonesia reports the export of, on average,  $2,195 \pm 441$  live wild-caught individuals a year.

In addition, Indonesia reports the export of live captive-born (F), and some captive-bred (C), blood pythons, but these numbers vary considerably between years (mean  $1,112 \pm 731$  individuals, range 0 to 2,527 individuals). Excluding three years when Indonesia did not report the export of any captive-born blood pythons, there is a positive correlation between the (log-transformed) number of wild-caught and captive-born live blood pythons that are exported (Pearson's  $R = 0.8254$ ,  $N = 14$ ,  $P = 0.0003$ ). In years when many wild-caught blood pythons are exported – this being years that the maximum quota is reached – many more captive-born ones are exported in addition to the wild-caught individuals. In years when fewer wild-caught individuals are exported –and when there is room within the quota to export more—far fewer captive-born ones are exported. This may suggest that in certain years when demand is high, wild-caught blood pythons are exported under the label of captive-born.

Finally, the trade in blood pythons from Indonesia is not restricted to whole skins or live animals. Indonesia is also the exporter of small leather products made from wild-caught blood pythons (it reports the export of 67,950 small leather products over the period 2004–2020, Malaysia reports the export of 2 small leather products over



**Figure 4.** Relationship between the annual number of live wild-caught blood pythons that Indonesia reports as being exported between 2004 and 2020 and the number of captive-born blood pythons it exports in that same year. Wild-caught blood pythons are subject to a harvest and export quota (between 1,890 and 2,250 individuals per year) whereas the export of captive-born blood pythons is not subjected to a quota.

this period). For those years that Indonesia did report these exports (in 2013 and 2014 Indonesia did not report any export), on average 4,850 small leather products are exported. It is difficult to convert this to whole animal equivalents, and the export may occur years after the blood pythons have been harvested, but this adds to the export of whole skins and live blood pythons reported above.

## Discussion

### Assessing sustainability in the harvest and trade of blood pythons

I here aimed to establish if there was sufficient data to assess whether blood pythons are exploited sustainably based on information that has been presented in the literature. The first question that needed to be answered was whether there was sufficient time between the first and the second assessment period for an assessment to be made. This varied greatly between studies, ranging from a few months to twenty years. The lower end of this is obviously too short to make an assessment of sustainability and the latter makes it unlikely that what is measured reflects just changes (or the absence of changes) in the population of blood pythons. Siregar (2012) and Semiadi and Sidik (2011) assessed sustainability over a three-year and ten-year period, respectively, and based on information provided by traders found that there had been a decline in numbers that were harvested.

For the studies that assessed change over a longer period, it was clear that the methods, and quite likely intensity, of harvest had not remained the same, with more targeted collecting in the latter compared to the former periods. Likewise, there is good support that in North Sumatra access to harvest areas improved over time. Harvest areas had either been enlarged or significant shifts in harvest areas had occurred. As such any changes in the numbers or sizes or condition of the blood pythons that end up in trade may be due to changes in harvest methods or changes in harvest areas. Conversely, any non-change can be due to genuine stability of the population, or it can be due to harvesters moving to other areas or deploying different collecting strategies. The other areas may even include neighbouring provinces as suggested by Natusch et al. (2018).

While Natusch et al. (2020) stressed that the two slaughterhouses they visited in 1996–1997 and 2014–2015 were continually operated by the same owners, in a similar manner, across the survey period, it appears that the former period included data from visits to slaughterhouses in two cities and the latter period, including data from one more city. Shine et al. (1999) reported on the harvest in blood pythons in four cities, i.e., Medan, Sei Suka, Rantau Prapat, and Cikampak, and the latter two were included in Natusch et al. (2020) study. Natusch et al. (2018) however, reports the same data (survey days, number of blood pythons harvested, harvest rate) as Natusch et al. (2020), but this was obtained by visits not to two but three facilities. The third one, Simalungun, is a five-hour drive from Rantau Prapat and a seven-hour drive from Cikampak so it is unlikely that this could have been legitimately pooled with either

city. Simalungun is also not near Medan or Sei Suka so it cannot have been pooled with these cities in the earlier study (Fig. 2). Hence it seems that Natusch et al. (2020) were comparing data from three slaughterhouses visited in 2014 and 2015 with data from two slaughterhouses in 1996–1997. This obviously is problematic in terms of assessing sustainability of the harvest and trade.

The predictions on how blood python populations were expected to change are based largely on the knowledge of the biology of exploited animal populations (Sianturi 2016; Sianturi et al. 2018; Natusch et al. 2020); they are not based on the decisions made by harvesters, traders, exporters, regulators, or consumers. Biologists only expect these changes in the biological traits of blood python populations over time if the actions of the people involved in the trade remain static. The economic and regulatory landscape of the blood python trade has changed considerably over the last two decades, making it difficult to disentangle whether any change between periods is due to changes in the populations of the snakes or due to changes in the decisions consumers, traders and / or harvesters had to make. Especially changes in how the domestic and international trade is regulated can have a marked impact on what will be observed at a trader's premises. Imagine a trader that is free to buy and sell each and every python that is brought to their processing facility and assume that profits are positively correlated to size (i.e., the largest profit can be made on the largest individuals: corrected for inflation to December 2021 values, Siregar (2012) reported that harvesters in North Sumatra fetch a price of US\$13.35 for a large blood python but only US\$8.00 for a small one, thus supporting that assumption). A logical economic decision for a trader is to buy all those animals that will give a profit, including large, medium, and small ones (but perhaps not the very small ones) especially as the process of inspection and measuring already requires an investment. Over time over-exploitation will lead to harvesters bringing in fewer snakes and proportionally smaller ones and fewer very large ones. These are the assumptions under which Natusch et al. (2020)'s model works, and this was the situation that may have been the case when Shine et al. (1999) collected their data in the late 1990s. But now imagine that a trader is not free to buy whatever he or she wants, and that not all can be sold into a free market (i.e., trade is regulated). In this scenario, the most profitable economic decision is to buy first (or preferably) the ones that will bring the largest profit (in our example, the largest snakes), then the ones that bring in sufficient profit (the medium-sized snakes) but traders will not purchase the smallest ones that bring in only a small profit (using data from Siregar (2012) suggest a loss of potential revenue in the order of 40% if a small rather than a large blood python enters the trade). If the restrictions are time-bound, this may translate into a trader buying only large snakes at the beginning of the year, large and medium-sized snakes in the middle of the year, and large, medium-sized and small snakes at the end of the year to maximize profit. The anthropogenic Allee effect proposes that when prices for wildlife products increase with species rarity, then financial incentives are created to extract the last remaining individuals of a population, despite higher search and harvest costs (Holden and McDonald-Madden 2017). Harvesters and others involved in the blood python trade chain will increase their efforts to catch those snakes that

make the most profit, i.e., the largest individuals, resulting in an increase in costs but not necessarily in a change in the number of large snakes entering the trade. In these scenarios, even for heavily exploited populations one would not necessarily expect to see the changes in snakes at the processing facilities predicted by Natusch et al. (2020) and Sianturi et al. (2018). This is the situation in which blood python snake traders and harvesters operate at present.

### Misdeclared, underreported and illegal trade in blood pythons

As noted by Sutherland (2001) when assessing the sustainability of exploitation, almost invariably, the illicit part of this is not, and often cannot be, taken into account. While in the present study it was not possible to assess whether individual traders had engaged in any illegal activities or had underreported the real intensities of trade, at the aggregate level it is clear that there are numerous indications that blood pythons are traded illegally, that trade is underreported and/or that trade is misdeclared. At the international level, reported levels of trade in blood pythons do not match, and this takes different forms. For instance, Singapore re-exports many more blood python skins from Indonesia than Indonesia exports to Singapore. Lao PDR for a short period was a significant exporter of blood python skins without it being a range country and without it having imported blood pythons to initiate this trade.

Trade in live blood pythons from Indonesia, shows anomalies, whereby in the years that the maximum number of wild-caught individuals is reached, the number of blood pythons that are declared as captive-born (and not included in the annual harvest quota) that are exported actually increases. At least since 2019 it has not been allowed to harvest gravid female blood pythons from the wild and the captive-born and captive-bred blood pythons must have been derived from dedicated captive breeding facilities. It is questionable, however, that actual captive breeding blood pythons makes economic sense. As noted above, depending on the size, harvesters get paid between US\$8–15 for a blood python (Siregar 2012). Housing, feeding, maintaining, and breeding blood pythons in a commercial setting cost more (Anonymous 2011; Siregar 2012). This is supported by research conducted by TRAFFIC (2013) who, for three species of blood python concluded “There is little evidence of captive breeding these species due to the relatively low price paid for skins compared to the larger python species”. The close link with the number of wild-caught blood pythons that are exported and the number of captive-born ones, such that the latter is dependent on the former, suggests an economically uncertain market, and makes it less plausible that blood pythons are indeed bred at a commercial scale (for a similar case with wild-caught vs captive-bred Tokay geckos, see Nijman et al. 2018).

The reason the Indonesian government, and in a global arena, CITES, sets limits on harvest and export, is to prevent species such as the blood python from being overharvested. In Indonesia, it is the Indonesian Institute of Sciences that provides the scientific justification for these limits (Soehartono and Mardiasuti 2002). In Indonesia, for many species Non-Detriment Findings (the conclusion by experts that the

export of specimens of a particular species will not impact negatively on the survival of that species in the wild) are rare (Soehartono and Mardiatuti 2002; Auliya et al. 2016). This is partially due to the lack of biological and harvest data, but also due to economic pressure and lack of political will. In practice then, the final decision on quota numbers and what is harvested where is negotiated and decided upon annually in a meeting where members of the IRATA are present in addition to members of the Indonesian Institute of Sciences and the Ministry of Forestry (Amir et al. 1998; Nijman et al. 2012).

It is possible that one of the outcomes of the studies by Shine et al. (1999), Semiadi and Sidik (2011), Siregar (2012), Sianturi (2016), Sianturi et al. (2018) and Natusch et al. (2020) is to argue that despite a substantial harvest above the permitted quotas and evidence of illegal trade, the harvest in blood pythons as conducted so far is sustainable, and therefore harvest quotas can be (and perhaps should be) raised. I would argue that given that the decisions traders make in relation to what they can and cannot buy and sell are not just theirs to make, the conclusion that the best way to assess sustainability of the commercial harvest is to monitor the attributes of harvested pythons, is flawed.

While harvest quotas for different provinces, or indeed for Indonesia as a whole, differ little from year to year when seen over a longer time period some marked geographic changes are apparent (Table 3). For instance, Riau saw a ten-fold increase and Aceh a more than three-fold increase between 2008 and 2015. Harvest of 4,750 blood pythons (12% of the country's total) was allowed from Lampung in 2008, but none were permitted to be harvested in 2015. While these changes may be indicative of changes in the abundance of blood pythons, possibly due to local overharvesting, they most likely simply reflect the requests of Indonesian Reptile and Amphibian Trade Association members and what they wish to export. The harvest of blood pythons from South Sumatra requires scrutiny and continued monitoring. The data presented by Natusch et al. (2018) may suggest that the number of blood pythons arriving at one slaughterhouse already exceeds agreed quotas. It is furthermore noteworthy that Shine et al. (1999) recorded very few blood pythons at the Palembang slaughterhouse (mean of 11.7 / visit), and Natusch et al. (2018) indicate that very few blood pythons arriving at this facility were harvested in the South Sumatra. There seems to be a consensus that the species is not abundant in the province. The blood pythons that were received originated from Bangka Island (Natusch et al. 2018). Bangka (and the neighbouring island of Belitung) administratively separated from South Sumatra in 2000 and thus became Indonesia's 31<sup>st</sup> province. In the period up to 2019, quota-wise, Bangka was included in South Sumatra, but in 2021 and 2022 it has been given its own quota of zero (Table 3). The quota for South Sumatra has remained stable at 5,000 skins and 700 live blood pythons. Monitoring is required to ensure that blood pythons arriving at the slaughterhouse and at traders' premises in Palembang are indeed harvested in South Sumatra and not in Bangka (as they have been in the past), and conversely, that the harvest of blood pythons on Bangka, a regular occurrence for decades, is indeed completely halted.

## Monitoring of wild populations

Contrary to, for instance Natusch et al. (2019b), as argued convincingly by Sutherland (2001), to assess sustainability of harvest (and trade) it is better to monitor the population than the harvest. For this in-depth and objective analysis of critical population parameters such as harvest rates at different points in time (past, present, and potentially future) and how this affects density is crucial (Challender et al. 2021). The fact that different studies, visiting the same slaughterhouses in roughly the same time period, measuring, in part, the same parameters, come to diametrically opposite conclusions, is testament that just visiting processing facilities to determine sustainability needs reconsidering. Determining changes in population size is better for adjusting the exploitation level as it is the population size that really matters (Sutherland 2001). The reason Natusch et al. (2020) gave for not assessing the sustainability of the trade in pythons directly by measuring the effects of the harvest on the populations themselves, as done by Abel (1998), Riquier (1998) and Auliya (2006), amongst others, and as advocated by Sutherland (2001), was due to difficulties in obtaining these data from the field (another argument is that it is presumably cheaper). The studies conducted by Abel (1998), cited by Natusch et al. (2020) as an example where field studies had been unsuccessful in quantifying abundance and demographic attributes of harvested python populations, and Siregar (2012) offers some insight in the feasibility of conducting mark-recapture population estimates as a potential approach for these assessments. Abel (1998), over a 4 to 5-month period, during which two other reptile species were studied, captured 113 blood pythons, recaptured 22 of them twice and three were recaptured three times. Two professional python harvesters interviewed by Siregar (2012) were able to collect 503 blood pythons over a 7 to 8-month period. With a suitable team, including one or more professional python harvesters, collecting relevant data in a standardised manner from the field rather than from just relying on potentially biased data from processing facilities should be feasible. Based on data Indonesia reported to CITES it exported over three million snake skins over the last decade; there is no valid reason why this multi-million-dollar business cannot properly assess the real effects on the wild populations it is dependent on.

## Conclusion

Measuring sustainability is often done indirectly by testing predictions regarding what would happen if a harvest was not sustainable. These studies in general cannot demonstrate sustainability; at best all they can do is to demonstrate with a level of certainty that harvest is not not sustainable. Five studies commented or attempted to assess sustainability in the harvest of blood pythons in the province of North Sumatra using data from slaughterhouses to establish if vital attributes of the harvested animals changed over time. Semiadi and Sidik (2011) and Siregar (2012), relying on data provided by the staff of the slaughterhouses, suggested that the number of blood pythons that were harvested had declined and that harvesters had shifted collection areas. Shine et al.

(1999) and Sianturi et al. (2018) conducted their studies over relatively short time intervals, and while the former concluded that it was not possible to assess sustainability, the latter suggested it did without providing any relevant data to support this conclusion. Natusch et al. (2020) included data from Shine et al. (1999) in their assessment, and concluded that the harvest had been too severe. However, the introduction of regulations on harvest and export, including harvest and export quotas, likely changes in the harvest area (from near the processing facilities to further away), differences in the number of processing facilities between years (two vs three) and collection methods (from opportunistic to in part targeted collection) largely invalidates their predictions.

As such, despite decades of commercial trade from North Sumatra, there is insufficient data to suggest whether the harvest and trade of blood pythons out of this province is sustainable. Data on the sustainability from other parts of the blood python's range, including from southern Sumatra (Lampung, South Sumatra, Jambi, Bangka) where over the last decade ~100,000 individuals were allowed to be harvested, are lacking. There is, however, substantial evidence of underreported and illegal international trade in blood pythons. Part of any assessment of sustainability of the harvest and trade in blood pythons must address this as a matter of urgency.

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## References

- Abel F (1998) Status, population biology and conservation of the water monitor (*Varanus salvator*), the reticulated python (*Python reticulatus*), and the blood python (*Python curtus*) in Sumatra and Kalimantan, Indonesia—Project report North Sumatra. *Mertensiella* 9: 111–117.
- Amir M, Sugardjito J, Boeadi (1998) The Scientific Authority of CITES, the Indonesian Institute of Sciences, LIPI. *Mertensiella* 9: 17–20.
- Anonymous (2008) Kuota pengambilan tumbuhan alam dan penangkapan satwa liar yang termasuk Appendix CITES untuk periode tahun 2008. Ministry of Forestry, Jakarta.
- Anonymous (2011) Country report of Indonesia: snake trade and conservation. Ministry of Forestry, Jakarta.
- Anonymous (2016) Kuota pengambilan tumbuhan alam dan penangkapan satwa liar – periode tahun 2016. Ministry of Environment and Forestry, Jakarta.
- Anonymous (2020) Kuota pengambilan tumbuhan alam dan penangkapan satwa liar – periode tahun 2020. Ministry of Environment and Forestry, Jakarta.
- Anonymous (2021) Kuota pengambilan tumbuhan alam dan penangkapan satwa liar – periode tahun 2021. Ministry of Environment and Forestry, Jakarta.

- Auliya MA (2006) Taxonomy, life history and conservation of giant reptiles in West Kalimantan (Indonesian Borneo). Natur und Tier-Verlag, Münster.
- Auliya M, Mausfeld P, Schmitz A, Böhme W (2002) Review of the reticulated python (*Python reticulatus* Schneider, 1801) with the description of new subspecies from Indonesia. *Naturwissenschaften* 89(5): 201–213. <https://doi.org/10.1007/s00114-002-0320-4>
- Auliya M, Altherr S, Ariano-Sanchez D, Baard EH, Brown C, Brown RM, Cantu JC, Gentile G, Gildenhuis P, Henningheim E, Hintzmann J, Kanari K, Krvavac M, Lettink M, Lippert J, Luiselli L, Nilson G, Nguyen TQ, Nijman V, Parham JF, Pasachnik SA, Pedrono M, Rauhaus A, Córdova DR, Sanchez M-E, Schepp U, van Schingen M, Schneeweiss N, Segniagbeto GH, Somaweera R, Sy EY, Türkozan O, Vinke S, Vinke T, Vyas R, Williamson S, Ziegler T (2016) Trade in live reptiles, its impact on wild populations, and the role of the European market. *Biological Conservation* 204: 103–119. <https://doi.org/10.1016/j.biocon.2016.05.017>
- Barker DG, Auliya MA, Barker TM (2018) A guide to the identification of the pythons of Indonesia, Papua-New Guinea, Philippines, and continental Asia. Vida Preciosa Library, Boerne.
- Böhm M, Collen B, Baillie JE, Bowles P, Chanson J, Cox N, Hammerson G, Hoffmann M, Livingstone SR, Ram M, Rhodin AGJ, Stuart SN, van Dijk PP, Young BE, Afuang LE, Aghasyan A, García A, Aguilar C, Ajtic R, Akarsu F, Alencar LRV, Allison A, Ananjeva N, Anderson S, Andrés C, Ariano-Sánchez D, Arredondo JC, Auliya M, Austin CC, Avci A, Baker PJ, Barreto-Lima AF, Barrio-Amorós CL, Basu D, Bates MF, Batistella A, Bauer A, Bennett D, Böhme W, Broadley D, Brown R, Burgess J, Captain A, Carreira S, Castañeda MR, Castro F, Catenazzi A, Cedeño-Vázquez JR, Chapple DG, Cheylan M, Cisneros-Heredia DF, Cogalniceanu D, Cogger H, Corti C, Costa GC, Couper PJ, Courtney T, Crnobrnja-Isailovic J, Crochet P-A, Crother B, Cruz F, Daltry JC, Daniels RJR, Das I, de Silva A, Diesmos AC, Dirksen L, Doan TM, Dodd Jr CK, Doody JS, Dorcas ME, Duarte de Barros Filho J, Egan VT, El Mouden EH, Embert D, Espinoza RE, Fallabrino A, Feng X, Feng Z-J, Fitzgerald L, Flores-Villela O, França FGR, Frost D, Gadsden H, Gamble T, Ganesh SR, Garcia MA, García-Pérez JE, Gatus J, Gaulke M, Geniez P, Georges A, Gerlach J, Goldberg S, Gonzalez J-CT, Gower DJ, Grant T, Greenbaum E, Grieco C, Guo P, Hamilton AM, Hare K, Hedges SB, Heideman N, Hilton-Taylor C, Hitchmough R, Hollingsworth B, Hutchinson M, Ineich I, Iverson J, Jaksic FM, Jenkins R, Joger U, Jose R, Kaska Y, Kaya U, Keogh JS, Köhler G, Kuchling G, Kumlutaş Y, Kwet A, La Marca E, Lamar W, Lane A, Lardner B, Latta C, Latta G, Lau M, Lavin P, Lawson D, LeBreton M, Lehr E, Limpus D, Lipczynski N, Lobo AS, López-Luna MA, Luiselli L, Lukoschek V, Lundberg M, Lymberakis P, Macey R, Magnusson WE, Mahler DL, Malhotra A, Mariaux J, Maritz B, Marques OAV, Márquez R, Martins M, Masterson G, Mateo JA, Mathew R, Mathews N, Mayer G, McCranie JR, Measey GJ, Mendoza-Quijano F, Menegon M, Métrailler S, Milton DA, Montgomery C, Morato SAA, Mott T, Muñoz-Alonso A, Murphy J, Nguyen TQ, Nilson G, Nogueira C, Núñez H, Orlov N, Ota H, Ottenwalder J, Papenfuss T, Pasachnik S, Passos P, Pauwels OSG, Pérez-Buitrago N, Pérez-Mellado V, Pianka ER, Pleguezuelos J, Pollock C, Ponce-Campos P, Powell R, Pupin F, Quintero Díaz GE, Radder R, Ramer J, Rasmussen AR, Raxworthy C, Reynolds R, Richman N, Rico EL, Riservato E, Rivas G, da Rocha PLB, Rödel M-O, Rodríguez Schettino L, Roosenburg WM, Ross JP, Sadek R, Sanders K, Santos-Barrera G, Schleich HH, Schmidt BR, Schmitz A, Sharifi M, Shea G, Shi H-T, Shine R, Sindaco R, Slimani T, Somaweera R, Spawls S, Stafford P, Stuebing R, Sweet

- S, Sy E, Temple HJ, Tognelli MF, Tolley K, Tolson PJ, Tuniyev B, Tuniyev S, Üzümlü N, van Buurt G, Van Sluys M, Velasco A, Vences M, Veselý M, Vinke S, Vinke T, Vogel G, Vogrin M, Vogt RC, Wearn OR, Werner YL, Whiting MJ, Wiewandt T, Wilkinson J, Wilson B, Wren S, Zamin T, Zhou K, Zug G (2013) The conservation status of the world's reptiles. *Biological Conservation* 157: 372–385. <https://doi.org/10.1016/j.biocon.2012.07.015>
- Challender DW, Brockington D, Hinsley A, Hoffmann M, Kolby JE, Massé F, Natusch DJ, Oldfield TE, Outhwaite W, 't Sas-Rolfes M, Milner-Gulland EJ (2021) Mischaracterizing wildlife trade and its impacts may mislead policy processes. *Conservation Letters* 15: e12832. <https://doi.org/10.1111/conl.12832>
- Cox N, Young BE, Bowles P, Fernandez M, Marin J, Rapacciuolo G, Böhm M, Brooks TM, Blair Hedges S, Hilton-Taylor C, Hoffmann M, Jenkins RKB, Tognelli MF, Alexander GJ, Allison A, Ananjeva NB, Auliya M, Avila LJ, Chapple DG, Cisneros-Heredia DF, Cogger HG, Colli GR, de Silva A, Eisemberg CC, Els J, Fong A, Grant TD, Hitchmough RA, Iskandar DT, Kidera N, Martins M, Meiri S, Mitchell NJ, Molur S, Nogueira CDC, Ortoz JC, Penner J, Rhodin AGJ, Rivas GA, Rödel MA, Roll U, Sanders KL, Santos-Barrera G, She GM, Spawls S, Stuart BL, Tolley KA, Trape JF, Vidal MA, Wagner P, Wallace BP, Xie Y (2022) A global reptile assessment highlights shared conservation needs of tetrapods. *Nature* 2022: 1–10 <https://doi.org/10.1038/s41586-022-04664-7>
- Erdelen W, Abel F, Riquier M (1997) Status, Populationsbiologie und Schutz von Bindenwaran (*Varanus salvator*), Netzpython (*Python reticulatus*) und Blutpython (*Python curtus*) in Sumatra und Kalimantan, Indonesien. Federal Agency for Nature Conservation, Bonn.
- Gibbons JW, Scott DE, Ryan TJ, Buhlmann KA, Tuberville TD, Metts BS, Greene JL, Mills T, Leiden Y, Poppy S, Winne CT (2000) The Global Decline of Reptiles, Déjà Vu Amphibians: Reptile species are declining on a global scale. Six significant threats to reptile populations are habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change. *Bioscience* 50(8): 653–666. [https://doi.org/10.1641/0006-3568\(2000\)050\[0653:TGDORD\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2000)050[0653:TGDORD]2.0.CO;2)
- Grismer L, Chan-Ard T (2012) *Python brongersmai*. The IUCN Red List of Threatened Species 2012: e.T192169A2050353. <https://doi.org/10.2305/IUCN.UK.2012-1.RLTS.T192169A2050353.en> [Downloaded on 04 March 2021]
- Holden MH, McDonald-Madden E (2017) High prices for rare species can drive large populations extinct: The anthropogenic Allee effect revisited. *Journal of Theoretical Biology* 429: 170–180. <https://doi.org/10.1016/j.jtbi.2017.06.019>
- Janssen J (2021) A primer to the global trade of reptiles: Magnitude, key challenges, and implications for conservation. In: Underkoffler SC, Adams HR (Eds) *Wildlife Biodiversity Conservation*. Springer, New York, 439–461. [https://doi.org/10.1007/978-3-030-64682-0\\_17](https://doi.org/10.1007/978-3-030-64682-0_17)
- Janssen J, Blanken LJ (2016) *Going Dutch: An analysis of the import of live animals from Indonesia by the Netherlands*. TRAFFIC, Cambridge.
- Kasterine A, Arbeid R, Caillabet O, Natusch D (2012) *The trade in South-East Asian python skins*. International Trade Centre, Geneva.
- Keogh JS, Barker DG, Shine R (2001) Heavily exploited but poorly known: Systematics and biogeography of commercially harvested pythons (*Python curtus* group) in Southeast Asia. *Biological Journal of the Linnean Society*. *Linnean Society of London* 73(1): 113–129. <https://doi.org/10.1111/j.1095-8312.2001.tb01350.x>

- Marshall BM, Strine C, Hughes AC (2020) Thousands of reptile species threatened by under-regulated global trade. *Nature Communications* 11(1): 1–12. <https://doi.org/10.1038/s41467-020-18523-4>
- Murray-Dickson G, Ghazali M, Ogden R, Brown R, Auliya M (2017) Phylogeography of the reticulated python (*Malayopython reticulatus* ssp.): Conservation implications for the worlds' most traded snake species. *PLoS ONE* 12(8): e0182049. <https://doi.org/10.1371/journal.pone.0182049>
- Natusch DJD, Lyons JA (2014) Assessment of python breeding farms supplying the international high-end leather industry. Occasional Paper of the IUCN Species Survival Commission No. 50. IUCN, Gland.
- Natusch DJ, Lyons JA, Riyanto A, Shine R (2016) Jungle giants: Assessing sustainable harvesting in a difficult-to-survey species (*Python reticulatus*). *PLoS ONE* 11(7): 0158397. <https://doi.org/10.1371/journal.pone.0158397>
- Natusch DJ, Lyons JA, Riyanto A, Shine R (2018) Interspecific divergence in biological attributes of short-tailed pythons (*Python breitensteini* and *P. brongersmai*) from Kalimantan and Sumatra. *Australian Journal of Zoology* 66(4): 272–278. <https://doi.org/10.1071/ZO19011>
- Natusch DJD, Fitzgerald L, Lyons JA, Toudonou ASC, Micucci P, Waller T (2019a) Harvest monitoring of snakes in trade. A guide for wildlife managers. IUCN SSC Occasional Paper no. 65. IUCN, Gland.
- Natusch DJD, Lyons JA, Riyanto A, Mumpuni, Khadiejah S, Shine R (2019b) Detailed biological data are informative, but robust trends are needed for informing sustainability of wildlife harvesting: A case study of reptile offtake in Southeast Asia. *Biological Conservation* 233: 83–92. <https://doi.org/10.1016/j.biocon.2019.02.016>
- Natusch DJD, Lyons JA, Riyanto A (2020) Harvest effects on blood pythons in North Sumatra. *The Journal of Wildlife Management* 84(2): 249–255. <https://doi.org/10.1002/jwmg.21790>
- Nijman V (2010) An overview of international wildlife trade from Southeast Asia. *Biodiversity and Conservation* 19(4): 1101–1114. <https://doi.org/10.1007/s10531-009-9758-4>
- Nijman V, Shepherd CR, Mumpuni, Sanders KL (2012) Over-exploitation and illegal trade of reptiles in Indonesia. *The Herpetological Journal* 22: 83–89.
- Nijman V, Imron MA, Nekarlis KAI (2018) Trade in Tokay geckos for medicine on Java. *Journal of Indonesian Natural History* 6: 36–40.
- Rawlings LH, Donnellan SC (2003) Phylogeographic analysis of the green python, *Morelia viridis*, reveals cryptic diversity. *Molecular Phylogenetics and Evolution* 27(1): 36–44. [https://doi.org/10.1016/S1055-7903\(02\)00396-2](https://doi.org/10.1016/S1055-7903(02)00396-2)
- Reznick D, Bryant MJ, Bashey F (2002) R- and K-selection revisited: The role of population regulation in life history evolution. *Ecology* 83(6): 1509–1520. [https://doi.org/10.1890/0012-9658\(2002\)083\[1509:RAKSRT\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2002)083[1509:RAKSRT]2.0.CO;2)
- Riquier MA (1998) Status, population biology and conservation of the water monitor (*Varanus salvator*), the reticulated python (*Python reticulatus*), and the blood python (*Python curtus*) in Sumatra and Kalimantan, Indonesia—Project report Kalimantan. *Mertensiella* 9: 119–129.
- Rothenberg AD (2013) Transport infrastructure and firm location choice in equilibrium: evidence from Indonesia's highways. Department of Economics, University of California, Berkeley.

- Scheffers BR, Oliveira BF, Lamb I, Edwards DP (2019) Global wildlife trade across the tree of life. *Science* 366(6461): 71–76. <https://doi.org/10.1126/science.aav5327>
- Schlaepfer MA, Hoover C, Dodd K (2005) Challenges in evaluating the impact of the trade in amphibians and reptiles on wild populations. *Bioscience* 55(3): 256–264. [https://doi.org/10.1641/0006-3568\(2005\)055\[0256:CIETIO\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2005)055[0256:CIETIO]2.0.CO;2)
- Semiadi G, Sidik I (2011) Karakteristik penangkapan ular di wilayah Sumatera Utara. *Biota* 16: 206–213. <https://doi.org/10.24002/biota.v16i2.101>
- Shepherd CR, Gomez L, Nijman V (2020) Illegal wildlife trade, seizures and prosecutions: A 7.5-year analysis of trade in pig-nosed turtles *Carettochelys insculpta* in and from Indonesia. *Global Ecology and Conservation* 24: e01249. <https://doi.org/10.1016/j.gecco.2020.e01249>
- Shine R, Harlow PS (1998) Ecological divergence among sympatric colour morphs in blood pythons, *Python brongersmai*. *Oecologia* 116(1–2): 113–119. <https://doi.org/10.1007/s004420050569>
- Shine R, Harlow PS (1999) Reticulated pythons in Sumatra: Biology, harvesting and sustainability. *Biological Conservation* 87(3): 349–357. [https://doi.org/10.1016/S0006-3207\(98\)00068-8](https://doi.org/10.1016/S0006-3207(98)00068-8)
- Shine R, Ambariyanto, Harlow PS, Mumpuni (1999) Ecological attributes of two commercially-harvested *Python* species in northern Sumatra. *Journal of Herpetology* 33(2): 249–257. <https://doi.org/10.2307/1565722>
- Sianturi MMP (2016) Kajian biologi ular sanca darah merah (*Python brongersmai* Stull, 1938) guna pemanfaatan hasil tangkapan secara berkelanjutan. MSc thesis, Universitas Sumatera Utara, Medan.
- Sianturi MMP, Jumilawaty E, Hartanto A (2018) Predicting size limit of wild blood python (*Python brongersmai* Stull, 1938) harvesting in North Sumatera. IOP Conference Series. Earth and Environmental Science 130(1): e012052. <https://doi.org/10.1088/1755-1315/130/1/012052>
- Siregar J (2012) Upaya pelestarian pemanfaatan ular sanca batik (*Python reticulatus*) dan ular darah merah (*Python brongersmai*) ditinjau dari aspek penangkapan dan pemasarannya di provinsi Sumatera Utara. MSc thesis, Institut Pertanian Bogor, Bogor.
- Siswomartono W (1998) Review of the policy and activities of wildlife utilization in Indonesia. *Mertensiella* 7: 37–44.
- Soehartono T, Mardiatuti A (2002) CITES – Implementation in Indonesia. Nagao NEF, Jakarta.
- Sutherland W (2001) Sustainable exploitation: A review of principles and methods. *Wildlife Biology* 7(3): 131–140. <https://doi.org/10.2981/wlb.2001.017>
- TRAFFIC (2013) Inspection manual for use in commercial reptile breeding facilities in South-east Asia. CITES, Geneva.
- Tsikliras AC, Froese R (2019) Maximum sustainable yield. *Encyclopedia of Ecology* 1: 108–115. <https://doi.org/10.1016/B978-0-12-409548-9.10601-3>
- Yamaguchi N (2014) Biodiversity conservation and sustainability. *Sustainable Development: An Appraisal from the Gulf Region* 19: 291–310.