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Original Research Article

Valuable stones: The trade in porcupine bezoars

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ABSTRACT

Old-world porcupines (Order: *Rodentia* Family: *Hystricidae*) face many threats, including an increasing demand for their different body parts such as meat, quills, hairs and bezoars. Bezoars are masses of undigested organic and inorganic material that are occasionally formed in an animal's gastrointestinal tract. Bezoars of a variety of species, especially porcupines, have been used for medicinal purposes for centuries and have high commercial value. Demand for bezoars appears to have increased substantially in recent years. We monitored e-commerce websites in Singapore, Malaysia, and Indonesia to estimate the extent of porcupine bezoars for sale. We found 121 listings (excluding listings advertising supply ability instead of specific bezoars) advertising approximately 680–1332 bezoars and likely representing ten-fold as many porcupines within our three month study period. Most listings were from sellers located in Indonesia, followed by sellers from Malaysia, and Singapore. The mean adjusted price per gram was 151.8 USD, which is substantially lower than previously reported prices in the literature. Porcupines have an important ecological role and highly developed social structures. Current trade levels are likely unsustainable and we predict that porcupine species may become threatened in the future should current trade levels continue. We urge source and consumer countries to: (i) review the species' conservation status in range countries; (ii) regulate domestic trade through legislative changes in countries where trade is most prominent; and (iii) ensure existing laws are enforced. Additionally, the Hystricidae may benefit from a CITES Appendix II listing to monitor and regulate the international trade.

1. Introduction

Millions of people globally are dependent on wildlife for their livelihoods, either through direct use or as a source of income (Spenceley, 2012; Robinson, 2016; Sinovas et al., 2017; Stone and Nyaupane, 2018). The trade in wildlife species can be sustainable (Bodmer and Lozano, 2001; Natusch et al., 2016); however, some species are more vulnerable to persistent harvesting pressure than others (Sigouin et al., 2017). If wildlife trade is not consistently monitored and regulated in order to detect and prevent potential negative impacts on populations, even abundant species can quickly become depleted before protective measures are taken (Harrison, 2011; Nijman and Shepherd, 2015). This was the case, for example, for pangolins

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(Order: *Pholidota*, Family: *Manidae*), which were once widespread, but are now heavily threatened, largely due to unsustainable exploitation and illegal trade (Newton et al., 2008; Heinrich et al., 2016).

Old-world porcupines (Order: *Rodentia*, Family: *Hystricidae*) are often encountered in trade. There are eleven species of Hystricidae, eight of which are native to Asia, and three to Africa (Rovie-Ryan et al., 2017). Porcupines and their parts and derivatives have been used and traded for centuries – their meat is consumed as an important source of protein, their quills and hairs are used for decorative purposes, and their inner organs and derivatives are used for medicinal purposes (Sodeinde and Soewu, 1999; Chevallier and Ashton, 2006; Brooks et al., 2010; Duffin, 2013; Barthelmess, 2016; Altaf et al., 2018). Porcupines are among the most frequently encountered animals in surveyed markets across Asia (Luskin et al., 2014; Cantlay et al., 2017) and Africa (Fa et al., 2000; Basa et al., 2017).

Some animals, including porcupines, occasionally produce a stone-like structure in their gastrointestinal tract due to a high intake of non-digestible food materials (Yew et al., 2018). These so called 'bezoars', are masses of undigested organic and inorganic material, and have been used for medicinal purposes for centuries (Duffin, 2013). The word 'bezoar' is derived from the Persian 'padzhar' which literally translates to 'antidote' (Duffin, 2013). Bezoars were first reported to be used as far back as 968 AD in Arabia and Persia, from where it was adopted by Europeans (Duffin, 2013). By the 16th century, porcupine supply had come under such pressure, that fake bezoars and bezoars of a variety of other animal species had flooded the market. During the 16th to late 19th century, the European market value for porcupine bezoar was as high as forty times its own weight in gold (Duffin, 2013). Early supplies reportedly came predominantly from Asia, and today, bezoars continue to be used in traditional medicines to cure a variety of ailments, including cancer, inflammation, and dengue fever (Wong and AbuBakar, 2013; Yew et al., 2018).

Bezoars can reportedly be derived from a variety of animals, including goats, cattle, monkeys or porcupines (Yew et al., 2018). *Calculus bovis*, for example, the bezoar derived from ox/cattle, is reported to be frequently used in traditional Chinese medicine (TCM) (Yew et al., 2018; Dan et al., 2016). To obtain a bezoar the animal has to be killed and, at least in the case of porcupines, only a small proportion of killed animals in fact contain the valuable stone. It is unknown what exact percentage of porcupines actually contain bezoar, however, the formation is believed to be incidental (Mori and Sforzi, 2013; Tan et al., 2019).

To our knowledge, no study to date has focussed specifically on the trade in porcupine bezoars and its conservation implications. In recent years, the trade in wildlife has increasingly moved from physical to e-commerce marketplaces (Lavorgna, 2014; Siriwat and Nijman, 2018, 2020; Nijman, 2020). While the magnitude and rate of this transition inevitably differs between countries, study taxa and use-types, the surveillance of e-commerce trade in wildlife is essential for anticipating emergent trade-based threats. Considering the increasing shift to online markets, here we investigate the trade in porcupine bezoar on e-commerce platforms and provide evidence for online bezoar trade in Indonesia, Malaysia and Singapore. Our aims are three-fold: (i) to raise awareness about the potentially unsustainable trade in porcupines throughout Asia; (ii) to call for further research into, and monitoring of, this trade; and (iii) to recommend informed legislative management strategies to alleviate the threat posed by this trade.

2. Methods

We conducted preliminary online searches of e-commerce platforms known or suspected *a priori* to facilitate the trade of porcupine bezoars across May–June 2019, in order to (i) examine the frequency of bezoar trade on each platform, (ii) generate a list of specific keywords, and (iii) develop inclusion/exclusion criteria for relevant websites selling porcupine bezoars. Based on our preliminary study, we used selected search terms, followed by the phrase 'for sale', to select a candidate list of e-commerce sites on the Google search engine (https://www.google.com). The selected search terms, in English, Malay, Indonesian, and Chinese/Mandarin, were: porcupine bezoar/date/stone, lord of the herbs, Hao Zhu Zhao, 豪猪枣, batu landak and geliga landak. Only the first ten results for each Google search were included in our candidate list. Candidate sites were excluded if (i) no evidence of porcupine bezoar trade was identified, (ii) fewer than three new listings were added during the preliminary study, and (iii) at least some listings advertised a specific quantity of bezoar product (wholesale or powdered) rather than supply capacity. If candidate sites had multiple sub-sites (for different countries, e.g., Shopee), the total number of listings across sub-sites was considered as an inclusion/exclusion criterion.

We selected 11 e-commerce sites where porcupine bezoar appeared to be widely available: i) Alibaba, ii) Shopee (Malaysia, Singapore, Indonesia), iii) Borneo Porcupine Bezoar, iv) Lazada (Malaysia, Singapore), v) Instagram, vi) Bukalapak, vii) Asia-Porcupine (Malaysia), viii) Carousell (Singapore), ix) MiracleMedicine (Malaysia), x) Mudah (Malaysia) and xi) Qoo10 (Singapore). We sampled these sites for listings pertaining to the sale specifically of porcupine bezoars from July–October 2019. If we observed more than five new listings on a site during the preliminary study, monitoring took place on a weekly basis, otherwise monitoring was conducted monthly. If listings advertised porcupine bezoars among other wildlife-derived products (e.g., cow bezoars), we excluded the listing. We also excluded listings that advertised supply capacity rather than individual products, and it should be noted that some of these excluded listings advertised implausibly high quantities of bezoars per year (2000 tons in one instance). In total, our criteria led to the exclusion of seven listings on the monitored websites.

For all included listings, we assumed the supplied information in regards to taxa, quantity and authenticity to be accurate, a caveat associated with most e-commerce trade studies. We acknowledge that this limitation may potentially result in inaccuracies. However, given that the trade in porcupine derived products is currently poorly regulated, we assume there

would be relatively low incentive to falsely declare the intention to sell porcupine bezoars. We have taken several steps to preserve the anonymity of online traders. We recorded trader usernames in order to help identify potential duplicate products, then de-identified usernames after data collection was complete. The username information will remain anonymous and confidential. Additionally, any figures displaying trader activity were modified to remove identifiable information.

There are five general classifications of so called 'phytobezoars' (i.e., bezoars that consist of primarily plant and organic material); these include i) blood date, ii) grassy date, iii) powdery date, iv) black date, and v) kernel date. These subtypes differ in their appearance and structure (for more details see Yew et al. (2018)). While it was deemed beyond the scope of our study to determine whether bezoar classes truly differ in medicinal efficacy, we noted during our preliminary study that there was a perceived difference in quality and price between bezoar types and hypothesised that this perception may affect trade dynamics. As such, we classified the bezoars accordingly based on the description and the pictures provided in the listings.

If listings provided a price range, we recorded the highest price. If no specific information about shipping was provided, the product was considered not to be shipped internationally, unless advertised on an international e-commerce site with access to international customers. For listings advertising powdered forms of porcupine bezoar, if no quantity units (i.e., individual bezoars) were specified, we assumed quantity referred to grams. Conversely, for wholesale bezoar listings, we assumed quantity referred to the total number of bezoars for sale. Based on listings that provided both bezoar wholesale quantity and overall weight ($n = 53$), we calculated the mean bezoar weight in grams from a total of 159 individual bezoars. Prior to analysis, all listings that provided quantity only were converted into 'adjusted' number of bezoars, using the mean bezoar weight that was calculated earlier.

Indonesian Rupiah, Malaysian Ringgit and Singapore Dollars were standardised to US Dollars (USD; www.xe.com) on the day of recording. For listings where price per bezoar was provided, the mean weight per bezoar was used to standardise all listing price information to adjusted price per gram prior to analysis.

Bezoar price was compared between country of sale and bezoar type using two-way ANOVA. The data were analysed in the R software environment (version 3.6.1; R Core Team (2019)). The map was created using the 'leaflet' package (Cheng et al., 2018).

3. Results

A total of 121 listings were found on 11 websites during the three month study period (Table 1).

The search term languages that resulted in the most listings were in Malay/Indonesian ($n = 71$ listings), followed by English ($n = 69$) and Chinese/Mandarin ($n = 26$). Most of the 77 sellers (84%) only had a single listing online. Only 12 sellers had more than one listing, with 17 being the maximum number of listings per seller. In 24 of the listings (19%) the sellers also specifically indicated that international shipping was available.

There were a total of 63 listings from Indonesia, 41 from Malaysia, six from Singapore, and 11 where no country could be assigned to the seller (e.g., a listing from an international site with deficient seller information). Most listings were from sellers located in Java, followed by the Malay Peninsula, Borneo, Sumatra, and the Riau Islands (Fig. 1). On Java, 77% of listings ($n = 24$) indicated the location of the seller in Jakarta, but additional listings also came from West-, East- and Central-Java, and Banten. In Peninsular Malaysia, most listings came from the province of Selangor ($n = 21$), but other provinces were also involved, i.e., Kuala Lumpur, Johor, Melaka, Negeri Sembilan, and Perlis. On Borneo we found listings in West Kalimantan ($n = 12$) and Sabah ($n = 4$).

The most commonly advertised type of bezoar was blood bezoar (51), followed by powdery (24), black (19), and grassy bezoar (15). There were 16 listings that did not specify a bezoar type, nor could a type be derived from product images (e.g., when in powdered form).

Table 1
Number of listings on the monitored websites, and the corresponding quantity (whole bezoars) and weight (in grams) of advertised bezoars. Grams and whole bezoars are independent of each other.

Website	# Listings	Grams (if specified)	Bezoars (if specified)
Instagram	48	3623	98
Shopee Malaysia	16	3328	95
Alibaba	14	13279	95
Bukalapak	14	505	28
Shopee Indonesia	6	168	4
Lazada Malaysia	4	83.1	3
Borneo Porcupine Bezoar	3	772	46
AsiaPorcupine Malaysia	3	–	3
Carousell Singapore	3	48.6	3
MiracleMedicine Malaysia	3	1115	24
Mudah Malaysia	3	19.6	18
Qoo10 Singapore	2	10	20
Lazada Singapore	1	10	–
Shopee Singapore	1	10	6
Total	**121**	**22971.12**	**443**

A total of 443 individual bezoars were identified for sale over the study period. The mean weight per bezoar was 44.25 g (95% CI: 18.6–69.9). Based on this estimate of mean weight per bezoar, sales of bezoars in powdered form represent an additional 237 to 889 total bezoars, assuming powdered products contained no additional products as advertised. The cumulative number of bezoars detected over the study period is approximately 680–1332.

The mean adjusted price per gram was 151.8 USD (95% CI: 105.5–198.2). Bezoar price (±SE) was higher in Malaysia (USD 182.8 ± 35.57) compared with Indonesia (USD 124.6 ± 37.08) and Singapore (USD 119.31 ± 72.6) (Fig. 2). Blood (USD 188.9 ± 36.83) and powdery (USD 229.5 ± 82.35) bezoar prices were higher than other bezoar types. However, we found no statistically significant differences in price per gram between countries of sale ($F = 0.658$, $P = 0.524$) nor bezoar types ($F = 0.779$, $P = 0.545$).

4. Discussion

4.1. Bezoar trade

Porcupines are perceived as a 'common' taxa. Yet, in reality, they face many threats, including habitat destruction, persecution as agricultural pests, and unsustainable exploitation (Brooks et al., 2010; Manzar and Nehvi, 2012; Talukdar et al., 2019). Their different body parts have been consumed for centuries, for decoration, traditional medicines, and meat. Currently, demand for bezoars appears to be on the rise and is putting additional pressure on all porcupine species. Here we show that there is considerable porcupine bezoar trade in Southeast Asia and, as we only monitored individual bezoar sales and excluded listings that advertised supply ability, our results are certainly underestimating the true extent of this trade.

There are several limitations to our study including the relatively short data collection period and the fact that it is impossible to determine with certainty whether or not the advertised bezoars are genuine or fake from the pictures alone, and whether the advertised quantities are correct, as the bezoars and stocks could not be physically examined. For the purpose of this study we had to assume that the provided information is correct, but we acknowledge that this may potentially result in inaccuracies. Even if stocks could be physically examined it can be challenging to determine whether a bezoar is fake or authentic. Consequently, it is also possible that especially bezoars sold in powdered form contain other

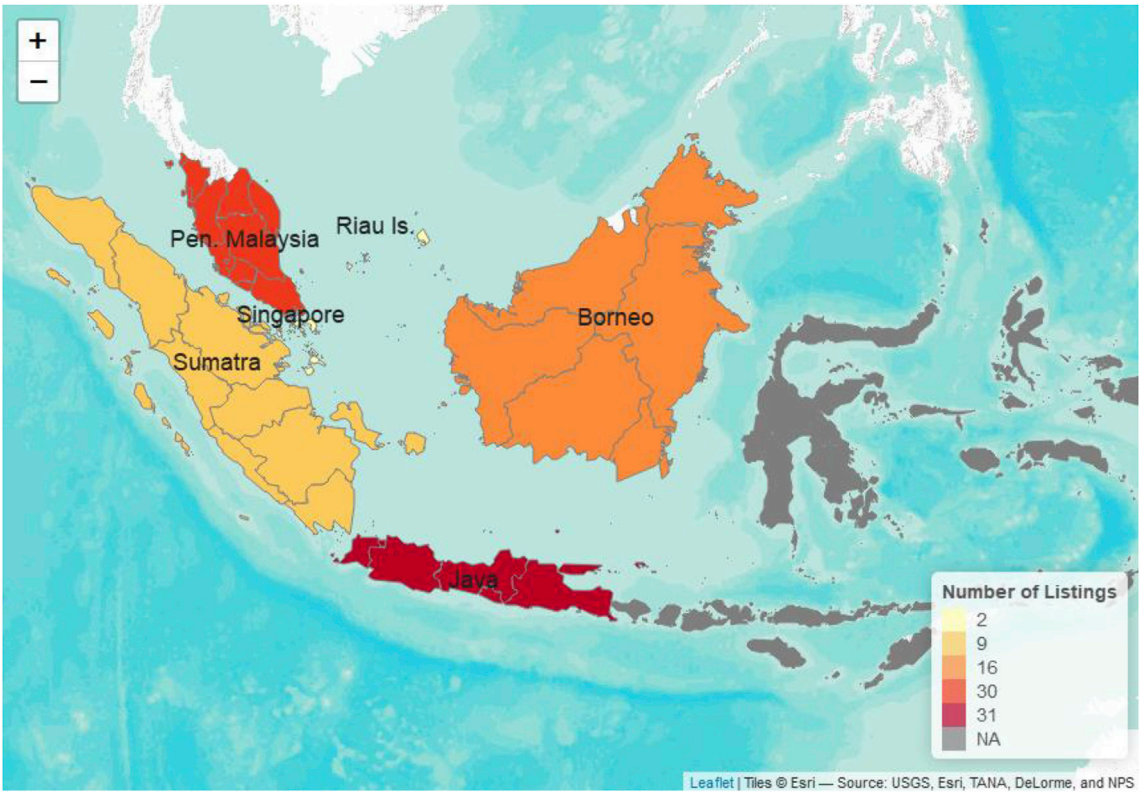

Fig. 1. Distribution of the number of listings found online. The number of listings was summed per island (Borneo, Java, Riau Islands, and Sumatra), the Malay Peninsula, and Singapore and it should be noted that we did not detect advertisements in every province. The political boundaries on Borneo between Malaysia, Indonesia and Brunei Darussalam are not displayed separately; rather we treat the island as a geographical unit. Four listings from Malaysia, and nine listings from Indonesia are not included in this map, as they could not be assigned to individual provinces/islands.

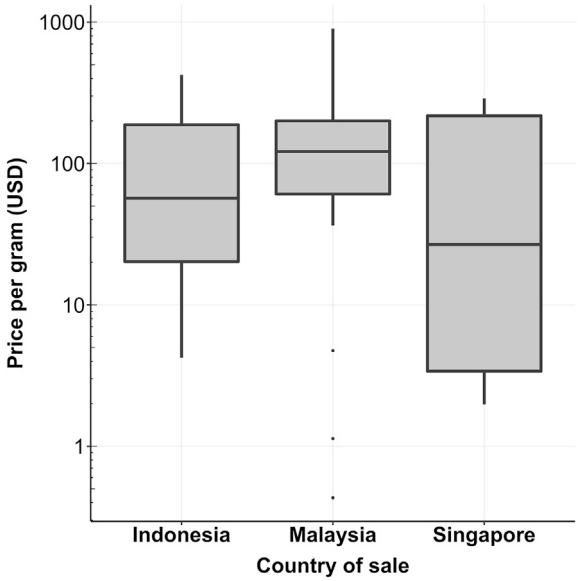

Fig. 2. Median bezoar price per gram, including upper and lower quartiles for each country of sale.

substances, as has been observed for other types of medicines (e.g., mixed bear bile; Gomez et al. (2020)). Further, it is nearly impossible to identify bezoars to the species level solely based on visual cues, and further methods (e.g., using genetic markers) may need to be considered in future studies for forensic authentication. Further, we noted during our preliminary online searches that there was a perceived difference among traders between the different types of bezoars, which was also observed during physical market surveys in Malaysia (Gomez, L., personal observation). We found no statistical differences among prices in this study, but future research should take into account potential implications that the distinction of these different bezoar types may have.

Chung et al. (2016) noted that increasing demand and high commercial value of porcupine bezoar may present one of the leading causes for overhunting and a decline of the Malayan porcupine (*Hystrix brachyura*) in Singapore and throughout its range. Borschberg (2006; as cited in Chung et al., 2016) estimated the price of porcupine bezoars at approximately 7000 USD per gram in Singapore in 2005. This is much higher than our results for prices in Singapore, which we estimate at an average of USD 119.3 $\pm$ 72.6 per gram. Comparable prices were observed during market surveys in Malaysia in 2020, which ranged from 300 to 2700 Malaysian Ringgit (i.e., 73–650 USD; Gomez, L., personal observation). Our results indicate similar prices per gram; i.e., USD 182.8 $\pm$ 35.57 in Malaysia. We found a comparatively small amount of listings in Singapore, but it is possible that customers buy bezoars directly from sellers in other countries, e.g., Malaysia or Indonesia. We found ~20% of bezoar listings available for international shipping, and it appears common practice to send bezoars via postal services, domestically, as well as internationally. Bezoars reportedly sourced from Indonesia and Thailand were also found for sale in traditional medicine shops during market surveys in Malaysia in 2020, confirming the international nature of this trade (L. Gomez, personal observation).

We discovered 16 bezoar listings of sellers located in Borneo. Most of them (75%) were located in Kalimantan (Indonesian Borneo). It is possible that Kalimantan appears prominent in trade due to other factors, such as differing internet accessibility across geographic locations, the short data collection period of our study, etc. It is further important to note that physical markets may follow different dynamics than online markets. However, Nijman (2005) also reported a population decline of 50–80% of Hose's langur (*Presbytis hosei*) over a 7-year period on Kalimantan, due to relentless hunting for their bezoars. It is possible that Kalimantan may represent a hotspot for bezoars from Borneo, but further research is required to establish these findings. Porcupine bezoars from Borneo are highly coveted, as consumers believe that Borneo still contains a particularly well-preserved flora, including a high proportion of medicinal plants which the animals eat, thus making their bezoars particularly valuable. One website (www.porcupinebezoar.com), which was not monitored during this study as it offered continuous supply as opposed to individual bezoars for sale, states for example:

> "*The most valuable for the porcupine bezoars are procured from porcupines in the rainforest of Indonesia or Borneo. The porcupines here eat unpolluted herbs that have high medicinal value causing the bezoars produced here to be of the rarest and highest value. The price is very high and has collection, medicinal and stockpiling value*".

Apart from Borneo, mainland Malaysia has been reported to be heavily involved in porcupine bezoar trade (Tan et al., 2019) and our findings confirm this. In particular, Selangor appeared to be heavily involved in Malaysia, with the most

advertisements per province. However, we found Indonesia to have more listings (n = 63) compared to Malaysia (n = 41), thus making Indonesia another important source country for porcupine bezoars.

Even though most information is available for the Malayan porcupine (*H. brachyura*), there are a total of six porcupine species native to Indonesia, Malaysia, and Singapore (*H. javanica*, *H. brachyura*, *H. sumatrae*, *H. crassispinis*, *Atherurus macrourus* and *Trichys fasciculata*), and it is likely that all six of them are found in trade to varying extents. Our results indicate that most records of bezoar listings came from sellers based in Jakarta. The Malayan porcupine has a wide range and is believed to be common, though decreasing (Lunde et al., 2016). Its range extends from mainland Southeast Asia to Indonesian Borneo, and Sumatra. It does not occur, however, on Java, where Jakarta is located. We thus believe that it is possible that the only Javan native porcupine species (*H. javanica*), may be considerably involved in this trade. However, it is also possible that bezoars of other species were obtained elsewhere prior to the listing of the advertisements.

4.2. Legal situation

Different species of porcupines are protected to varying degrees in Indonesia, Malaysia and Singapore (Table 2). Singapore is reportedly home to one species (*H. brachyura*), which is considered protected and cannot be harvested without a permit. In Malaysia, the protection of porcupines falls under different wildlife laws that govern Peninsular Malaysia, Sabah and Sarawak. Generally, all porcupine species are listed as 'Protected' with the exception of the Long-tailed porcupine (*T. fasciculata*), which is listed as a 'Totally Protected' species in Peninsular Malaysia. Essentially, the hunting and trade of protected species is possible with a permit, while hunting and trade in totally protected species is strictly prohibited. However, this difference in protection status complicates enforcement efforts in identifying and determining the source of the species in trade. In Indonesia, five porcupine species exist, but only one (*H. javanica*; endemic to Java, Bali and surrounding islands) is protected (Table 2). This leaves the remaining species vulnerable to exploitation. Further, the Thick-spined porcupine (*H. crassispinis*, endemic to the island of Borneo) is protected in Sabah and Sarawak, but not in Indonesia's Kalimantan, which further complicates enforcement efforts to monitor uptake and trade of the species. That said, the harvest of wild non-protected species in Indonesia are generally governed by annually set quotas dedicated for domestic use and/or export. Currently no quotas exist for porcupines, which technically means that trade in any porcupine species is illegal in Indonesia. In addition, as none of the porcupine species are currently listed on the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the international trade in porcupines is likely to be neither detected nor regulated, rendering determination of uptake for trade much more difficult.

There are also farms that breed porcupines, for example in Vietnam, Indonesia, Malaysia and Thailand. However, there is also anecdotal evidence of some illegitimate porcupine farms that supply captive bred or wild animals, or a mix of both, for the meat and bezoar trade (Brooks et al., 2010; C. Shepherd, pers. Comm.). It is uncertain how many of the advertised bezoars from our study came from farmed animals, and how many from wild-caught animals. The low average quantity of bezoars for sale per seller might suggest that they do not come from porcupine farms. One Instagram seller, for example, also indicated they regularly visit the local communities who hunt porcupines in the wild and purchase the bezoars to stockpile them for later sale. Another seller posted images of both dead porcupines and harvested bezoars (Fig. 3).

4.3. Trade impacts and threats to the hystricidae

The Malayan porcupine is likely the main species of Asian porcupines in trade, both for its meat, but also its bezoar, mainly due to its wide distribution. Hystricidae in general, and specifically *H. brachyura* have been shown to be overrepresented in illegal trade in Cambodia (Heinrich et al., 2020) and the species is often encountered in trade elsewhere in Asia (Norsuhana et al., 2012). It was once widespread in Singapore, but populations have been greatly reduced (Chung et al., 2016). Populations have also been reduced by 20% in the 1990s in Vietnam, where it is often farmed (Nowak, 1999). The farming reportedly does not have a positive conservation impact, as wild Malayan porcupines are usually caught to re-stock existing captive populations, and demand for porcupines is on the rise (Brooks et al., 2010). Norsuhana et al. (2012) also found that consumers in Malaysia preferred wild over captive bred porcupine meat. Concerns have been raised about potential population declines, largely due to overhunting, for different species of Asian porcupines, including *H. javanica* (Mustikasari et al., 2019), *A. macrourus* (Dhendup and Dorji, 2017), and *H. brachyura* (Farida et al., 2019). In contrast to other parts of Asia, *H. brachyura* appears to have increased in Hong Kong (Chung and Corlett, 2006), although this information, from over 14 years ago, may be outdated by now due to increasing demand for porcupine parts throughout Asia. Unfortunately, we were unable to distinguish between species in this study, but the geographic distribution of the trade suggests that more species than just *H. brachyura* are involved in this trade.

The main threats all species of porcupine face are habitat loss and unsustainable exploitation, and porcupines may be more susceptible to these threats than previously assumed. The IUCN classifies all Asian porcupine species as Least Concern, with the exception of *H. pumila* (Clayton, 2018). Given that in the current IUCN Redlist assessments international trade is generally not considered a threat to most Asian porcupine species, their status may need updating, potentially to a higher threat category, to reflect this. As some species can reach fairly high densities in certain areas, they are also often persecuted as agricultural pests (Alkon and Saltz, 1985; Barthelmess, 2016). Further to the threats of habitat loss, preventative or retaliatory killings, and targeted hunting, porcupines are, like many other animals in the region, increasingly threatened by the widespread use of snares in Southeast Asia. Snares are non-selective and cheap to replace, and their use is depleting native species

Table 2
Protection status of the different porcupine species native to Indonesia, Malaysia, and Singapore.

Country	Species	IUCN Red List Assessment	Protection Status	Law	Notes
Indonesia	Long-tailed porcupine (*T. fasciculata*)	LC Hunted for food but unlikely to have impact on populations	Not protected	–	–
	Malayan porcupine (*H. brachyura*)	LC Hunted for food and medicinal use but not considered a threat to populations	Not protected	–	–
Endemic to Sumatra	Sumatran porcupine (*H. sumatrae*)	LC No major threats described/no data on use and trade	Not protected	–	Used to be protected under the old species protection list, prior to 2018
Endemic to Java, Bali, Sumbawa, Flores, Lombok, Madura, and Tonahdjampea	Sunda porcupine (*H. javanica*)	LC No major threats described/no data on use and trade	Protected	Act of the Republic of Indonesia no. 5 of 1990 concerning conservation of living resources and their ecosystems; & Government Regulation no. 7 of 1999 on preservation of flora and fauna (GR 7/1999)	No harvesting/trade is allowed without a permit
Endemic to Borneo Island	Thick-spined porcupine (*H. crassispinis*)	LC No major threats described/no data on use and trade	Not protected	–	–
Country	**Species**	**IUCN Red List Assessment**	**Protection Status**	**Law**	**Notes**
Malaysia	Asiatic Brush-tailed porcupine (A. macrourus)	LC Threatened by habitat loss and harvesting for food/no data on use and trade	Protected Protected	PM: Wildlife Conservation Act 2010 SK: Wildlife Protection Ordinance 1998	Unlicensed hunting/trade in 'protected' species is illegal while hunting/trade in 'totally protected 'species is strictly prohibited
	Long-tailed porcupine (*T. fasciculata*)	LC Hunted for food but unlikely to have impact on populations	Totally Protected Protected Protected	PM: Wildlife Conservation Act 2010 SA: Wildlife Conservation Enactment SK: Wildlife Protection Ordinance 1998	
	Malayan porcupine (*H. brachyura*)	LC Hunted for food and medicinal use but not considered a threat to populations	Protected Protected	PM: Wildlife Conservation Act 2010 SK: Wildlife Protection Ordinance 1998	
Endemic to Borneo Island	Thick-spined porcupine (*H. crassispinis*)	LC No major threats described/no data on use and trade	Protected Protected	SA: Wildlife Conservation Enactment SK: Wildlife Protection Ordinance 1998	
Singapore	Malayan porcupine (*H. brachyura*)	LC Hunted for food and medicinal use but not considered a threat to populations	Protected	Wild Animal and Bird Act 1965	Prohibits the hunting/trade of any wild animal or bird without a permit

(PM: Peninsular Malaysia (mainland), SA: Sabah (Borneo Island), SK: Sarawak (Borneo Island)).

populations in Southeast Asia's forests at alarming rates (Gray et al., 2018; Heinrich et al., 2020). Further, Asian porcupines show a high rate of endemism, with half of all Asian porcupine species endemic to islands: the Sumatran porcupine (*H.sumatrae*) and Sunda porcupine (*H.javanica*) are endemic to different islands in Indonesia; the Philippine porcupine (*H. pumila*) endemic to small islands in the Philippines; and the Thick-spined porcupine (*H.crassispinis*) endemic to Borneo (Barthelmess, 2016). We found listings from sellers on Borneo, Java, and Sumatra, suggesting that species endemic to these islands may also be involved in this trade. Island endemic species face a greater risk of extinction than mainland species and the effect of hunting and associated trade urgently requires further research.

Another interesting feature is that species of Hystricidae, e.g., Cape porcupine (*H. africaeaustralis*), Crested porcupine (*H. cristata*), Indian porcupine (*H. indica*), and potentially Asiatic Brush-tailed porcupine (*A. macrourus*) and other Asian species are monogamous (Lovari et al., 2013; Barthelmess, 2016). Parental care is long, intense, and generally well developed among species of Hystricidae (Gosling, 2009; Barthelmess, 2016). Further, Old-world porcupines are long lived with reports of captive individuals living over 20 years (Barthelmess, 2016). The average generation length is indicated at 7 years (IUCN, 2019). Depending on the species, Asian porcupines bear between one and (seldom) six offspring per year (Gosling, 2009;

Fig. 3. Instagram profile of anonymised individual advertising porcupine bezoars for sale.

Barthelmess, 2016; IUCN, 2019) and African Brush-tailed porcupines (*A. africanus*) only reach sexual maturity at 2 years of age (Barthelmess, 2016). All of these factors (i.e., longevity, well developed and long-lasting parental care, well-developed social structures, and monogamy) suggest that unsustainable exploitation and associated disruptions in their social structure could have negative impacts on their breeding success and long-term survival. There is currently no information available on the social structure or breeding ecology of any of the four island endemic species and only limited information on the remaining four Asian species, all of which urgently needs to be addressed. Further, porcupines are prey species (Kawanishi and Sunquist, 2004; Barthelmess, 2016) and some species of Hystricidae are ecosystem engineers (Barthelmess, 2016), providing habitat for a variety of species. Thus, unsustainable exploitation of porcupines may ultimately also impact other potentially endangered species of a variety of taxa.

5. Conclusion

We found porcupine bezoars for sale on online platforms in Indonesia, Malaysia and Singapore. Our study highlights the occurrence of this trade, likely across borders, in Southeast Asia and the potential threat that the different porcupine species face should they continue to be overexploited. Due to the apparent high demand for porcupine bezoars, but also their meat and other body parts, we urge consumer and source countries to monitor and regulate the domestic and international trade in all porcupine products. Indonesia must take action against porcupine trade taking place outside their quota system, which is technically illegal. In all countries, the enforcement of existing legislation regulating the domestic trade should be enhanced and stronger legislation should be considered to prevent overexploitation at national levels. To monitor and regulate international trade the Hystricidae would potentially benefit from a listing on CITES Appendix II, to avoid them declining at such rates that they may become threatened in the future. For this, further research is necessary to estimate the extent of the international, but also the domestic trade, and the impact it has on porcupine populations. An analysis of seizures may be warranted to gauge the extent of illegal trade and identify potential legislative loopholes. Forensic tools for rapid identification and authentication of porcupine bezoars may need to be developed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Alkon, P.U., Saltz, D., 1985. Patterns of crested porcupine (Hystrix indica) damage to cultivated potatoes. Agric. Ecosyst. Environ. 14 (3—4), 171—183.
Altaf, M., Umair, M., Abbasi, A.R., Muhammad, N., Abbasi, A.M., 2018. Ethnomedicinal applications of animal species by the local communities of Punjab, Pakistan. J. Ethnobiol. Ethnomed. 14 (1), 55.
Barthelmess, E.L., 2016. Family Hystricidae (Old world porcupines). In: Wilson, D.E., Larcher, T.E., Mittermeier, R.A. (Eds.), *Handbook Of the Mammals Of the World*. 6 (Lagomorphs and Rodents I): 304-330. Lynx Edicions, Barcelona.

Basa, O., Nebesse, C., Kaswera, C., Tsongo, J., Gambalemoke, S., 2017. Bush meat sold on the markets in Kisangani: analysis addressed to the right on species conservation in the Democratic Republic of the Congo. Int. J. Environ. Agri. Biotech. 2 (2).
Bodmer, R.E., Lozano, E.P., 2001. Rural development and sustainable wildlife use in Peru. Conserv. Biol. 15 (4), 1163–1170.
Borschberg, P., 2006. The trade, forgery and medicinal use of porcupine bezoars in the early Modern Period (c. 1500–1750). Orient 14, 60–78.
Brooks, E.G.E., Roberton, S.I., Bell, D.J., 2010. The conservation impact of commercial wildlife farming of porcupines in Vietnam. Biol. Conserv. 143 (11), 2808–2814.
Cantlay, J.C., Ingram, D.J., Meredith, A.L., 2017. A review of zoonotic infection risks associated with the wild meat trade in Malaysia. EcoHealth 14 (2), 361–388.
Cheng, J., Karambelkar, B., Xie, Y., 2018. Leaflet: Create Interactive Web Maps with the JavaScript "Leaflet" Library. R Package Version 2.0.2. https://CRAN.R-project.org/package=leaflet.
Chevallier, N., Ashton, B., 2006. A Report on the Porcupine Quill Trade in South Africa. IFAW.
Chung, K.P., Corlett, R.T., 2006. Rodent diversity in a highly degraded tropical landscape: Hong Kong, South China. Biodivers. Conserv. 15 (14), 4521–4532.
Chung, Y., Lim, N., Shunari, M., Wang, D., Chan, S., 2016. Records of the malayan porcupine, Hystrix brachyura (mammalia: Rodentia: Hystricidae) in Singapore. Nat. Singapore 9, 63–68.
Clayton, E., 2018. Hystrix Pumila. https://doi.org/10.2305/IUCN.UK.2018-1.RLTS.T10753A22231557.en. Viewed 19 November 2019.
Dan, Y., Qian, Z.Z., Peng, Y., Chen, C.Q., Liu, Y.Z., Tai, W., Qi, J.W., 2016. Revision and improvement of criterion on traditional Chinese medicines in Chinese pharmacopoeia 2015. Chin. Herbal Med. 8 (3), 196–208.
Dhendup, T., Dorji, R., 2017. First record of the asiatic brush-tailed porcupine Atherurus macrourus linnaeus, 1758 (mammalia: Rodentia: Hystricidae) from western Bhutan. J. Threat. Taxa 9 (11), 10959–10960.
Duffin, C.J., 2013. Porcupine stones. Pharm. Hist. 43 (1), 13–22.
Fa, J.E., Yuste, J.E.G., Castelo, R., 2000. Bushmeat markets on Bioko Island as a measure of hunting pressure. Conserv. Biol. 14 (6), 1602–1613.
Farida, W.R., Sari, A.P., Inayah, N., Nugroho, H.A., 2019. Observations of behavioral development on common Porcupines (Hystrix brachyura) undergoing domestication. IOP Conf. Ser. Earth Environ. Sci. 308.
Gomez, L., Shepherd, C.R., Khoo, M.S., 2020. Illegal trade of sun bear parts in the Malaysian states of Sabah and Sarawak. Endanger. Species Res. 41, 279–287. https://doi.org/10.3354/esr01028.
Gosling, L., 2009. Reproduction of the Himalayan porcupine (Hystrix hodgsom) in captivity. J. Zool. 192, 546–549.
Gray, T.N.E., Hughes, A.C., Laurance, W.F., Long, B., Lynam, A.J., O'Kelly, H., Ripple, W.J., Seng, T., Scotson, L., Wilkinson, N.M., 2018. The wildlife snaring crisis: an insidious and pervasive threat to biodiversity in Southeast Asia. Biodivers. Conserv. 27 (4), 1031–1037.
Harrison, R.D., 2011. Emptying the forest: hunting and the extirpation of wildlife from tropical nature reserves. Bioscience 61 (11), 919–924.
Heinrich, S., Ross, J.V., Gray, T.N.E., Delean, S., Marx, N., Cassey, P., 2020. Plight of the commons: 17 years of wildlife trafficking in Cambodia. Biol. Conserv. 241.
Heinrich, S., Wittmann, T.A., Prowse, T.A., Ross, J.V., Delean, S., Shepherd, C.R., Cassey, P., 2016. Where did all the pangolins go? International CITES trade in pangolin species. Glob. Ecol. Conser. 8, 241–253.
IUCN, 2019. The IUCN Red List of Threatened Species, Version 2019-2.
Kawanishi, K., Sunquist, M.E., 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biol. Conserv. 120 (3), 329–344.
Lavorgna, A., 2014. Wildlife trafficking in the Internet age. Crime Sci. 3 (5) https://doi.org/10.1186/s40163-014-0005-2.
Lovari, S., Sforzi, A., Mori, E., 2013. Habitat richness affects home range size in a monogamous large rodent. Behav. Process. 99, 42–46.
Lunde, D., Aplin, K., Molur, S., 2016. Hystrix Brachyura (Errata Version Published in 2017). The IUCN Red List of Threatened Species. Viewed 19 November 2019.
Luskin, M., Christina, E., Kelley, L., Potts, M., 2014. Modern hunting practices and wild meat trade in the oil palm plantation-dominated landscapes of Sumatra, Indonesia. Hum. Ecol. 42 (1), 35–45.
Manzar, A., Nehvi, F., 2012. Indian crested porcupine Hystrix indica Kerr (Rodentia: Hystricidae): an emerging threat to saffron cultivation in Jammu and Kashmir. IV Int. Symposium Saffron Biol. Technol. 1200, 133–138.
Mori, E., Sforzi, A., 2013. Structure of phytobezoars found in the stomach of a crested porcupine, Hystrix cristata L., 1758. Folia Zoologica 62 (3), 232–235.
Mustikasari, I.A., Withaningsih, S., Megantara, E.N., Husodo, T., Parikesit, P., 2019. Population and distribution of Sunda porcupine (Hystrix javanica F. Cuvier, 1823) in designated area of cisokan hydropower, west Java, Indonesia. Biodiver. J. Biol. Div. 20 (3), 762–769.
Natusch, D.J., Lyons, J.A., Riyanto, A., Shine, R., 2016. Jungle giants: assessing sustainable harvesting in a difficult-to-survey species (Python reticulatus). PloS One 11 (7), e0158397.
Newton, P., Nguyen, T.V., Roberton, S., Bell, D., 2008. Pangolins in peril: using local hunters knowledge to conserve elusive species in Vietnam. Endanger. Species Res. 6, 41–53.
Nijman, V., 2005. Decline of the endemic hose's langur Presbytis hosei in kayan mentarang national park, East Borneo. Oryx 39 (2), 223–226.
Nijman, V., Shepherd, C.R., 2015. Adding up the Numbers: an Investigation into Commercial Breeding of Tokay Geckos in Indonesia. TRAFFIC, Petaling Jaya, Selangor, Malaysia.
Nijman, V., 2020. Illegal trade in Indonesia's National Rare Animal has moved online. Oryx 54, 12–13 (Cambridge University Press).
Norsuhana, A., Shukor, M., Aminah, A., 2012. Perceptions on captive malayan porcupine (Hystrix brachyura) meat by Malaysian urban consumers. Health Environ J 3 (1), 67–78.
Nowak, R.M., 1999. Hystricidae: Old world porcupines. In: Nowak, R.M., Walker, E.P. (Eds.), Walker's Mammals of the World, vol. 2. JHU press.
Rovie-Ryan, J.J., Khan, F.A.A., Zahari, Z., Zainuddin, A.H.A., Gani, M., Julaihi, A.M., Saaban, S., 2017. Molecular phylogeny of the Old world porcupines (family Hystricidae) using mitochondrial cytochrome B gene. J. Sustain. Sci. Manag. 12 (1), 1–11.
Sigouin, A., Pinedo-Vasquez, M., Nasi, R., Poole, C., Horne, B., Tien, M., 2017. Priorities for the trade of less charismatic freshwater turtle and tortoise species. J. Appl. Ecol. 54 (2).
Siriwat, P., Nijman, V., 2018. Illegal pet trade on social media as an emerging impediment to the conservation of Asian otters species. J. Asia Pac. Bus. 11, 469–475.
Siriwat, P., Nijman, V., 2020. Wildlife trade shifts from brick-and-mortar markets to virtual marketplaces: a case study of birds of prey trade in Thailand. J. Asia Pac. Bus. https://doi.org/10.1016/j.japb.2020.03.012 in press.
Sodeinde, O., Soewu, D., 1999. Pilot Study of the Traditional Medicine Trade in Nigeria. TRAFFIC Bulletin, vol. 18. TRAFFIC International, Cambridge (UK), pp. 35–40.
Talukdar, N.R., Choudhury, P., Singh, B., 2019. Current records of porcupine in northeast India: distribution, habitat preference and conservation. Trop. Ecol. 60 (1), 41–51.
Tan, C.S., Ng, C.H., Loh, Y.C., Yam, M.F., 2019. A traditional folk medicine in Malaysia: porcupine bezoar. Orient. Pharm. Exp. Med. 19 (2), 131–136.
Wong, L.P., AbuBakar, S., 2013. Health beliefs and practices related to dengue fever: a focus group study. PLoS Neglected Trop. Dis. 7 (7), e2310.
Yew, P.N., Goh, B.H., Lim, Y.Y., Lee, W.L., 2018. Gastrointestinal bezoar stones: current knowledge and future perspective on the potential of plant-derived phytobezoar in cancer treatment. In: Akhtar, M.S., Swamy, M.K. (Eds.), Anticancer Plants: Natural Products and Biotechnological Implements:, vol. 2. Springer Singapore, Singapore, pp. 19–39.