A dry season glimpse of watersnake bycatch and trade from the flooded forests of Kampong Khleang, Tonlé Sap Lake

Megan ENGLISH[1,2,3,*], Kameron WINTERS[4], Mary LASATER[5], Mark DAINTY[6], Michael MEYERHOFF[7] & Philipp WAGNER[8,9]

[1] The School for Field Studies, Center for Environmental Research in Conservation and Development Studies, Sala Kanseing Village, Siem Reap, Cambodia.

[2] Taronga Conservation Society, Bradleys Head Road, Mosman, New South Wales, 2088, Australia.

[3] University of Sydney, Camperdown, New South Wales, 2006, Australia.

[4] Bucknell University, Pennsylvania, One Dent Drive, Lewisburg, 17837, USA.

[5] Davidson College, 405 Main Street, North Carolina, 28035, USA.

[6] Angkor Wildlife and Aquarium, Kboun Village, Khchas Commune, Sothnikum, Siem Reap, Cambodia.

[7] Zoo Leipzig, Pfaffendorfer Street 29, 04105 Leipzig, Germany.

[8] Angkor Centre for Conservation of Biodiversity, Kbal Spean, Cambodia.

[9] Allwetterzoo, Sentruper Street 315, D48161 Münster, Germany.

* Corresponding author. Email megs.english@gmail.com

Paper submitted 3 September 2021, revised manuscript accepted 9 May 2022.

មូលន័យសង្ខេប

បឹងទន្លេសាប គឺជាប្រព័ន្ធអេកូឡូស៊ីដ៏សម្បូរបែបមួយ ទោះបីជាប្រភេទសត្វទឹកជាច្រើនត្រូវបានថយចុះ ដោយសារតែការប្រមូលផលច្រើនលើសលុបក៏ដោយ។ យើងបានធ្វើការវាយតម្លៃលើបរិមាណ និងសមាសភាពនៃពស់ទឹកដែលចាប់បានដោយចៃដន្យដោយអ្នកនេសាទ តាមរយៈការពិនិត្យឯកត្តៈនីមួយៗដែលជាផលចាប់របស់អ្នកនេសាទ និងដាក់លក់ប្រចាំថ្ងៃដោយអ្នកជំនួញ ក្នុងរយៈពេល ១០ថ្ងៃ ក្នុងស្រុកកំពង់ឃ្លាំង នៅខែវិច្ឆិកា ឆ្នាំ២០១៩។ ប្រវែងនិងទម្ងន់នៃសំណាកនីមួយៗ ព្រមទាំងប្រេកង់នៃការកើតឡើង (frequency of occurrence) នៃប្រភេទពស់នីមួយៗត្រូវបានកត់ត្រា។ អ្នកនេសាទចំនួន២១នាក់ និងអ្នកភូមិជាច្រើននាក់ផ្សេងទៀតត្រូវបានសម្ភាសន៍ដើម្បីស៊ើបអង្កេតបន្ថែមទៀតពីបរិមាណ និងនានាភាពនៃពស់ទឹកចាប់បានដោយចៃដន្យ វិធីសាស្ត្រចាប់ ពេល និងទីតាំងនៃការបន្តពូជ និងការប្រើប្រាស់ផ្សេងៗទៀត។ ពស់ទឹក៨ប្រភេទត្រូវបានកត់ត្រា ប្រភេទដែលមានច្រើនជាងគេក្នុងគំរូតាងនៃទិន្នផលនេសាទ និងពស់ដែលដាក់លក់ គឺពស់ព្រលិតដូង [Tonle Sap watersnake (*E. longicauda*)] (*n*=763) និងពស់ព្រលិត [rainbow watersnake (*E. enhydris*)] (*n*=209)។ តាមរយៈការសម្ភាសន៍បានបង្ហាញថា ទិន្នផលពស់ទឹកដែលចាប់បានដោយចៃដន្យខ្ពស់បំផុតមានពីរដងក្នុងមួយឆ្នាំ គឺនៅរដូវបន្តពូជ។ ដោយពស់ទឹកទន្លេសាបជាប្រភេទដែលរងគ្រោះជាសាកល (*globally Vulnerable)* និងមានលក្ខណៈដោយឡែកសម្រាប់បឹង យើងស្នើឲ្យមានការស្រាវជ្រាវបន្តទៀតដើម្បីស្វែងយល់ពីបម្រែបម្រួលផលចាប់ និងជំនួញទៅតាមពេល និងទីតាំង ក៏ដូចជាផលចាប់ដោយចេតនា ដើម្បីកំណត់ការរឹតបន្តឹង ការពារប៉ូពុយឡាស្យុងពស់ទឹកនៅក្នុងតំបន់ ជាពិសេសក្នុងរដូវបន្តពូជ។

CITATION: English, M., Winters, K., Lasater, M., Dainty, M., Meyerhoff, M. & Wagner, P. (2022) A dry season glimpse of watersnake bycatch and trade from the flooded forests of Kampong Khleang, Tonlé Sap Lake. *Cambodian Journal of Natural History*, **2022**, 38–46.

Abstract

The Tonlé Sap Lake is a rich ecosystem although many of its aquatic species have been depleted by overharvesting. We assessed the quantity and composition of watersnakes unintentionally caught during routine fishing practices by examining individuals in the bycatch of a fisherman and sold by a snake trader each day for ten days in Kampong Khleang Commune in November 2019. The length and mass of each specimen and frequency of occurrence of each species was recorded. Twenty-one fishermen and other villagers were interviewed to further investigate the volume and variety of watersnakes caught as bycatch, methods of capture, timing and location of breeding and subsequent uses of snakes. Eight species of watersnake were recorded. The species most commonly reported and most abundant in our bycatch and trader samples were the Tonlé Sap watersnake *Enhydris longicauda* (*n*=763) and the rainbow watersnake *E. enhydris* (*n*=209). Interviews revealed that watersnake bycatch was highest at two times of the year which coincided with their breeding seasons. As the Tonlé Sap watersnake is globally Vulnerable and endemic to the lake, we recommend further research into spatial and temporal variation in bycatch and trade, as well as intentional harvesting, to determine if restrictions are warranted to safeguard local watersnake populations, particularly during the breeding season.

Keywords Bycatch, Cambodia, Kampong Khleang, Tonlé Sap Lake, watersnakes.

Introduction

Squamate reptiles are often under-represented in conservation initiatives (Beaupre & Douglas, 2009; Tingley *et al*., 2016) with around 15% of species being classified as Data Deficient by the IUCN Red List of Threatened Species and 16% threatened with extinction (IUCN, 2021). Snakes serve as a source of food for other predators and they regulate the populations of their prey species. Their use of multiple habitats for feeding, hibernation and reproduction means that major changes to snake populations may be an early sign of habitat degradation, associated effects of climate change, and other alterations (Beaupre & Douglas, 2009).

The Tonlé Sap Lake, in the centre of Cambodia, is the largest freshwater lake in Southeast Asia. The lake is unique for its flood pulse ecosystem which causes it to expand from 2,600 km^2 in the dry season to 15,000 km^2 during the peak of the wet season (Arias *et al*., 2014a). This creates a seasonally flooded forest near the margins of the lake which serves as a breeding ground for fish and other aquatic life including watersnakes (Campbell *et al*., 2006). As a result of decreases in annual rainfall in Cambodia since 1951, the seasonality of the lake has become more irregular (Thoeun, 2015). The construction of dams along the Mekong and the effects of irrigation and water use for agricultural purposes have also modified the hydrology of the lake (Evans *et al*., 2005; Arias *et al*., 2014b). The dams regulate water flow from the Mekong River and reduce the water entering the lake during the flood pulse. These changes have a detrimental effect on the wildlife of the lake that may delay their breeding and migration to match the increase in rain and rising water levels (Campbell *et al*., 2006).

Fish comprise 70% of the protein intake of Cambodian people, most of which is sourced from the lake. In the past, many of the fishing grounds in Tonlé Sap Lake were contained within commercial fishing lots, but these have since been replaced with communal use zones (Cooperman *et al*., 2012). Unfortunately, this has led to communities over-exploiting the natural resources of the lake and depleting populations of fish (Kuenzer, 2013). Residents of the lake have raised crocodiles since the 1940's including pure species and hybrids of the native Siamese crocodile (*Crocodylus siamensis*) and saltwater crocodile (*C. porosus*) to supplement their livelihoods. Since the 1990's, the Cuban crocodile (*C. rhombifer*) has also been imported (Targarona *et al*., 2008; Daltry *et al*., 2016). This has resulted in a need for low-cost crocodile food with many people having turned to watersnakes as a means to meeting this demand (Brooks *et al*., 2010). Watersnakes are often caught as bycatch along with fish, making them an easy supplement for crocodile food when fish are in short supply (Stuart *et al*., 2000; Brooks *et al*., 2007). In addition, in recent years, watersnakes have begun to be consumed by people who live around the lake and in other parts of Cambodia (Brooks *et al*., 2007).

Seven watersnake species are commonly caught in the Tonlé Sap Lake (Brooks *et al*., 2009). Most are homalopsids, with the rainbow watersnake (*Enhydris enhydris*) dominating the catch (Stuart *et al*., 2000; Brooks *et al*., 2009). Rainbow watersnakes are widespread across Southeast Asia and are easily mistaken for the closely related Mekong mudsnake (*E. subtaeniata*). Most of the watersnakes caught in the lake eat primarily fish except for the semi-aquatic yellow-spotted keelback (*Fowlea flavipunctatus*) which mostly eats large frogs, and the

red-tailed pipe snake (*Cylindrophis ruffus*) which preys on snakes and eels (Brooks *et al*., 2009). The Tonlé Sap watersnake (*E. longicauda*) is the only snake species endemic to the Tonlé Sap Lake and is categorized as Vulnerable (Murphy *et al*., 2010). All of these species are commonly found in the trade in aquatic snakes from the Tonlé Sap although less commonly than *E. enhydris* (Stuart *et al*., 2000; Brooks *et al*., 2007). Other common snake species found in the trade include the banded swamp snake (*Homalopsis buccata*), Bocourt's watersnake (*Subsessor bocourti*) and the tentacled snake (*Erpeton tentaculatum*). *Homalopsis buccata* and *S. bocourti* are particularly desirable for snake traders because the skins can be sold in foreign markets for clothing and accessories (Lieng *et al*., 2010). Very little is known about the ecology of most snake species in the lake and no published data are available on their preferred habitat types or movement patterns.

Over 770 tons of snakes (roughly 6.9 million individuals) were traded annually from the Tonlé Sap Lake between 2004–2005 (Brooks *et al*., 2007). This is the largest watersnake trade in the world. The snakes are used primarily as crocodile food but are also traded for their skins and human consumption. Watersnakes can be dried and sold as food for prices that are comparable to those of fish (Chhut, 2018). *Enhydris enhydris* comprises two-thirds to three-quarters of the trade and *E. longicauda* is the second most common species, accounting for roughly 10% of the trade (Brooks *et al*., 2007). These figures are similar to results from a foundational study on homalopsid trade in Tonle Sap, which found that *E. enhydris* comprised 80% of 3,000–4,000 snakes harvested in 1999–2000 (Stuart *et al*., 2000). The trade follows seasonal trends and peaks near the beginning and at the end of the wet season (June–October) when water starts to enter and then recede from the lake. This coincides with the beginning of snake breeding season which occurs at the onset of the wet season. Overharvesting has caused severe decline in snake populations (Brooks *et al*., 2007). Most species have slow growth cycles and late maturity which do not allow their populations to recover if they are heavily exploited (Brooks *et al*., 2007).

The aim of our study was to assess the diversity, abundance and sizes (mass and length) of watersnake species caught as bycatch and traded during the dry season at Chamkar Youn village in Kampong Khleang Commune, Siem Reap Province, Cambodia. Despite this being a short-term study in one location, we were interested to determine if species composition and sizes had changed since those found in earlier studies (Brooks *et al*., 2009).

Methods

Our data collection took place in Chamkar Youn village in Kampong Khleang Commune near the northern edge of the Tonlé Sap Lake (13°06.204′N, 104°07.478′E) for ten days in November 2019. The village is located in the floodplain of the lake and is heavily influenced by the flood pulse. The flooded forest nearby allows locals to catch a wide range of fish and watersnake species at different life stages. Watersnakes and fish lay their eggs or give birth to live young in the flooded forest (Campbell *et al*., 2006).

We employed two approaches in data collection. The first was to quantify watersnake bycatch of a local fisherman, as well as the composition of species sold by a local snake trader. Secondly, to supplement our observations we interviewed fishermen and other local villagers to understand the volume and species diversity of watersnakes caught as bycatch, their habitats, common capture methods, the timing and location of breeding, and their subsequent uses.

Some of our watersnake specimens came from the same fisherman who provided access to his catch each day for ten days. The fisherman used a trap known as a "lop" to collect fish, trapping watersnakes as bycatch (Fig. 1). Each specimen was weighed in grams and measured for snout-vent length (SVL, in cm) to calculate the minimum, maximum and mean mass and body length for each species. We also counted and weighed watersnakes sold at the local market by one snake trader each day. A total count of each species was recorded. We then compared our results to the means reported by Brooks *et al*. (2009) using 2-tailed *t*-tests. Due to time constraints, we opted to focus on one fisherman and one trader for this section of the study to get an accurate overview over time of their individual activity.

Interviews were semi-structured and aimed to develop our understanding of which species are caught, their habitats, capture methods, the timing and location of breeding, and their use. The questions were translated into Khmer by a graduate translator from the Royal University of Phnom Penh. Respondents were selected using key informant (Marshall, 1996), snowball, convenience and random sampling methods (Miller & Brewer, 2003). A total of 21 fishermen, watersnake traders and other local villagers were interviewed. To assist the interviewees and verify their reliability, we showed pictures of snakes common in the lake and some non-native or non-aquatic species (e.g., *Boiga siamensis* and *B. cyanea*) to determine if the interviewees were genuinely able to recognise species from the lake.

Fig. 1 "Lop" trap used by many fishermen in Kampong Khleang Commune, Cambodia.

Table 1 Snout to vent length and mass of watersnake species recorded in bycatch and trade in Kampong Khleang Commune, along with values reported for females (f) and males (m) by Brooks *et al*. (2009). Figures for bycatch and trade are given as min–max, mean ± standard error (*n*), and mean ± standard error (*n*) for Brooks *et al*. (2009).

Species	Snout to Vent Length (cm)		Mass (g)		
	Bycatch	Brooks *et al*. (2009)	Bycatch	Trade	Brooks *et al*. (2009)
Acrochordus granulatus	26.9 (1)	-	11.0 (1)	-	-
Enhydris enhydris	28.4–72.0, 42.8 ±0.9 (77)	50.5 ±1.2 (f) 47.6 ±0.1 (m) (4197)	17.0–216.0, 65.19 ±4.18 (77)	14.0–178.0, 59.53 ±3.07 (132)	97.8 ±1.2 (f) 81.5 ±0.5 (m) (3602)
Enhydris longicauda	24.9–61.0, 38.9 ±0.4 (228)	48.9 ±0.2 (f) 44.2 ±0.2 (m) (1602)	20.0–310.0, 82.33 ±2.37 (228)	17.0–243.0, 87.07 ±1.79 (534)	150.9 ±2.6 (f) 117.5 ±4.6 (m) (1617)
Cylindrophis ruffus	39.0–69.4, 57.6 ±9.2 (3)	71.5 ±0.8 (f) 68.6 ±1.2 (m) (115)	177.0–300.0, 220.67 ±39.73 (3)	-	224.4 ±8.0 (f) 220.9 ±10.5 (m) (127)
Homalopsis buccata	41.6–42.2, 41.9 ±0.3 (2)	74.0 ±0.5 (f,m) (1573)	57.0–77.0, 67.0 ±10.0 (2)	73.0 (1)	242.2 ±5.5 (f) 249.8 ±3.8 (m) (1452)
Erpeton tentaculatum	42.5–57.0, 49.6 ±1.4 (10)	50.1 ±0.3 (f) 45.9 ±0.2 (m) (746)	83.0–217.0, 132.90 ±15.20 (10)	292.0 (1)	104.1 ±2.3 (f) 81.8 ±1.3 (m) (766)
Fowlea flavipunctatus	33.7–78.8, 49.8 ±3.18 (18)	-	34.0–356.0, 126.94 ±24.68 (18)	74.0 (1)	-
Subsessor bocourti	28.9–84.0, 43.9 ±5.3 (11)	57.3 ± 2.6 (f) 53.2 ±1.7 (m) (141)	44.0–473.0, 143.27 ±41.36 (11)	41.0–287.0, 116.11 ±15.05 (27)	267.9 ±31.8 (f) 196.9 ±14.7 (m) (136)

Results

Data from a total of 87.94 kg and 1,046 watersnake specimens was collected over our ten-day study period. Three hundred and fifty of these snakes were caught by one local fisherman as bycatch and 696 were being sold by one local snake trader. Eight species were caught by the fisherman including *E. longicauda* (*n*=228), *E. enhydris* (*n*=77), *E. tentaculatum* (*n*=10), *S. bocourti* (*n*=11), *F. flavipunctatus* (*n*=18), *H. buccata*, *C. ruffus* and *Acrochorhus granulatus* (*n*=<5 apiece). The fisherman's bycatch yielded a mean of 3.01 kg (SE ± 0.18) of watersnakes per day. The mean SVL and mass for each species were calculated from this daily catch (Table 1).

Data collected from the watersnake trader showed that 9.7 kg of snakes were bought by the trader to sell per day on average (SE±1.73). Similar to the fisherman's catch, *E. longicauda* was the most common species bought by the snake trader (*n*=534). The total number of other snakes the seller received included *E. enhydris* (*n*=132) and *S. bocourti* (*n*=27). There was only one specimen of each of the three remaining species (Table 1).

The mean mass of species with larger sample sizes from the fisherman and trader (*E. enhydris*, *E. longicauda* and *S. bocourti*) appeared to be less than values reported in 2009: *E. enhydris* (fisherman= 65.19 ± 1.48 g, trader= 59.53 ± 3.07 g, Brooks *et al.,* 2009= 97.8 ± 1.2 g (females) and 81.5 ± 0.5 g (males)), *E. longicauda* (fisherman= 82.33 ± 2.37 g, trader= 87.07 ± 1.79 g, Brooks *et al.,* 2009= 150.9 ± 2.6 g (females) and 117.5 ± 4.6 g (males)), and *S. bocourti* (fisherman= 143.27 ± 41.36 g, trader= 116.11 ± 15.05 g and Brooks *et al.,* 2009= 267.9 ± 31.8 g (females) and 196.9 ± 14.7 g (males)) (Table 1). However, there were no significant differences between our data and the means reported for male or female snakes by Brooks *et al.* (2009) (*p*=>0.05). The same was true for mean SVL measurements.

Eleven of the 21 respondents we interviewed reported catching watersnakes as bycatch. Five respondents reported buying snakes from market sellers for personal consumption and two reported they bought them for crocodile food. The remaining three respondents reported that they exclusively caught fish and did not purchase watersnakes for consumption. Our interviewees also included two crocodile farmers, one of whom indicated that they purchased 300–400 kg of snakes each week to feed ca. 100 crocodiles. In contrast, the other farmer said they bought ca. 30 kg each week to feed ca. 50 crocodiles.

Sixteen respondents claimed the lop (Fig. 1) was their fishing tool when they unintentionally caught watersnakes and eight of these said it was used in addition to a gillnet. Only two respondents said they exclusively used a gillnet. Three respondents were able to indicate locations where watersnakes were more abundant and claimed they caught more in shallower areas of the lake near the flooded forest. Four of the 21 respondents (19%) reported watersnakes in their catch were smaller compared to the past, whereas eight (38%) reported no change in size. The remainder were unsure.

Consistent with our quantitative data, all respondents indicated that *E. enhydris* and *E. longicauda* were the most common species caught (Fig. 2), followed by *Xenochrophis piscator*, despite none of the latter being recorded in our bycatch and trade samples.

Most respondents said more snakes were caught during the months of June and July (wet season) as well as November and December (Fig. 3). These months were also reported as the period when respondents found eggs in the snake oviduct.

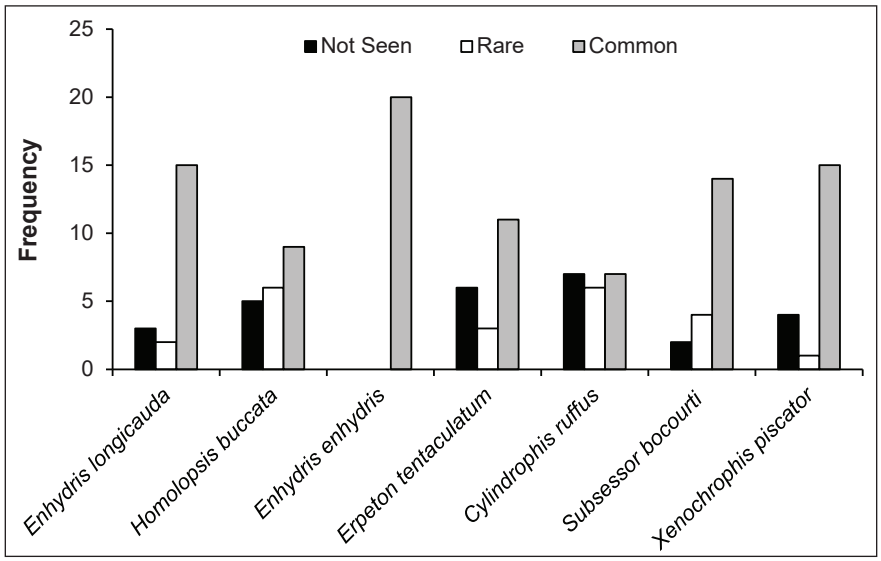

Fig. 2 Frequency of reports from 21 respondents on different watersnake species as common, rare, or not seen in Kampong Khleang Commune, Cambodia.

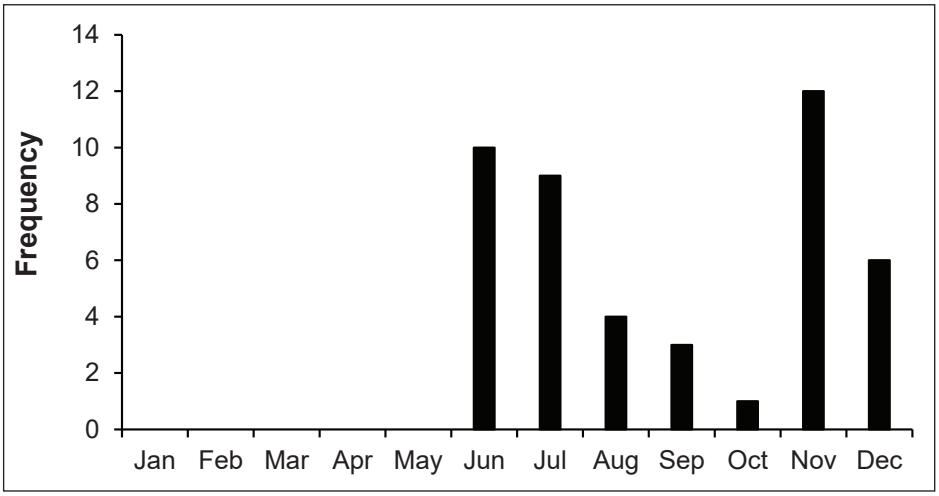

Fig. 3 Frequency of reports from 21 respondents on months when greater numbers of watersnakes are present in fish catches in Kampong Khleang Commune, Cambodia.

Discussion

Our short study found that *E. longicauda* was more abundant than *E. enhydris* in samples from the snake trader and bycatch. The former species accounted for 77% of the trader's collection and 65% of the bycatch. This differs from previous studies which found *E. enhydris* was the most common watersnake caught (Stuart *et al*., 2000; Brooks *et al*., 2007). Despite earlier studies being more extensive, our results offer a glimpse that suggests three possible scenarios: a decrease in the *E. enhydris* population which could be related to harvesting for crocodile food or human consumption; an increase in the *E. longicauda* population; or greater proportions of *E. longicauda* being caught due to the use of lops rather than gillnets as the main capture method. Further studies comparing temporal and spatial variations and catch techniques are required. The fact that *E. longicauda* was the most commonly caught species in our study is a cause for concern because the species is endemic to the waters and surrounding wetlands of Tonlé Sap Lake and listed as Vulnerable by the IUCN (Murphy *et al*., 2010). If these trends continue unabated by any of kind restrictions, the quantities harvested could place major stress on local populations of the species and increase their risk of extinction.

Although the average mass of some watersnake species in our study appeared to be lower than previous reports (Table 1), the differences were not statistically significant. Since our sample size was much smaller than Brooks *et al*. (2009), this may have affected the reliability of our comparison. If future studies with a larger sample size were to show significant differences however, it is possible that over-fishing at the Tonlé Sap Lake could have altered the reproductive ecology of *E. enhydris* (Murphy *et al*., 2002). It is necessary to consider that many of the large, mature and fecund individuals might be captured and removed from the lake at increased rates, leaving only younger and smaller snakes behind. As such, continuation and expansion of our study during the wet season might provide more information on the mass and length of more fully-grown snakes and reduce the number of juveniles collected.

Because many of our respondents indicated that the lop was the primary tool used for fishing—a generalized trap traditionally used to catch fish which does not specifically target snakes—this could have implications for any future attempts to regulate the capture of watersnakes (Deap *et al*., 2003). Additionally, it is possible that people on the lake use an alternative means of catching snakes that we did not learn about; for example, the use of illegal fishing equipment. Moreover, the use of the lop may have skewed our results towards the types and sizes of watersnakes caught.

Although some of our respondents claimed they only caught fish and never buy or sell watersnakes, all of them were able to distinguish the different species and often provided their Khmer names. Even people who claimed to have limited interactions with watersnakes recognized and named at least some of the species displayed in photographs. Additionally, the species that most respondents identified as common matched those most often found in the samples we examined from the individual fisherman and trader. Some respondents also

identified the rarer and more expensive species such as *S. bocourti*.

Our interview data regarding the seasonality of snakes and their eggs were fairly consistent. The periods that respondents claimed most snakes were caught coincided with those when they claimed eggs were found in the oviduct or when more snakes than normal were present. June and July were identified as the months of greatest snake abundance and this period also marks the onset of rising water levels in the lake during the flood pulse (Kummu *et al*., 2008). This observation is consistent with reports that *E. enhydris* has two breeding seasons (in April/May and November), whereas the other species only enter vitellogenesis in November and December (Murphy *et al*., 2002; Brooks *et al*., 2009). This corresponds with villager reports that more watersnakes are caught in the flooded forest in June and July where they give birth to live young. November and December were also commonly identified as months when more snakes were caught, which aligns with the snakes following the water's edge for refuge during the dry season (Brooks *et al*., 2007).

Previous studies have indicated that crocodile farms are the main destination of watersnakes caught in the Tonlé Sap Lake (Brooks *et al*., 2008, 2010). However, most of our respondents indicated that snakes are mostly used for human consumption. One of the crocodile farmers we interviewed also claimed that only three large crocodile farms existed near the lake, thus accounting for a relatively small portion of snake harvests and sales conducted in the region. However, our respondents did not refer to the hundreds of smaller farms located in the region (Daltry *et al*., 2016). While it was claimed that the larger crocodile farms might consume upwards of 300 kg of watersnakes per week, 10 of 21 respondents reported buying or selling watersnakes for human consumption. This shift may have consequences for watersnake populations and families living on the lake. The crocodile farmers we interviewed indicated that prices for snakes were much lower in the past and that they now bought fewer snakes for their crocodiles due to their higher costs. Previous research has suggested that the price of snakes has increased with the price of fish regardless of their abundance (Brooks *et al*., 2010; Chhut, 2018) and most of our respondents reported prices of 2.50–3.00 USD per kg for *E. longicauda* and *E. enhydris*. They also attributed the price increase to the growing popularity of snakes for human consumption.

Although we did not explore potential drivers of the increased popularity of watersnakes for human consumption, the decreasing abundance of fish in the lake could be one reason for this (Brooks *et al*., 2007; Campbell *et al*., 2006; Kuenzer, 2013). As the traditional food source (fish) decreases for people living on the lake, more people could turn to snakes to supplement their protein intake. Outside demand could represent another reason. Several respondents claimed that outsiders often came to the village to purchase watersnakes. While they did not indicate how many were bought and for what purpose, it is possible these are sold in the restaurant trade or street stalls in nearby Siem Reap and Phnom Penh.

Regular monitoring of watersnake populations in the Tonlé Sap ecosystem is important because Cambodians increasingly rely on them for food. This would also enable early recognition of population changes which could prevent negative impacts on the ecology of the lake if populations were to decline. Watersnakes serve as an important food source for a variety of bird species (Beaupre & Douglas, 2009), many of which are endemic and/or endangered. The watersnake populations themselves are also experiencing a decrease in their food supply as increasing amounts of fish are being taken from the lake (Campbell *et al*., 2006; Brooks *et al*., 2007; Kuenzer, 2013). The loss of their prey, combined with unmonitored harvesting from the lake and habitat degradation, could put some or all watersnake species in the lake at greater risk, along with the wildlife that depend on them for food.

While the findings we report are factual, these do have some limitations. For example, as our data collection was confined to a ten-day period, we were unable to identify seasonal trends that could have influenced our results. Further, since many of our study respondents indicated that our study took place during the peak snake season, our results regarding the quantity of snakes caught are probably not indicative of snake catches throughout the year but rather an over-estimate of yearly means. Further studies focusing on temporal variation in catches are required to report on this conclusively. Additionally, we trusted that our study respondents were honest in claiming that they caught watersnakes unintentionally, but this might not have been the case in every instance.

Our small sample size and inclusion of data from only one snake trader and fisherman also makes it difficult to generalize our findings. We cannot be sure that the data from our study village are representative of other villages found on the Tonlé Sap Lake and therefore recommend that future studies incorporate multiple study sites and fishermen utilizing various fishing techniques to facilitate direct comparisons with earlier studies. We also cannot be certain if the fisherman and snake trader we interviewed provided access to all the snakes they had each day. Because of our limited study period and potential

biases associated with our sampling techniques, further research is needed to confirm our results and generalize these to the wider Tonlé Sap region. Despite its limitations however, the fact that our data consistently indicates that the species caught most often is both endemic and Vulnerable suggests that a similar pattern could be emerging on a broader scale.

Overall, our results suggest that continuation of watersnake harvesting at current levels is unlikely to be sustainable. Because the times of year when watersnake catches are greatest coincides with their breeding seasons, this could lead to further population decreases which they may not recover from. We therefore recommend restriction of watersnake harvests during the breeding season to safeguard population recruitment. In line with previous studies (Murphy *et al*., 2002; Brooks *et al*., 2009), it would also be beneficial to restrict the capture of large, fecund females. Education of local people on the species currently threatened and creation and monitoring of more monitored conservation zones in the flooded forest would also help to reduce overharvesting of vulnerable species. Consideration of a national action plan for *E. longicauda* is also warranted, as is research evaluating the impact of crocodile farms and restaurant trade on the species. While *E. longicauda* populations still appear to be relatively abundant, establishment of an insurance population and studies to improve understanding of its behaviour and ecology are advisable considering the species is not only endemic and Vulnerable but increasingly consumed by people. Ultimately, should current harvests and trade levels continue or expand in future, the extinction risk for species such as *E. longicauda* will likely increase.

Acknowledgements

All information from our research was shared with the Fisheries Administration of the Cambodian Ministry of Agriculture, Forestry and Fisheries, as a preliminary assessment of watersnakes in Kampong Khleang Commune. We are grateful for their permission to carry out this collaborative project with the Angkor Centre for Conservation of Biodiversity (ACCB). Permission for our research was also provided by the School for Field Studies (SFS, CAM-60-19). We would like to especially thank H.E. Eng Chea San and Ouk Vibol for their crucial support. We would also like to thank Tea Mao and Chiara Parolin from the ACCB and Seang Samraksa from SFS for their assistance with fieldwork, Vat Chenda and Chhorn Soksan from Royal University of Phnom Penh for translating interviews in the field and Nguon Rothsophal for translating our abstract.

References

Arias, M.E., Cochrane, T.A. & Elliott, V. (2014a) Modelling future changes of habitat and fauna in the Tonle Sap wetland of the Mekong. *Environmental Conservation*, **41**, 165–175.

Arias, M.E., Piman, T., Lauri, H., Cochrane, T.A. & Kummu M. (2014b) Dams on Mekong tributaries as significant contributors of hydrological alterations to the Tonle Sap Floodplain in Cambodia. *Hydrology and Earth System Sciences*, **18**, 5303–5315.

Beaupre, S.J. & Douglas, L.E. (2009) Snakes as indicators and monitors of ecosystem properties. In *Snakes: Ecology and Conservation* (eds S.J. Mullin & R.A. Seigel), pp. 244–261. Cornell University Press, New York, USA.

Brooks, S.E., Allison, E.H. & Reynolds, J.D. (2007) Vulnerability of Cambodian water snakes: initial assessment of the impact of hunting at Tonle Sap Lake. *Biological Conservation*, **139**, 401–414.

Brooks, S., Allison, E.H. & Reynolds, J.D. (2008) Sustained by snakes? Seasonal livelihood strategies and resource conservation by Tonle Sap fishers in Cambodia. *Human Ecology*, **36**, 835–851.

Brooks, S., Allison, E., Gill, J. & Reynolds, J. (2009) Reproductive and trophic ecology of an assemblage of aquatic and semi-aquatic snakes in Tonle Sap, Cambodia. *Copeia*, **2009**, 7–20.

Brooks, S., Allison, E., Gill, J. & Reynolds, J. (2010) Snake prices and crocodile appetites: aquatic wildlife supply and demand on Tonle Sap Lake, Cambodia. *Biological Conservation*, **143**, 2127–2135.

Campbell, I.C., Poole, C., Giesen, W. & Valbo-Jorgensen, J. (2006) Species diversity and ecology of Tonle Sap Great Lake, Cambodia. *Aquatic Sciences*, **68**, 355–373.

Chhut C. (2018) Cambodia's water snake trade—not just crocodile feed and skins but also snacks. *Catch and Culture Environment*, **24** (December), 14–19.

Cooperman, M.S., So N., Arias, M., Cochrane, T.A., Elliott, V., Hand, T., Hannah, L., Holtgrieve, G.W., Kaufman, L., Koning, A.A., Koponen, J., Kum V., McCann, K.S., McIntyre, P.B., Min B., Ou C., Rooney, N., Rose, K.A., Sabo, J.L. & Winemiller, K.O. (2012) A watershed moment for the Mekong: newly announced community use and conservation areas for the Tonle Sap Lake may boost sustainability of the world's largest inland fishery. *Cambodian Journal of Natural History*, **2012**, 101–106.

Daltry, J.C., Langelet, E., Solmu, G.C., van der Ploeg, J., van Weerd, M. & Whitaker, R. (2016) Successes and failures of crocodile harvesting strategies in the Asia Pacific region. In *Tropical Conservation* (eds A.A. Aguirre & R. Sukumar), pp. 345–362. Oxford University Press, New York, USA.

Deap L., Degen, P. & Zalinge, N.V. (2003) *Fishing Gears of the Cambodian Mekong*. Cambodia Fisheries Technical Paper Series, Volume IV, Inland Fisheries Research and Development Institute of Cambodia, Phnom Penh, Cambodia.

Evans, T., Gray, T., Chamnan H., Mouyheang S. & Vanny L. (2005) *Farming and its Impact on Flooded Grasslands around the Tonle Sap Lake—a Survey in the Kruos Kraom Area of Kompong*

Thom. Wildlife Conservation Society Cambodia Program, Phnom Penh, Cambodia.

IUCN Red List (2021) *The IUCN Red List of Threatened Species*. https://www.iucnredlist.org [Accessed 27 March 2022].

Kuenzer, C. (2013) Threatening Tonle Sap. *Political Geographies*, **40**, 29–31.

Kummu M., Penny, D., Sarkkula, J. & Koponen, J. (2008) Sediment: curse or blessing for Tonle Sap Lake? *Ambio*, **37**, 158–164.

Lieng S., Srun L. & Tob C.A. (2010) *Livelihood Situation of Water Snake Hunter and Conservation Option of Water Snake in Tonle Sap Lake, Cambodia*. Inland Fisheries Research and Development Institute of Cambodia, Phnom Penh, Cambodia.

Marshall, M. (1996) The key informant technique. *Family Practice*, **13**, 92–7.

Miller, R. & Brewer, J. (2003) *The A-Z of Social Research: A Dictionary of Key Social Science Research Concepts*. SAGE publications, London, UK.

Murphy, J.C., Voris, H.K., Stuart, B.L. & Platt, S (2002). Female reproduction in the Rainbow Water Snake, *Enhydris enhydris* (Serpentes, Colubridae, Homalopsinae). *The Natural History Journal of Chulalongkorn University*, 2, 31–37.

Murphy, J., Brooks, S.E. & Auliya, M. (2010) *Enhydris longicauda. The IUCN Red List of Threatened Species*. Http://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T176669A7280782.en [Accessed 30 November 2019].

Stuart, B.L., Smith, J., Davey, K., Prom D. & Platt, S.G. (2000) Homalopsine watersnakes: the harvest and trade from Tonle Sap, Cambodia. *TRAFFIC Bulletin*, **18**, 115–124.

Targarona, R.R., Soberón, R.R., Cotayo, L., Tabet, M.A. & Thorbjarnarson, J. (2008) *Crocodylus rhombifer. The IUCN Red List of Threatened Species*. Http://dx.doi.org/10.2305/IUCN.UK.1996.RLTS.T5670A11516438.en [Accessed 30 November 2019].

Thoeun H.C. (2015) Observed and projected changes in temperature and rainfall in Cambodia. *Weather and Climate Extremes*, **7**, 61–71.

Tingley, R., Meiri, S. & Chapple, D.G. (2016) Addressing knowledge gaps in reptile conservation. *Biological Conservation*, **204**, 1–5.

About the authors

Megan English is an ecologist who has conducted research in Southeast Asia for 12 years, most recently with The School for Field Studies, Cambodia. The teaching and research focuses on exploring animal ecology, biodiversity, the human-wildlife interface and the role of animals in traditional culture. Megan currently teaches wildlife biology and conservation with the Taronga Conservation Society and University of Sydney. She holds a PhD in Biodiversity and Ecology and BSc Hons in Animal Science and Zoology.

Kameron Winters recently graduated from Bucknell University, Pennsylvania with a degree in Animal Behaviour and Mary Lasater recently graduated from Davidson College, North Carolina, with a degree in Biological Sciences. They undertook the field research for this paper during a semester abroad with The School for Field Studies, Cambodia.

Mark Dainty is a wildlife specialist who has worked with a wide variety of species for 20 years. His work with animals in captivity and in the field centres on animal welfare, conservation, education and research. He specialises in reptilian husbandry, research and conservation with a focus on snakes and crocodilians.

Michael Meyerhoff is a conservationist who has been involved in species and habitat conservation and research efforts in Southeast Asia since 2014. His focus is integrated conservation planning and the role of ex situ conservation projects for highly threatened mammal, bird and reptile species. Michael previously spent seven years in Cambodia in various roles at the Angkor Centre for Conservation of Biodiversity and now serves as a conservation officer at Zoo Leipzig in Germany, managing the global conservation efforts of the zoo.

Philipp Wagner is a systematist and conservationist who has conducted herpetological research in Africa and Asia for 20 years and holds a PhD in Zoology from the Research Museum Alexander Koenig and University of Bonn, Germany. The focus of his research are generally lizards and snakes, but specifically the lizard family Agamidae, where he has described several new species from Africa and Asia. Philipp did postdoctoral studies at the Villanova University, USA and has taught systematics and biodiversity as visiting professor and lecturer at the Universities of Herat and Tel Aviv. He currently works as curator for research and conservation at Allwetterzoo, Germany which includes responsibility for the Angkor Centre for Conservation of Biodiversity.

